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As the General Chair of the 2nd International Conference on Water and Environmental Engineering, 19-22 January 2019, Dhaka (iCWEE2019), I would like to thank the Plenary Speakers, Keynote Speakers, Invited Speakers, Authors, Sponsors, Secretaries, IT Team Members, Authors, Conference Advisory Committee Members, Organising Committee Members, Technical Committee Members, Reviewers and Volunteers for making this conference successful.

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PLENARY SPEAKER

Professor Dr. Ainun Nishat

Topic: Water Sharing: An International Perspective

Biography

Professor Dr. Ainun Nishat is recognized as a pioneering expert of water resource management and climate change in Bangladesh. Currently, he is involved in BRAC University as Professor Emeritus. He was former vice chancellor of this university. He is engaged in carrying out diversified research projects in the field of climate change and environment with the Centre for Climate Change and Environmental Research, BRAC University. Previously he was the Country Representative, Bangladesh and followed by Senior Advisor Climate Change, Asia Region in International Union for Conservation of Nature (IUCN).

He is a key member of the Climate Change Negotiation Team for Bangladesh and represented Bangladesh at the United Nations Climate Change Conferences (CoP) since Bali, Indonesia at CoP 13 till today. He is also a member of the Compliance Committee of the Kyoto Protocol of the UNFCCC since 2006. He was a key member of experts that prepared the National Adaptation Program of Action (NAPA-2005), Bangladesh Climate Change Strategy and Action Plan (BCCSAP 2008 and 2009) and also was one of the Lead Authors of Working Group-II of IPCC in preparation of the Third Assessment Report.

As an expert in water resource management, he was a member of the Indo-Bangladesh Joint River Commission and played a vital role in the Ganges Water Treaty Negotiations that were finalized in 1996. He was a member of the Panel of Experts who consulted the construction of the Jamuna Bridge, the longest bridge in Bangladesh and currently a member of the Panel of Experts consulting the construction of the Padma Bridge.

Besides working at various projects of the World Bank, Asian Development Bank, UNDP and other international and inter-governmental organizations, he has a close association with leading NGO's in Bangladesh. Before joining BRAC University, he was a Member of the Governing Body of BRAC. He also works closely with Bangladesh Center for Advanced Studies (BCAS), Bangladesh Center for Sustainable Development (CFSD), Bangladesh Unnayan Parishad (BUP), Bangladesh Environmental Lawyers Association (BELA) and other leading NGOs. He was Adjunct Professor in Institute of Natural Resources Management, University of Manitoba, Canada; IHE, Delft, The Netherlands; Bangabandhu Shaikh Mujibur Rahman Agriculture University. He also worked as a Professor at North South University, and Independent University, Bangladesh (IUB). As a resource person, he delivers lectures regularly at the Bangladesh Public Administration Training Center (BPATC), Planning Academy, National Academy for Educational Management (NAEM), National Defense Collage and the Armed Forces Staff College at Mirpur, Dhaka etc.

PLENARY SPEAKER

Professor Dr. Ataur Rahman

Topic: Bangladesh has so much rain: but so less water for drinking: is there any sustainable solution?

Biography

Prof. Dr. Ataur Rahman is working in Western Sydney University, Australia. He is also serving as Co-Chair of Water Education and Research Committee of Australian Water Association, the national peak body of water research and practice. He is a Fellow of Engineers Australia and Member of American Society of Civil Engineers, American Geophysical Union and International Water Association. He is a world leader in flood modelling, water quality management, water-related sustainability and rainwater harvesting. His total publications on various aspects of water and environmental engineering are 402; including 7 books, 31 scholarly book chapters and 93 ISI listed journal articles. He received the G. N. Alexander Medal from Engineers Australia for his outstanding research paper on flood modelling. He initiated and led Australian Rainfall and Runoff (ARR) Revision Project 5 'Regional flood methods' for over a decade and co-developed RFFE Model (which has become a national application tool as part of the 4th edition of ARR, the National Guideline). He is the founder Chair of Global Circle for Scientific, Technological and Management Research (GCSTMR), which has organized three successful international congresses to promote scientific and technological research and practice. He served as Expert Peer Reviewer for numerous projects including Sea Outfall Assessment Project of Qatar Government, Pilot Study on Rainfall Estimation (Australian Bureau of Meteorology), Design Loss Estimation (Australia) and Australia Wide Flood Risk Assessment (GHD, Australia).

Abstract of the speech

Access to safe drinking water is a basic human right, but Bangladesh has achieved little development on this regard despite its notable economic development in recent years. Tap water is regarded unsafe in Bangladesh and hence boiling or special filtering of tap water before drinking has become a common practice in Bangladesh. Bottled water has also concerns. Bangladesh receives 2,000 to 3,000 mm of rainfall as compared to about 1,000 mm in Sydney, Australia. Sydney sources its drinking water for its 5 million populations from rainwater collected via a series of reservoirs. Shallow groundwater in Bangladesh has been badly contaminated with Arsenic. In this presentation, it is proposed a mini-water supply scheme for 2,000 to 10,000 populations in rural areas of Bangladesh where a multipurpose surface water reservoir system, fed by rainwater and shallow tube-wells, to be developed to solve drinking water crisis in Bangladesh.

KEYNOTE SPEAKER

Professor Dr. Ataur Rahman

Topic: Recent developments in Flood Estimation Practice in Australia

Biography

Prof. Dr. Ataur Rahman is working in Western Sydney University, Australia. He is also serving as Co-Chair of Water Education and Research Committee of Australian Water Association, the national peak body of water research and practice. He is a Fellow of Engineers Australia and Member of American Society of Civil Engineers, American Geophysical Union and International Water Association. He is a world leader in flood modelling, water quality management, water-related sustainability and rainwater harvesting. His total publications on various aspects of water and environmental engineering are 402; including 7 books, 31 scholarly book chapters and 93 ISI listed journal articles. He received the G. N. Alexander Medal from Engineers Australia for his outstanding research paper on flood modelling. He initiated and led Australian Rainfall and Runoff (ARR) Revision Project 5 'Regional flood methods' for over a decade and co-developed RFFE Model (which has become a national application tool as part of the 4th edition of ARR, the National Guideline). He is the founder Chair of Global Circle for Scientific, Technological and Management Research (GCSTMR), which has organized three successful international congresses to promote scientific and technological research and practice. He served as Expert Peer Reviewer for numerous projects including Sea Outfall Assessment Project of Qatar Government, Pilot Study on Rainfall Estimation (Australian Bureau of Meteorology), Design Loss Estimation (Australia) and Australia Wide Flood Risk Assessment (GHD, Australia).

Abstract of the speech

Australia is the driest inhabited continent on this planet; however, it is also affected by major floods. For example, 2010 floods in Queensland costed $30 billion to Australian national GDP. In Australia, Australian Rainfall and Runoff (ARR), the National Guide presents state-of-the art practices on rainfall and flood estimation in Australia. ARR is the most widely used documents published by Engineers Australia. ARR is also regarded as the Bible of Flood Hydrology and widely cited by many countries for flood risk assessment. This paper presents how ARR has been evolved since 1958 to the current time in Australia. In particular, it presents how regional flood frequency estimation (RFFE) for ungauged catchments method was developed and validated in the 2016 version of the ARR. The author served as the National Project Leader of the ARR RFFE project that lasted for a decade and produced a significant body of literature consisting of over 60 refereed publications. Finally, this paper presents how Bangladesh can develop a standard like ARR, which can be called "Bangladesh Rainfall and Runoff" (BRR). The proposed BRR can document the vast expertise of the water engineers and hydrologists in Bangladesh where the author can assist based on his Australian experience.

KEYNOTE SPEAKER

Professor Dr. Muhammad Mizanur Rahaman

Topic: Management of South Asian International Rivers: Challenges and Opportunities

Biography

Dr. Muhammad Mizanur Rahaman is currently working as a Professor at Department of Civil Engineering, University of Asia Pacific. He was a post-doctoral fellow at Department of Civil and Environmental Engineering, Aalto University, Finland (2009-2013) and visiting scholar at Department of Geography, the University of Cambridge (01/2011 - 12/2011). Rahaman received Doctor of Science degree from Helsinki University of Technology in June 2009. He has been an invited lecturer in nine universities including the University of Toronto, University of East Anglia (UK), University of Bergen (Norway), Fudan University (China) and OSCE Academy (Kyrgyzstan). Dr. Rahaman was interviewed by *Aljazeera* about the construction of the Grand Ethiopian Renaissance Dam on Nile river basin. His research interests include: (1) integrated water resources management, (2) transboundary river basin institutions, (3) water conflicts and security, (4) global water policies and laws, (5) water pricing.

Abstract of the speech

Management of water resources along international rivers is undoubtedly one of the foremost challenges to achieve regional development in South Asia. Lack of trust, unavailability of authentic data, unilateral management approach, increasing demand of food and energy, dependency on high water consuming crops *et cetera* are creating enormous pressure in achieving regional development based on integrated management of South Asian international rivers. This lecture focuses on two major rivers basins in the region, namely, Ganges and Brahmaputra. The total drainage area of the basins is about 1660,000 km^2 that are shared by China, Nepal, India, Bhutan, and Bangladesh. These basins are blessed with ample water resources and huge hydropower potential. However, due to temporal and spatial distribution of water resources, during the monsoon period, there is abundant water but during non-monsoon months, the countries become water stressed. The characteristics of the monsoon vary substantially from year to year, adding to the unpredictability of the hydrological conditions in South Asia and, thus, affecting the availability of water for agriculture and other sectors. Additional challenges threatening water and food security in the region include increasing food and energy needs, lack of transboundary cooperation and political constraints. Absence of multilateral cooperation to address this natural phenomenon and lack of integration between different sectors contribute to mismanagement and water conflicts between the riparian nations.

This lecture explores the interconnections between different sectorial policies related to water management and the potentials of integrated water management approach for overcoming the current water crises and achieving Sustainable Development Goals along the basins. It also looks at the role of water, energy, food policies and geopolitical ambitions to manage transboundary water resources in the region and highlights the opportunities for cooperation among the riparian countries.

KEYNOTE SPEAKER

Professor Dr. Md. Mujibur Rahman

Topic: SDG 6-The Driver for Reaching Other SDGs

Biography

Prof. Dr. Md. Mujibur Rahman currently, is a Professor of Civil Engineering at the University of Asia Pacific, **UAP**. Formerly he was Professor and Head of Civil Engineering Department at **BUET**. He is a Life Fellow of the Institution of Engineers, Bangladesh, IEB (F-2200). He obtained B.Sc. in Civil Engineering from BUET (1976), M.Eng.Sc from the University of Melbourne (1984) and Ph.D. (1988) from the University of Adelaide, Australia. Prof. Mujibur Rahman specializes in Environmental Engineering and has current research and work interests in Urban Environmental Challenges, Sanitation and Fecal Sludge Management, and Environmental and Social Impact Assessment. He has more than **80 publications** in national and international peer reviewed journals and conference proceedings, and as research reports. Prof. Mujibur Rahman is the co-Author of the Text Book on **Water Supply and Sanitation**: **Rural and Low Income Urban Communities** and is also editor of several Books on Contemporary Environmental Challenges. He played the lead role in establishing **ITN-BUET,** a national capacity building center for water and waste management in the country and worked as its Director. Prof. Rahman is also the founder Director of the Centre for Environmental and Resource Management, **CERM at BUET**. Prof. Mujibur Rahman as an Environmental/Sanitation Expert provided leadership in formulation of national policies and strategies that include "**Institutional and Regulatory Framework for FSM in Bangladesh 2017**", "**National Strategy for Water Supply and Sanitation in Hard to Reach Areas of Bangladesh 2012**", and "**National Sanitation Strategy 2005**". He also provided leadership in many challenging projects of national importance including the very challenging "**Integrated Development of Hatirjheel including Begunbari Khal",** a project that aimed at improving urban stormwater drainage, traffic congestion and severely degraded environmental conditions of central Dhaka.

Abstract of the speech

The 'water goal', SDG 6 - "Ensure availability and sustainable management of water and sanitation for all", places water and sanitation at the core of the 2030 Agenda for Sustainable Development. The 2030 Agenda recognizes that these 17 Sustainable Development Goals and 169 associated targets are integrated and indivisible, global in nature and universally applicable. The linkages and interdependency between the targets under Goal 6 on water and sanitation and other Goals and targets is evident. It is vital that these Interlinkages are understood and addressed effectively by harnessing synergies between them to achieve the social, economic and environmental dimensions of the 2030 Agenda.

The vast majority of target-level linkages across the 2030 Agenda with Goal 6 are positive, because implementing the Goal 6 targets mutually supports a large number of other targets, and vice versa. Examples of synergies include increasing access to water supply, sanitation and hygiene (Goal 6 targets) in households, healthcare facilities, schools and workplaces, complemented by wastewater treatment (target 6.3 of Goal 6), as a way to reduce risk of water-borne disease (targets of Goal 3) and

malnutrition (Goal 2) support education (targets of Goal 4) and a productive workforce (targets of Goal 8); and address poverty (Goal 1 targets), gender inequality (targets of Goal 5) and other inequality (Goal 10). Recovering and reusing the valuable resources present in excreta and wastewater (target 6.3) also contributes to resource efficiency (Goal 12) and can help improve food security (Goal 2). Sustainable sanitation and wastewater management value chains (targets 6.2, 6.3) provide new livelihood opportunities (Goals 1 and 8). Making tomorrow's cities livable (Goal 11) is unthinkable without adequate sanitation and wastewater management.

However, it is extremely important that governments, concerned ministries and other development partners realize that the targets of Goal 6 cannot be achieved if each target is treated in isolation. Goal 6 targets are wider in scope, highly interdependent and will require considerably more effort to achieve. Increased access to sanitation (target 6.2) must be matched by increased wastewater treatment (target 6.3) if good ambient water quality (target 6.3) and healthy water-related ecosystems (target 6.6) are to be sustained. Good ambient water quality greatly facilitates the provision of safe drinking water (target 6.1), which in turn must be provided sustainably (target 6.4), without negative consequences for water-related ecosystems (target 6.6). Thus, SDG 6 targets related to sustainable water supply and use, good ambient water quality and healthy water-related ecosystems are interdependent and are extremely challenging to achieve. This keynote paper will discuss these challenges in the context of Bangladesh.

KEYNOTE SPEAKER

Associate Professor Dr. Amimul Ahsan

Topic: Why do we need scientific research and how to approach?

Biography

Associate Professor Amimul Ahsan was born in Netrokona, Bangladesh. Dr. Ahsan received a Ph.D. in Civil Engineering from the University of Fukui, Japan and he has about 15 years of research, teaching and industrial experiences. He is involved with a number of collaborative research projects in different countries. He specializes in Water and Environmental Engineering. He has published extensively in Water and Environmental Engineering including 9 books, 16 book chapters and over 125 journal articles (mostly ISI/Scopus indexed). He received 14 international awards, e.g. “Who's Who in the World 2015” & “Leading Engineers of the World 2013”. Sultan Selangor (Chancellor, UPM) conferred him “Vice Chancellor Fellowship Award” (Science and Technology) in 2015. He has been serving in the editorial board of a number of refereed journals for a long time as an Editor-in-Chief (4), Editor/Associate Editor (6) & Editorial Board Member (11), e.g. Membrane Water Treatment (ISI) & Cogent Engineering (Scopus). His h index in Scopus is 22. He was a former faculty in the Department of Civil Engineering and key researcher in the Institute of Advanced Technology (ITMA), University Putra Malaysia (UPM), Malaysia [2010-17]. Currently, he is an Associate Professor in the Department of Civil Engineering, Uttara University, Dhaka, Bangladesh and Adjunct Associate Professor in the Department of Civil and Construction Engineering, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Melbourne, Australia.

Abstract of the speech

Research is the organized scientific investigation to understand the nature, solve problems, test hypotheses or develop/discover/invent new findings/products/techniques. It is an effort to obtain new knowledge in order to answer a question or to solve a problem. Why do we need scientific research? The possible answers are to provide solutions to complex problems, to investigate laws of nature, to make new discoveries, to develop new products/methods/techniques, to reduce cost, to improve the life-style, to fulfill human demands/desires, to make a novel contribution to science or any fields, to make a better world for all living beings, and to get PhD/Masters/Bachelor degrees. Research must be done within a certain philosophical framework by using procedure/method/techniques that are reliable and properly designed so that it has objective(s) and not biased/influenced. Research methodology includes i) understanding the nature of problem to be studied and identifying the related knowledge, ii) reviewing literature to understand how others have approached or dealt with the problem, iii) collecting data in an organized and controlled manner so as to arrive at valid decisions, iv) analyzing data appropriately to address the problem(s), and v) drawing conclusions & making generalizations.

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E. Coli Removal Efficiency and Physical-Chemical Parameter Analysis of Mineral Pot Filters in Bangladesh

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Abstract

Treatment of water at the household level offers a promising approach to combat the global burden of diarrhoeal diseases. In Bangladesh and several other Asian countries, Mineral pot filters (MPFs), commercially produced household water purifiers, are used by millions of people as technologies for providing safe drinking water. MPF's are produced and distributed by the private sector and it has gained significant popularity in South East Asia. The effectiveness of the filters in reducing microbial indicators and other potential pathogens under realistic household usage have been previously investigated in peer reviewed publications. However, control experiments under laboratory setup to determine removal efficiency and assess physical-chemical performance of MPF have not been conducted in Bangladesh previously. We performed lab-based control experiments on three popular brands of MPF's in Bangladesh. Tests were performed for systematic evaluation of bacteria reduction capabilities of these technologies based on WHO recommended performance testing protocol. E.Coli was chosen as the test microbe since it is the primary indicator of water contamination and existence of disease causing organisms. Physical-Chemical parameters of water (Turbidity, pH, color, electrical conductivity and filtration rate) of feed and filtered water were also analyzed to assess the effect of filter materials and cartridge minerals on water parameters. The experiment was conducted over a total throughput volume of 1000 L per filter and samples were analyzed 0%, 25%, 50%, 75% and 100% of total throughput to assess the long-term effects on effectiveness of the filters. Results reveal that all of the filters were highly effective in reducing E. Coli (99.99%+) and can be termed 'Highly Protective' in terms of E.Coli removal (3.12 - 5.02log_{10}). However, performance decreased over time and fluctuation in Log Reduction Value (LRV) was observed for the filters which can be attributed to cleaning as recommended by the manufacturer. Both turbidity and color decreased while pH and electrical conductivity increased as water passed through the filter material. The filtration rate also decreased over the span of the experiment. Moderate variation was observed between the two experimental conditions used as per WHO guideline, but the performance was not significantly different after statistical analysis.

Keywords: Household Water Treatment Technologies, Mineral Pot Filters, Log Reduction Value

1. INTRODUCTION

Diarrhoea, cholera, enteric fever and hepatitis cause around 1.6 million deaths annually, a greater proportion being children according to WHO-UNICEF (2008). The main contributors are contaminated drinking water, inadequate supplies of water for personal hygiene and poor sanitation. Due to increasing population and lack of technology, access to safe drinking water is a challenge in developing countries. According to a study conducted by World Health Organization (WHO) it has been found that 884 million people do not have access to safe drinking water and in most cases the households are located 1 km or further from the source, WHO (2008). Around 700,000 children under five die every year from diarrheal diseases as per findings in Walker et al (2013). Diarrheal disease accounts for 21% of all deaths among children under less than five years old in developing countries. In Bangladesh deaths due to diarrhea is a common issue with the most effected group being children under the age of five years old. Diarrheal diseases are also responsible for malnutrition, leading to impaired physical growth and cognitive development, reduced resistance to infection, and potentially long-term gastrointestinal disorders because they inhibit normal consumption of foods and adsorption of nutrients.

For domestic uses urban dwellers are dependent on piped water supply. However, recent studies have shown that the effluent water at end points is amenable to contamination which makes the water unsafe for drinking. Source water and treatment process changes in water plants, flow of aged water from a storage reservoir, water demand variation, and quality deterioration in water distribution are examples of non-contaminant events that was experimented by Kroll and King (2006). A recent study in Bangladesh by Karim et al (2016) revealed microbial contamination of pipe water supply in Khulna and Jessore. The developing and under developed countries lack the infrastructure to provide clean piped water to their entire population and so household water treatment is very common in these countries as reported in a study by Rosa and Clasen (2010).

Household water treatment (HWT) interventions may play an important role in protecting public health where existing water sources, including those delivered via a piped network or other improved sources, are untreated, are not treated properly or become contaminated during distribution or storage according to UNICEF & WHO (2008). Therefore, it is important to implement an effective point-of-use water treatment. In the South Indian market, a wide variety of household-level water treatment devices are now available, mostly aimed at middle to upper-income consumers in urban areas (Brown et al 2009).

WHO has been testing household water treatment products according to WHO health-based performance criteria through the WHO International 'Scheme' to Evaluate Household Water Treatment Technologies since 2014 documented in WHO (2018). Similar studies of locally available HWT products are necessary to protect users from the pathogens that cause diarrheal disease and to strengthen policy, regulatory, and monitoring mechanisms at the national level to appropriate targeting and consistent and correct use of such products. In this study, Mineral Pot Filters (MPF) were tested for assessing their microbiological and physic-chemical disinfection efficiencies. Locally available Mineral Pot Filters (MPF) were tested according to WHO guidelines on two types of test water. E. coli bacteria were used as the microbial contaminant. Experimental results were compared with WHO guideline values and among the different treatment methods.

2. MATERIALS AND METHODS

Household-scale MPFs operate by gravity filtration: untreated water in a top container flows through one or more filter units, with treated water dispensed via a tap in the storage container (Figure 1). Treatment elements are a ceramic candle or other microporous, solid filter element followed by granular media filtration. A "mineral stone" cartridge containing additional mixed granular media in contact with product water imparts a distinctive mineral taste to the water. Granular media and "mineral stone" cartridges may contain activated carbon, zeolites, or other unspecified media. We tested the three most common MPF brands on the domestic market in Bangladesh in 2018, from an informal independent survey of retail outlets in Dhaka and Gazipur undertaken by IUT Research: The brands selected were 1) Miyako 2) Nova and 3) JCL. At least two filters should be used for the same Test water in order to determine performance reproducibility and identify any variations in results in accordance to guidelines in WHO (2011). Two setups of filters were arranged corresponding to two types of test water. Two additional filters were assigned as negative control filters for the two different types of test waters. Instead of spiking, they were seeded with autoclaved wastewater in type 2 test water. This setup enabled the detection of secondary contamination. We purchased two of each device and assembled units according to manufacturer instructions. All filters employed ceramic candle filtration followed by filtration through an apparent mixture of unspecified granular media in a packed bed. Product water was stored with a "mineral stone" cartridge in receiving containers where treated water could be dispensed via a tap which was a method implemented by Brown et. al (2012). The MPF's used in our experiment operated by gravity only and did not require any electricity or pressurized water input.

2.1. Test Waters

As per WHO guideline two types of test water is necessary for performing control experiments on HWT technologies. The two types of test waters prepared for this experiment are 1) Gazipur groundwater collected from IUT water tank and stored in the laboratory. Then they were spiked with E.Coli bacteria by ensuring a count of 10^5 CFU/100 ml, a process adopted by Mwabi et al (2011) 2) Tap water was mixed with 1% by volume of autoclaved sewage water. Type 2 water requires a turbidity of more than 30 NTU which was incorporated into the water by adding sieved clay from an undisturbed soil sample. It was then spiked with E.Coli bacteria ensuring a baseline count of 10^5 CFU/100 ml.

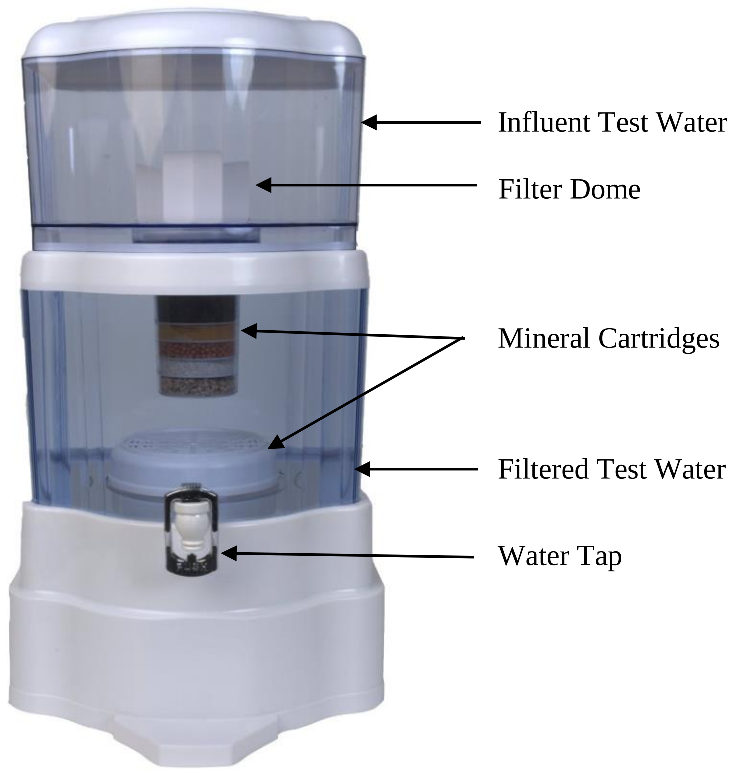

Figure 1. Mineral Pot Filter (MPF)

2.2. Overview of Testing Procedure

WHO (2011b) was used as a guideline for testing the filters in our experiment. A total of eight filters (three of each and two negative controls) were set up according to manufacturer recommendations.

They were initially washed with dechlorinated water to remove lose sediments present in the dome and cartridges. Each device was dosed with a volume equivalent to the capacity of the upper compartment of the MPFs used. These filters were monitored over a throughput of 1000 L. Test waters were spiked with E.Coli from pre-prepared stock solutions. Filters were cleaned weekly and as needed, according to manufacturer instructions on proper use and maintenance. Test waters were spiked with microbes daily in the morning, allowed to filter for approximately 8 h, and samples for analysis were taken from the post-treatment storage container as a composite of that day's filtrate. Filters were challenged with microbes daily, but untreated and treated waters were assayed once per week. Bacteria counts were recorded as coliform forming unit (cfu). A comparison of concentrations in pre- and post-treated water was used to determine the $\log_{10}$ microbial reductions, the principal outcome measures from testing, as:

$$\text{Log Reduction value (LRV)} = \log_{10}(\text{E. Coli concentration in flow test water}) - \log_{10}(\text{E. Coli concentration in filtered test water} \qquad (1)$$

Table 1. Average physico-chemical characteristics shown by the MPF for two types of Test waters

Parameter	Type 1	Type 2
Mean Turbidity (NTU), n = 192	2.96	45.60
Mean pH, n = 192	7.55	7.55
Mean EC (µS/cm), n = 192	722.34	748.27
Mean Color (TCU), n = 192	76.34	376.87

2.3. E. Coli Testing

E. Coli measurements were taken before and after test water passage through the filters. Sample waters of 250 ml were taken from each filter and subjected to the membrane filtration technique. 10 ml of each sample was filtered through filter papers having pores of 0.45 µm (Sartorious Stedim, Gottingen, Germany) placed on sterile magnetic membrane filter funnels and filter papers were in a broth made from Bactoagar and Emendo produced in a petri dish. This was then placed in an incubator at 37°C for 24 hours. *E.Coli* colonies have a characteristic magenta color which makes it possible to count the total number of colonies with the naked eye. Following the incubation period total number of colonies of *E.Coli* was counted and recorded for each of the samples. At certain instances the number of bacteria colonies was too large to be counted. To avoid such cases serial dilution was carried out before conducting the membrane filtration technique for counting bacteria. The bacteria were recorded as CFU/100ml (coliform forming unit) and it was maintained at greater than 10^5 CFU/100 ml as suggested in Mwabi et al (2011). In order to obtain representative sample and performance over time, measurements were made initially and after 25%, 50%, 75% and 100% of total water determined for the experiment consistent with WHO (2011,b) requirement.

2.4. Physico-Chemical Parameters

In addition to E.coli measurement, several physical-chemical parameters of the test waters were also measured. pH was measured by a calibrated HACH® pH meter (HACH sensION$^+$ PH31). Turbidity measurement was performed using proprietary nephelometric instrument for turbidity; HACH® series portable turbidimeter (HACH 2100Q. Turbidity is expressed as Nephelometric Turbidity Units (NTU). Laboratory based apparatus HACH® Spectrophotometer (HACH DR2800) was used to determine color concentration. Color is usually expressed in platinum-cobalt (pt.co units) which is based on the intensity of color. Electric conductivity was tested using a calibrated HACH® conductivity probe.

3. RESULTS

The data obtained after conducting the experiment has been summarized in Table 2 and 3 and the LRV of different filters for different types of water has been summarized in Figures 2-4. Following tests over 1000L throughput of the test waters in each filters it was found that all of the filters had a mean E. Coli removal greater than 99.99% (4.0 $\log_{10}$) as shown in Table 2. A statistical analysis (t-test) was performed to assess performance of the filters in different Test water conditions at 95% confidence interval. Both JCL and Nova filters didn't show significant variation in E. Coli removal efficiencies ($p = 0.005$ and $p = 0.03$ respectively) when subjected to Type 1 and Type 2 waters. In Myako filters the removal efficiencies had significant variation ($p = 0.765$) suggesting that the different water qualities had an impact on the E. Coli removal in Myako filters as shown in Figure 4. However the mean LRV was greater than 4.0 with no instances where the value dropped below 3.5, according to WHO it can be termed as 'Highly Protective' nonetheless.

Table 2. Summary of Testing Data on MPF Effectiveness against Test Microbes over 1000 Liters

Parameters	Type 1 Water			Type 2 Water		
	Myako	JCL	Nova	Myako	JCL	Nova
Turbidity	0.747 (0.61-1.20)	0.534 (0.29-0.9)	1.25 (0.82-2.5)	0.97 (0.65-1.9)	1.6 (0.98-2.2)	0.69 (0.32-1.5)
pH	7.99 (7.3 – 8.52)	8.12 (8.65-7.75)	8.06 (7.72-8.41)	8.07 (7.63-8.4)	8.07 (7.35-8.57)	8.11 (7.53-8.57)
EC	824.6 (715 – 887)	756.4 (710-850)	873.8 (810-965)	847.4 (736-910)	683.6 (624-785)	869.3 (812-950)
Color	34.55 (29-41)	41.89 (31-56)	30.78 (16-54)	41.11 (29-75)	52.67 (31-90)	17.89 (5-42)
LRV	4.04 (3.15-4.5)	4.31 (4.0-4.78)	4.35 (3.64-5.02)	4.04 (3.74-4.48)	4.09 (3.87-4.48)	4.01 (3.64-4.35)

Table 3. Average Physic-chemical performance over 1000L of passing of sample water

Average Physic-chemical performance over 1000L of passing of sample water												
	Type 1 water(Spiked ground water)						Type 2 water(Spiked ground water with 1% sterilized untreated wastewater)					
Physic-chemical parameters	Myako		JCL		Nova		Myako		JCL		Nova	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Average Turbidity (NTU)	2.43	0.74	1.84	0.52	4.62	1.21	46.64	0.959	49.14	1.52	41.02	0.64
Average pH	7.39	8.04	7.67	8.14	7.6	8.14	7.61	8.06	7.45	8.13	7.58	8.11
Average EC(μS/cm)	751.7	824.6	677	757.6	738.33	882.7	742.2	844.7	739	694.1	763.6	878.8
Average Color (TCU)	42	34.11	54.33	41.56	132.7	30.33	407	39	292.7	51.89	430.9	17

The turbidity was within permissible levels for drinking water (< 5 NTU) in both test waters. The pH of waters increased after filtration and in certain isolated occasions reaching as high as 8.65. The mean value was within permissible limits (6.5-8.5) as shown in Table 2.

Following the testing of filters over a total throughput of 1000L of test waters per filter, it may be concluded that all the filters exhibit "Highly Protective" quality in terms of E.coli removal. Fluctuation in performance over time, evident in Figures 2-4, may be related to unmeasured changes in water chemistry, variations in pretreatment concentration, or other factors which may also vary under use conditions which was also found in Brown et. al (2009).

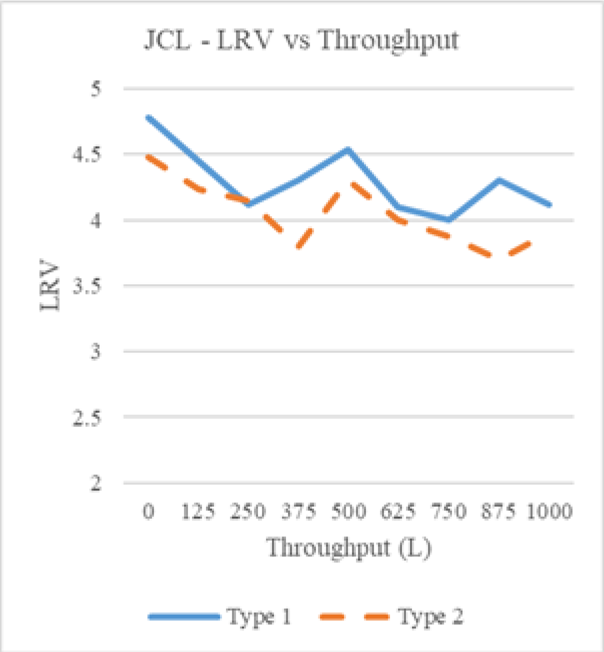

Figure 2. E. coli challenge test results showing mean $\log_{10}$ reductions over 1000 L in JCL

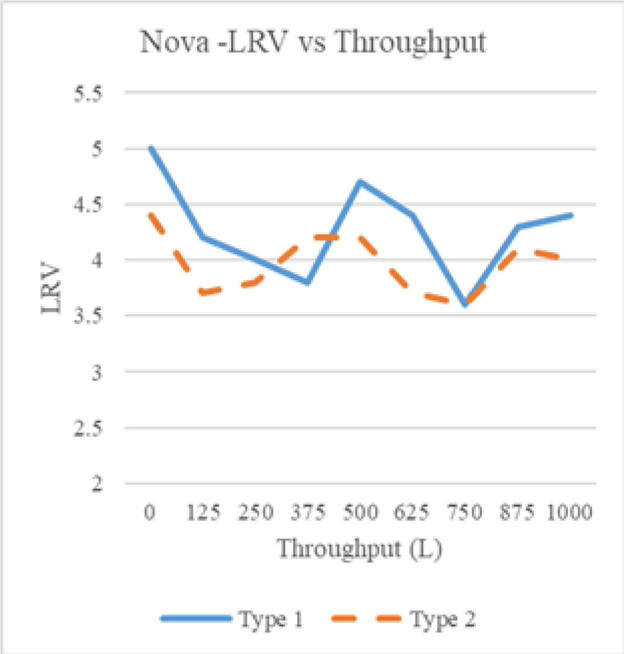

Figure 3. E. coli challenge test results showing mean $\log_{10}$ reductions over 1000 L in Nova

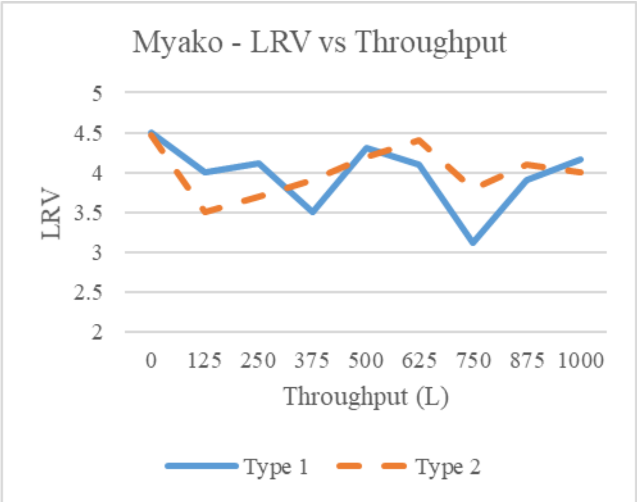

Figure 4. E. coli challenge test results showing mean $\log_{10}$ reductions over 1000 L in Myako

4. DISCUSSION

An overall increase in pH and Electrical Conductivity from raw water to treated water was observed in both test waters indicating that the quality of water had no effect on the filters influence in pH and Electrical Conductivity of water. This change may be attributed to the effect of minerals present in the filter cartridges on water. The nature and composition of these filter minerals have not been investigated in this experiment and further study is required to assess their effect. Moreover in this experiment we evaluated the capacity of filters to reduce E.Coli microbes and associated physic-chemical parameters, not an extensive chemical analysis to evaluate the capacity of filters to remove chemicals. According to an unpublished report by researchers at Resource Development International, Putheary et. al (2012). ―Cambodia and the Royal University of Phnom Penh, MPFs were not effective against arsenic or fluoride, removing a mean 30% of arsenic in laboratory testing. Therefore, further study and research is necessary to justify claims of manufacturers regarding reduction of arsenic and fluoride. In our experiment we tested for the efficiency of bacteria removal. However, several viruses and protozoan organisms such as MS2 coliphage and Bacillus Atrophaeus respectively are known to pose health threats upon consumption, the removal of which also needs to be assessed as an extension of our research work. The results from such further study will enable a more comprehensive conclusion regarding the overall efficiencies of MPFs.

There are various kinds of MPF's available in the market each having their own features making it impossible to make a generalized conclusion about MPF's. Moreover, varying conditions of test waters in field conditions, for instance water with much higher turbidity and pH may have a different effect on the microbes present in water. In practical conditions several other factors such as user behavior, hygiene maintenance, and secondary contamination from unclean handling of filters may significantly affect results. Hence results from this experiment should be dealt with caution and not generalized. Nonetheless it gives an insight into the nature and possibilities of MPFs as ideal household water treatment technologies upon further research under varying conditions.

5. CONCLUSION

With the increasing popularity of MPFs in South Asian countries and an increasing number of users of this technology, it is imperative to understand how they behave under different conditions so that their effects may be formulated. This experiment thus gives an insight into the capacity of MPFs in Bangladesh market and their effectiveness as per WHO testing protocols enabling assessment of their suitability as an effective household water treatment technology.

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Progression of Policy Developments Towards Sustainable Water Management in Bangladesh

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Abstract

Bangladesh, the delta of the Ganges-Brahmaputra-Meghna rivers system, one of the largest in the world. The country is traversed by a vast network of 24000 km with various category of rivers (405 prominent including 57 trans-boundary), dominated by low lying, flat flood plain, especially the coastal zone, vulnerable to seasonal, coastal floods and storm surges inundating average 20% (average)-60% (extreme) area annually; climate change will aggravate these badly. Main rivers are subject to active erosion and sedimentation (sediment inflow around 1.0 bln tons/year) processes. Water management of the country having 1211 bcm renewable water resources is mostly dependent on the understanding among the riparian countries. Water management of the country has a long history of continued efforts towards a good management started even 3000 years back and is still a living process which will be explored in this paper. During the long journey, process of adaptation with new technologies, management systems, role of administration of multiple dimensions from Kingdom-Colonial-Independent to modern democratic government and of the common people of the regimes. The present water management is combination of Integrated Participatory Sustainable management, adaptive and resilient to climate change.

Keywords: integrated, participatory, sustainable, adaptive, resilient

1. INTRODUCTION

Bangladesh (located between 20º34' to 26º38'N and 88º01' to 92º41'E), the delta of the Ganges-Brahmaputra-Meghna (GBM) river system, one of the largest and most active deltas in the world characterized by a constantly changing geographic and geomorphologic situation. The country is traversed by a vast network of huge Rivers totaling an approximate 24000 km with various category of rivers, their tributaries and distributaries, mountain streams, winding seasonal creeks and canals. BDP2100 (2018). Some 405 prominent rivers including 57 trans-boundary crisscross the country as per BWDB (2011). Main rivers are subject to active Erosion and Sedimentation processes. According to JRCB (2018) the total catchment area of the three rivers is 1.72 million km2 of which some 7% lies in Bangladesh. Bangladesh is characterized by a sub-humid to humid monsoon climate, with relatively cold, dry winters and warm, humid summers, 80% of rainfall is concentrated in the five monsoon months mentioned in BDP2100 (2018)). Topography is dominated by low lying, flat flood plain subject to annual floods inundating average 20% (average)-60% (extreme) area annually subject to aggravate with climate change. The coastal zone of Bangladesh facing the Bay of Bengal have a coast line of around 710 km, consisting large areas of potentially fertile land subject to tidal inundation, storm surge and river flood, contains several ecosystems of important conservation value including the world's largest mangrove, the Sundarbans (declared a World Heritage site in 1997). CSIRO (2014) mentions water management of the Country having 1211 bcm renewable water resources is mostly dependent on the understanding among the riparian countries.

2. METHODOLOGY

In order to review of literature on water policies, water governance and community based water management; books, documents, reports, papers have been searched in the BWDB, LGED, CEGIS, IWM libraries, resource persons have been contacted and discussed to collect information in different form which have been reviewed and compiled to prepare a comprehensive overview on existing policies and management practices and development.

3. REVIEW OF PROGRESSION OF POLICY DEVELOPMENTS TOWARDS A PARTICIPATORY WATER MANAGEMENT TO ACHIEVE SUSTAINABLE WATER MANAGEMENT SUPPLEMENTING WITH HISTORICAL PROJECTS

According to Ali (2002), irrigation (water management) in Bengal in the early stages was better than in other parts of the world. About 3000 year ago the rulers of the then Bengal introduced overflow irrigation system that was practiced till 1200. As in BNCID (1992), the medieval period (1200-1757)-Sultani/Turkish/Mughals Period, the irrigation practice improved from overflow to Tank irrigation. Flood control through construction of embankments and improvement of drainage facilities began during this time which continued till the end of the Mughal Empire in 1957. During this period, water governance and management was shared by root level local government bodies (village Panchayat) thus was the participation of people as per Ali (2002).

During Colonial Period (1757-1947); Ali (2002) mentions the development and maintenance of flood control, drainage and road communication was suddenly stopped, Zamindars were relieved of their traditional duties, the state support to village panchayat was withdrawn; negligence of water management for a long time (200 years) had led to a number of serious problems, cumulative results were frequent flooding and subsequent crop damage. However, during ancient rulers there was some form of water management and governance structure.

3.1. Modern period 1947 onward

This exercise of reviewing the literature related to Water Management and Water Governance attempted to gather information on what happened or are happening in this regard in Bangladesh. However, this paper discusses policy developments during the Modern period 1947 onward.

East Bengal got independence as a part of Pakistan named East Pakistan in 1947, the modern period starts. Prior to 1947 there had not been any government-led national scale water sector development policy, plan or program.

Following the consecutive devastating floods in 1954 and 1955 a Flood Commission (December 1955) looked into the problems and advised remedial measures, EPWAPDA (1964). Subsequently, a United Nations Technical Assistance Mission (Krug Mission) investigated the possibilities of water resources development in East Pakistan in 1956 and submitted the ‘Krug Mission report’ in 1957 after review of the Gigantic Problems associated with flooding (United Nations 1957). On the United Nations Mission recommendations, the East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959 for the unified and coordinated development of the Water and Power Resources in present Bangladesh. The EPWAPDA with the help of (International Engineering Company Inc.) IECO prepared a 20-year Master Plan for water resources development, EPWAPDA (1964). The plan focused on large scale flood control and development projects including Polders (Coastal Embankment Project, Ganges Kobadak Project, Karnafuli Irrigation Project). Ali (2002) mentions this plan marked the beginning of the formulation of an integrated plan for Flood Control and Development of Water Resources of the country. According to DFID (2011), the orientation of all water sector development to this time was almost exclusively aimed at achieving the goal of increasing agriculture production to achieve national self-sufficiency. This bias towards Agriculture meant that solutions tended to be in the form of flood control drainage and irrigation (FCDI) projects.

As per Ali (2002) and Talukrder (1991), the legend “Coastal Embankment Project (CEP)” was conceived and initiated by EPWAPDA in the early sixties, its first phase consisting 92 polders of area

1.01Mha (protected with 4022km dykes) was implemented under Grow More Food Program and completed by 1971; the second phase included the offshore Islands, relatively less saline areas, partially reclaimed and newly accreted lands due to major Cross-dams I (1957) & II (1964) around Meghna Estuary. These projects were initiated, planned and implemented by Government and Embankment Khalashi & Gate Khalashi were appointed for operation and maintenance thus everything under State Ownership.

According to IBRD (1972), the International Bank for Reconstruction and Development (IBRD) reviewed the investment and performance of the water sector Master Plan 1964 and incorporated its findings in the report titled" Land and Water Sector Study" in 1972; DFID (2011) mentions, the study recommended a strategy of extensive minor irrigation in winter using LLP and tube wells and for flood control small scale, low cost, quick-gestation flood control projects in shallow flooded area. This was a major deviation in the strategy followed since 1964 that shifted priority from large scale projects to small scale Irrigation, Flood Control and Drainage (FCDI/FCD) projects and recommended nonstructural measures in flood management. Following this Bangladesh Water Development Board (BWDB) was created (by Presidential Order no. 59 of 1972) restructuring the East Pakistan Water and Power Development Authority (EPWAPDA) with the vision "Sustainable Development and Management of Water Resources to achieve the overall national goals of economic development, poverty alleviation, food security, public health and safety, descent standard of living and protection of the natural environment." These will be achieved through: (1) Institutional strengthening and capacity building (2) Participatory approach & (3) Integrated Water Resources Management. Henceforth several projects adopted/practiced innovative approaches to achieve the visions viz. involvement of stakeholders in 1960s in Ganges-Kobadak (GK) project in the name of Chashi Club for field level water management.

IBRD recommendations were reflected in Bangladesh-Netherlands cooperation program started in 1975 by adopting the Early Implementation Project (EIP, 1975-1998) that completed 88 project/subprojects in 4 phases, supporting relatively small labor-intensive, quick yielding water sector projects through BWDB.

Datta (1999) mentions, in the first phase of Early Implementation Project (EIP 1975-81) social equity aspects received more attention, both engineering and socio-economic characteristics of the sub projects became an integral part of the selection procedure; marginal farmers & landless people were included in the project "Target Group (TG)" in 3rd phase of EIP (1986-90) as a major indicator for selection of projects under EIP; the target group was involved in the routine maintenance as Embankment Maintenance Group (EMG) and in periodic maintenance as Landless Contracting Society (LCS) - mainly for earth-work which was strengthened by introducing allocation of 25% earth work for Target Group. As per Datta (1999), in 1988, MoWR approved the policy to allocate 25% of all project-initiated earthwork to the LCS and enlist LCS as a D-class contractor thus from an early Engineering bias, EIP has gradually broadened to include specific attention to: (i) Stakeholders' Participation (ii) Local level Water Management (iii) Multidisciplinary Participatory project planning. These were internalized within BWDB and the Government by including in GPWM, 2001.

The contemporary Delta Development Project (DDP 1981-1991) initiated the local Stakeholders participation in project planning by site selection of irrigation inlets and organized inlet-committees for participatory O&M where committees contributed in cash and kind (labour & materials) for routine O&M. (The author has been a professional Engineer in the DDP).

The other contemporary Land Reclamation Project (LRP, 1977-1991) implemented experimental schemes/polders to promote a quicker and more effective use of accreted lands for improved food production and ensure better livelihood of poor farmers and provided "khas" land to the landless farmers, organized and trained them to take the role of O & M of the polders and settled the new community successfully. Thus, community-based water management and water governance was established there. (The author has been a professional Engineer in the LRP).

Sir William Halcrow and Partners (1997) mentions, another contemporary System Rehabilitation Project (SRP 1990-97) rehabilitated 38 subprojects that focused on (i) institutional development by Water Management Group (WMG) formation, training & development (ii) improved operation and maintenance which resulted (a) development of an approach for participatory water management (b) established the importance of maintenance of the projects involving local stakeholders. In 1994, the MoWR approved the Guidelines for People's Participation (GPP) in water management that ensured the scope of community-based water management and sharing water governance. SRP concentrated efforts to implement Guidelines of People's Participation (GPP).

Datta (1999) mentions, the BWDB has been successful in involving institutions, Water Management Organizations (WMOs) and Non-Government Organizations (NGOs) in the mobilization of the beneficiaries with regard to construction and maintenance. The works carried out by LCS and EMGs are of high standard and quality.

Lessons learned from all exercises in project planning, implementation and O & M during three decades resulted in formulation and enact the Guide Lines for Participatory Water Management GPWM, MoWR (2001) which ensured people's participation in all Water Sector and allied project cycle (planning, implementation & Operation and management) towards community water management and water governance. BWDB, IPSWAM (2001, 2004) mentions, closely related to the National Water Policy (NWPo) and building upon it, the GPWM elaborates the NWPo provisions and make available harmonized guidelines for field use intended to increased/improved participation of stakeholders in water management, decision making, awareness, capacity building, ownership building and play role in water governance.

In addition to the exercise of innovative approaches in project planning, implementation and O & M, water sector agencies simultaneously made several efforts to develop Strategy, Plan, Policy and Guidelines towards an improved integrated participatory water management and good governance, focus being shifted from mono-sector (agriculture) to multi-sector approach.

BWDB (2009) spells, after the severe floods of 1987and 1988 in Bangladesh, a comprehensive study titled "Flood Action Plan (FAP 1989-2000)" on water resources has been conducted by Flood Plan Coordination Organization (FPCO) under MoWR with international support; Ali (2002) mentions it was aimed at the identification, planning and possible construction of technically, economically, environmentally and socially feasible high priority projects. As per BWDB (2009), one of the outcomes of the study is Bangladesh Water and Flood Management Strategy-1995 that recommended preparing a National Water Policy and a National Water Management Plan, Consequently, FPCO was incorporated in the Water Resources Planning Organization (WARPO) under MoWR. Contemporary major achievement was the formulation of National Water Policy, MoWR (1999) by the GoB.

According to MoWR (1999), the declaration of the National Water Policy is a bold step towards Good Governance in Bangladesh, it is the policy of the Government that all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner. The policy (article 4.16) ensures that all stake holders actively and fruitfully participate in water resources management decision making at all stages, it also ensures favorable guidance towards community water management and good governance.

On the other hand, as per MoWR (2001), National Water Management Plan (NWMP), outlined 84 programs under 8 clusters relates to Community based Water Management and Water Governance including Local Government Capacity building for Water Management. (ID005); field testing of participatory water management Model & GPWM; raising public awareness in wise use and management of water; promotion of expanded minor irrigation, on farm water management, water management at local Government and community level; Environmentally Critical Area (ECA) and wetland management, improved water management and salinity control in the Sundarbans. Implementation of these programs will assure establishment of community based water management and good water governance to a great extent.

Setting in place all these strategy, policy, plan and guidelines water sector agencies took up some milestone projects to achieve integrated participatory sustainable water management and establish water governance, some examples are discussed herewith.

According to IPSWAM (2001, 2004), Integrated Planning for Sustainable Water Management IPSWAM has been formulated to assist BWDB to find out ways to introduce Practical Affordable and Sustainable Participatory and Integrated Water Resources Management that practiced the policies and guidelines in place and succeed to establish sustainable water management in 9 polders in the South-western Coastal Zone handing over and taking over shared responsibility of O & M of the projects by public agency and stakeholders community (The Author has been the Project Director).

The participation of the Poor was found higher than the participation of the non-poor in different stages of the IPSWAM project in most of the project areas due to increase of their awareness and involvement in WMOs members. Experiences gained through the implementation of the IPSWAM project has been replicated in other new generation projects, its latest version is ongoing Blue Gold Program of BWDB.

According to Euroconsult- Matt Macdonald (2011), Char Development and Settlement Project CDSP, a successor of LRP with support of GoN conceived all policy plan and guidelines in place, aimed at increasing the security of households in the coastal chars of south-eastern Bangladesh by providing them with individual assets land & housing and collective goods, as embankments, roads and cyclone shelters. These activities evolved as a regional multi-sectoral and multi-agency program under successive phases of CDSP I (1994-2000), CDSP II (2000-2005), CDSP III (2005-2010), CDSP IV (2011-2016); the provision of a land title to landless families (50% share of man & women ensured) formed the core of the efforts to reduce poverty levels in coastal char communities. This was followed by improvements in water management and agricultural practices, leading to higher farm incomes. In addition, general economic uplift of the project areas created employment opportunities. As per Euroconsult- Matt Macdonald (2011), involvement of the settlers in the chars with planning and implementation of the project activities has been given shape through the formation of community based, field level institutions as WMOs, Social forestry groups, Farmer Forums, LCS and NGO groups where LGIs were involved in the project as well. Euroconsult- Matt Macdonald (2011) also mentions, CDSP III has been successful in reducing gender gaps and achieving a more gender balanced society in the project area. Studies show that the program has had substantial impacts in term of reducing flooding and salinity and increasing agricultural production, which in turn has resulted in better livelihood and increased employment, leading to reduced poverty, increased income and degree of empowerment of women.

A contemporary effort was the involvement of Local Government Engineering Department LGED in implementing Small-Scale Water Resources Development Sector Project SSWRDSP since 1996 that also followed all policy, plan and guidelines in place for Water Sector. According to ADB (20077) and BIDS (2014), following learning through experience, the Local Government Engineering Department (LGED) suggests that the community needs to be involved in the process from the very beginning of project cycle, up to the actual project implementation, the LGED initiated this model and implemented 280 small water resources management subprojects under its Small Scale Water Resources Development Sector Project (SSWRDSP-1) during 1996-2002. According to LGED, the SSWRDSP implemented during its successive phases some 830 small scale schemes (280 in Phase I, 1996-2002; 300 in Phase II, 1999-2010 and 250 in Phase III, 2011-1017) spread over the Country. According to Huda (2006), the objectives of higher agricultural production and employment generation were to be realized through stake holder participation at all stages of project cycle including resource mobilization by project beneficiaries for sustainable O & M.

Many policies of the government directly and indirectly support community participation and empowerment that can influence Integrated Participatory Sustainable Water Management and Water Governance. Among them, important ones are, The Coastal Zone Policy (2005); National Adaptation Program of Action NAPA 2005; Bangladesh Climate Change Strategy and Action Plan BCCSAP 2009; Bangladesh Water Act 2013 and Guide Lines for Implementation of Bangladesh Water Act 2018. Other policies supporting Sustainable Water Management and Water Governance are Environment policy & implementation plan, MoEF (1992); National Tourism policy (1992); MoEF (1994); National Energy Policy (1996); National fish policy (1998); National policy for safe water supply and sanitation (1998); National agricultural policy (1999); Industrial policy (1999); National shipping policy (2000); National rural development policy (2001); National land use policy (2001) and many more.

3.2 Bangladesh delta Plan BDP2100

The evolution of Bangladesh is a story of dynamism and extraordinary resilience. The Bangladesh Delta achieved huge development in its socio-economic arena during last 5 decades with a remarkably consistent average economic growth rate of 6% over the last few years defying extreme adverse climate variability, frequent storm and tidal surges, flooding, and droughts, BDP2100 (2018). As mentioned in NEC (2018), in continuation of the development and recognition of the long-term development challenges of sustainable management of water, climate, environment and land resources, the Bangladesh Government has formulated the BDP2100 to achieve the goals of graduating from a least developed country (LDC) to middle-income one and eradicate the ultra-poor from the society (Vision 2021) and to become a Developed Country (Vision 2041) by which is approved by the Government as well. An Investment Plan of BDP2100 based on Adaptive Delta Management ADM, wide consultation and inclusive process has been formulated with support of World Bank, identifying 80 projects (65 for Infrastructure & 15 for Institutional Development, Capacity Building and Research) to be implemented by 2030 with an estimated cost of Tk.2987 /USD 37 billion.

According to NEC (2018), BDP 2100 is an Adaptive, Holistic and Long-term 50-100 year, Economic and Technical Plan to utilize the huge potentials of water, climate change, natural disasters, environment, ecological balance, agriculture, land use and inland water management and disaster management in national development. Main objective of Delta Plan is the sustainable management of water resources and protection from water induced disasters. BDP2100 (2018) spells, this includes short term measures and actions to solve urgent problems and to gain widespread socio-political support for implementation of a long-term strategy. In the approach, governance and institutional knowledge and experience have been integrated with knowledge of content, process management and program management services; also capacity building in all aspects has taken place not only to deliver quality outputs during the project, but also to help the people involved to improve their knowledge and skills which are required to further the implementation of BDP 2100. The project formulation has been implemented on behalf of GoB by the General Economic Division (GED) of the Planning Commission (PC), Ministry of Planning (MoP).

Vision and Goals: The Delta Vision aims for long term integrated development of the Bangladesh delta and is meant to achieve sustainable development goals through adaptive water governance. The Delta Vision is “Ensure long term water and food security, economic growth and environmental sustainability while effectively coping with natural disasters, climate change and other delta issues through robust, adaptive and integrated strategies, and equitable water governance.” As per BDP2100 (2018), the Goals to be achieved by 2100 or before are 1: Ensure safety from floods and climate change related disasters 2: Enhance water security and efficiency of water usages 3: Ensure sustainable and integrated river systems and estuaries management 4: Conserve and preserve wetlands and ecosystems and promote their wise use 5: Develop effective institutions and equitable governance for in-country and transboundary water resources management 6: Achieve optimal and integrated use of land and water resources. The mission of BDP2100 is to develop strategies which contribute to disaster risk reduction, climate change resilience and adaptation, water safety, food security, environmental safety and economic development of the country. The overall objective of BDP 2100 is to realize a sustainable and commonly agreed upon strategy, with all relevant stakeholders, for an optimum level of water safety and food security as well as sustained economic growth of Bangladesh and a framework for its implementation.

Since BDP2100 is an adaptive and Long-term Plan, it will have to integrate with the National Planning Process. Thus, this will be reviewed regularly time to time and be reflected in all FYP. More over the plan should be updated and enriched with new knowledge and technologies.

4. CONCLUSION

Efforts towards the best water resources management and management of water induced disasters with successive adoption/formulation of plan, policy, and Guidelines and application/practice of innovative approaches has been a continuous exercise during the modern period in Bangladesh (erstwhile East Pakistan). As per World Bank (1972), the journey started with large scale projects (20 year Master Plan 1964) shifted to small scale irrigation, flood control and drainage (FCDI/FCD) projects; introduced and exercised GPP, GPWM, NWPo, NWMP & Bangladesh Water Act 2013 during more than five decades. The journey finally anchors to the BDP210, a modern, adaptive, holistic, integrated and long-term (50-100 year) objectives, economic and technical plan to utilize the huge potentials of water, climate change, natural disasters, environment, ecological balance, agriculture, land use and inland water management and disaster management in national development along with an investment plan to be implemented by 2030 at a cost of around USD 37 billion. This is a living document to be revised/updated regularly with new knowledge, technology and experiences and be incorporated in all five-year plans FYPs to come till 2100.

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Effectiveness of Drought Indicators in Characterizing Past Droughts in the North-Western Part of Bangladesh

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Abstract

Drought is a widespread natural hazard and a major issue in the north-western part of Bangladesh. The characterization and identification of drought in the context of drought monitoring and management is challenging. Although several researchers have developed a variety of drought indicators, it is important to assess the effectiveness of these in characterizing the occurrence of drought. This study presents the characterization of drought indicator developed using ground and remote sensing data in Rajshahi and Rangpur districts in the north-western part of Bangladesh. The study focuses on the effectiveness of drought indicators in representing past drought events in support of effective drought monitoring and management. Past records of drought events were collected from relevant organizations through field surveys in Bangladesh. Meteorological, hydrological and groundwater data were collected from the related institutions in order to analyze the drought indicators. Additionally, MODIS 16 NDVI satellite images were downloaded to compute drought indicator based on remote sensing data. Analysis of historical drought events show that moderate to extreme drought occurred nine times in the last 42 years in the study area. Analysis of meteorological indicators (SPI and SPEI) show that the occurrence of past drought events was correctly identified by these indicators. On the other hand, the hydrological drought indicator (SRI) could not describe the drought phenomena in the study area properly because river discharge is governed by the upstream river basin and not by the drought in the region of the study area. The effect of over exploitation was seen since the last decade because of the extra abstraction of groundwater for the irrigation in the dry season. Moreover, deviation of the NDVI value also identified the occurrence of past drought although this analysis was only done for the period of 2001-2013 because of unavailability of satellite image data before 2001.

Keywords: Characterization, identification, effectiveness, drought monitoring and management.

1. INTRODUCTION

Drought is a natural hazard and resulted significant impact across the world. According to Alston et al (2004), Smakhtin et al (2004) and Masih et al (2014), drought occurred in the past has severe impact on society, environment and economy. Wanders et al (2010) suggested that normally a drought occurs when there is shortage of water compared to average condition. Heim et al (2002) defined drought as a hydrological imbalance due to deficiency of rainfall over a longer period of time. Iglesias et al (2009) stated that drought varies from region to region depending on the climatic variability as well as the appearance of the drought is influenced by rainfall, heat condition, and surface water. As a result, the intensity and the severity of drought may be different in different climate conditions.

Drought is a periodic observable fact. Brammer (1987) defined drought as the time frame when the

soil moisture is below the normal situation which is needed for plant growth as the economy of Bangladesh depends primarily on agricultural production. Hossain (1990) and Ericksen (1994) outlined in their research that Bangladesh has experienced drought several times over past. The different locations of Bangladesh affected by the drought are different in term of drought occurrence, severity and damage to the society, environment and economy. North-Western (N-W) part of Bangladesh has been affected by every drought occurred in the history of drought.
Several studies have shown the accounts of past records and monitored droughts using indexes like SPI, VCI, NDVI, SRI, SGWI, SPEI and so on. Nevertheless, it is important to know the effectiveness of different drought indexes to explain the occurrence of drought which is very useful in drought monitoring and management in the area of Bangladesh. This study focuses on the effectiveness of drought indicators to characterize the occurrence of past droughts in two districts (administrative boundary) namely Rajshahi and Rangpur in N-W part of Bangladesh (Figure 1). The Rajshahi district has a total area of approximately 2425 km^2 while it is 2400 km^2 for Rangpur. Both districts are characterized by tropical wet and dry climate with heavy rainfall during monsoon and low during dry season. The average rainfall is about 1450 mm and 2900 mm for Rajshahi & Rangpur respectively.

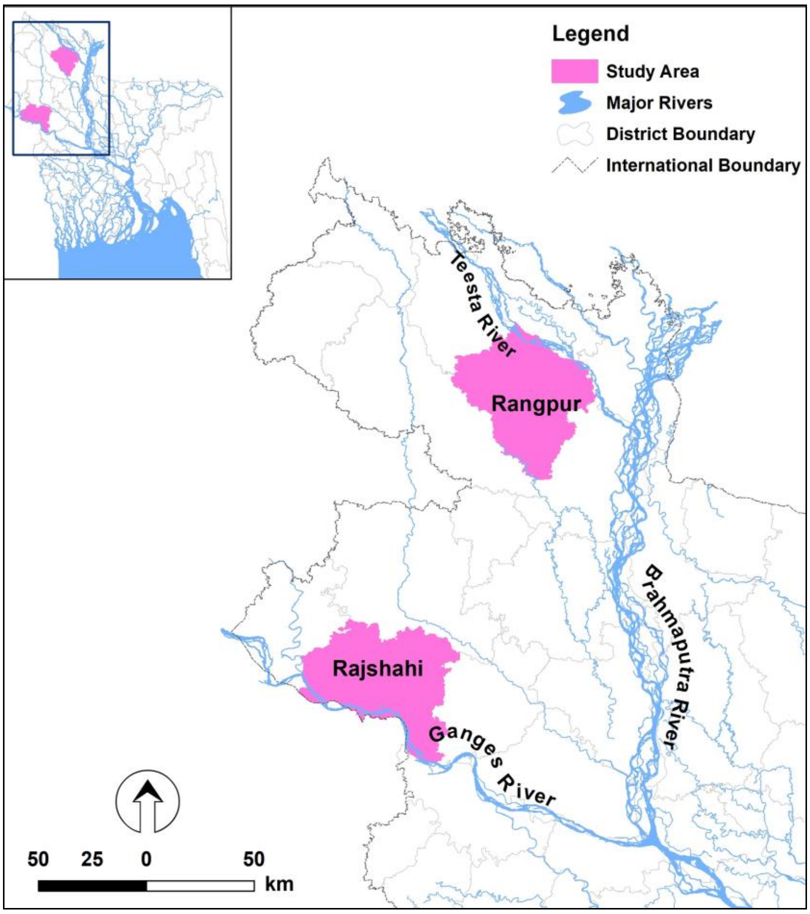

Figure 1. Location of Study area in N-W part of Bangladesh

2. METHODOLOGY

For the assessment of the effectiveness of the drought indicators, past records of drought events were collected from Department of Disaster Management, Bangladesh Bureau of Statistics as well as from literatures review and newspaper. These information were validated in the field through Focus Group Discussion and interview with relevant key informants and professionals. Then drought indicators were computed based on ground and remote sensing data.
For the computation of drought indicators of different time intervals, meteorological, hydrological and

ground water data were collected. The list collected data is presented in Table 1. Based on available data, Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Runoff Index (SRI) and Standardized Ground Water Level Index (SGWI) were computed using rainfall, temperature, discharge and ground water level data respectively. Moreover, Normalized Difference Vegetation Index (NDVI) data were used for the period of 2001-2013 which is based on remote sensing data during dry season as it was cloud cover in monsoon season. After that, drought indicator value were linked with past records to evaluate the effectiveness in characterizing the drought events. Records of ground data used for analysis is presented in Table 1.

Table 1. Data used for this study

Data Type	Data	Station and Period
Meteorological	Rainfall	Rajshahi (1972-2013); Rangpur (1982-2013)
	Temperature	Rajshahi (1972-2013); Rangpur (1982-2013)
Hydrological	Discharge	Hardinge Bridge (1985-2008)
Ground Water	Ground Water Level	Rajshahi (1981-2013); Rangpur (1981-2013)

3. RESULTS AND DISCUSSION

3.1. Drought Events

It has been found that drought events having moderate to extreme drought have occurred nine times in the last 42 years and four out of nine were in the severe to extreme condition (Table 2). This happened due to lack of rainfall in the monsoon season as well as the combination of lack of rainfall and high heat stress. Drought events were occurred in the dry period in the year of 1973, 1978/79 and 2001 while droughts were found in the monsoon season in 1972, 1981 and 1982 due to insufficiency of rainfall. In addition, drought events occurred in the year 1975, 1989 and 1994/95 both in dry and rainfall period. Drought started in the dry season and extended to the monsoon season during these drought events.

Table 2. Drought events and their level of impacts

Drought Events	Level of Impacts
1972	Moderate
1973	Moderate
1975	Severe
1978-1979	Extreme
1981	Moderate
1982	Moderate
1989	Severe
1994-1995	Extreme
2001	Moderate

3.2. Drought Indicators

Figure 2 and Figure 3 show the SPI at different time scales (SPI-3, SPI-6, SPI-12) both at Rajshahi & Rangpur districts respectively. Red arrows in the figure represent the occurrence of past drought events. It was found that SPI can effectively detect the occurrence of past droughts. It was also observed that like SPI, temperature based indicator SPEI (SPEI-3, SPEI-6, SPEI-12) characterizes the past drought events for Rajshahi and Rangpur districts (Figure 4 and Figure 5).

On the other hand, drought indicator (SRI) based on hydrological data (discharge) could not detect the historical drought events that occurred in Bangladesh (Figure 6). Because river discharge is not dependent to the local situation rather it is controlled by the upstream Ganges River basin as drought is local phenomenon.

Moreover, drought indicator (SGWI) using ground water level for Rajshahi and Rangpur districts is presented in Figure 7 and Figure 8. SGWI value less than zero than the normal indicates the vicinity to the ground level. It was found the two time periods for Rajshahi districts. One is from 1980-2004 where the SGWI value is less than zero since then it shows an increasing trend up to 2013 with extreme condition in 2010. On the other hand, ground water level shows much more variability in Rangpur district. It was above zero in the dry season and recharged again in the monsoon although depletion trend in the dry season was observed in the recent years.

Furthermore, NDVI value in Figure 9 shows that drought was in the year 2001 and 2010 during whole dry period in Rajshahi district while it was in 2001 and 2012 at Rangpur (Figure 10).

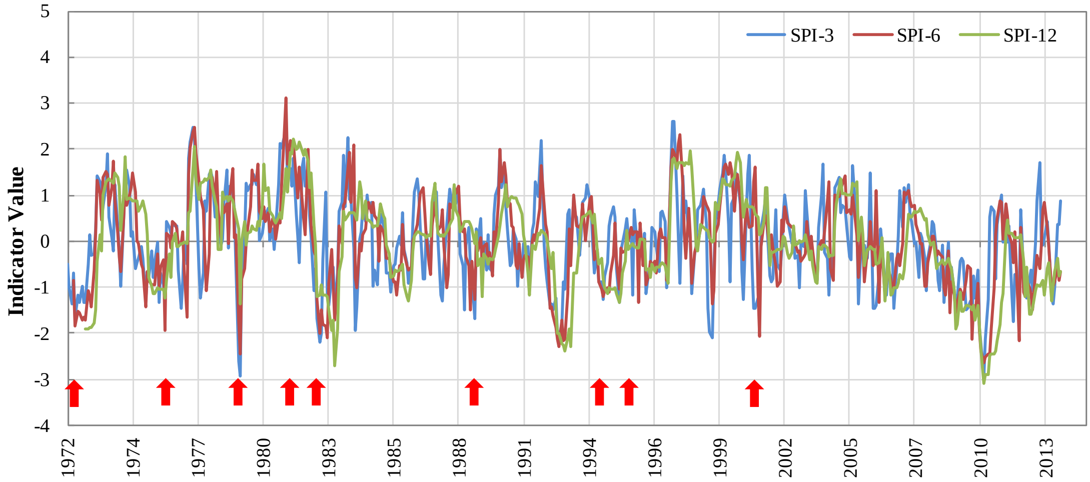

Figure 2. Standardized Precipitation Index at Rajshahi

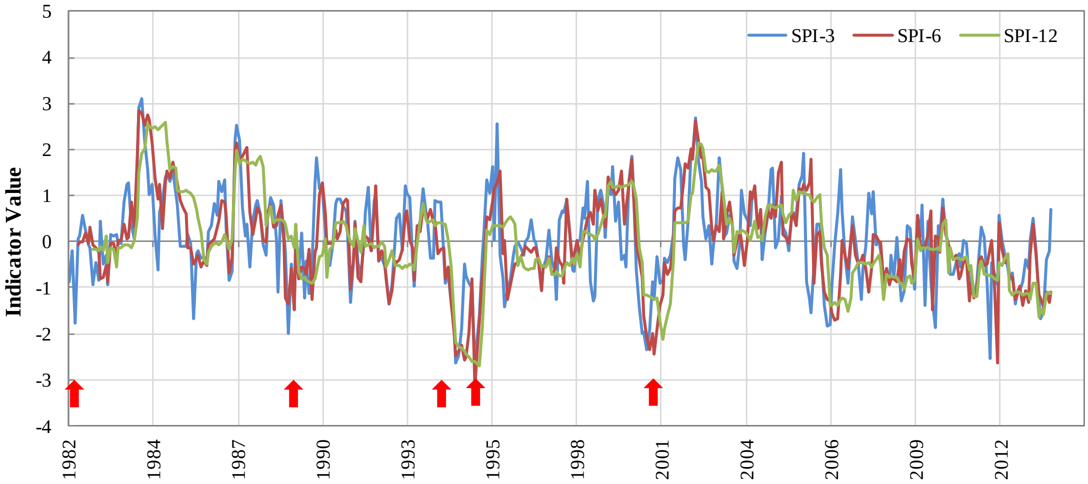

Figure 3. Standardized Precipitation Index at Rangpur

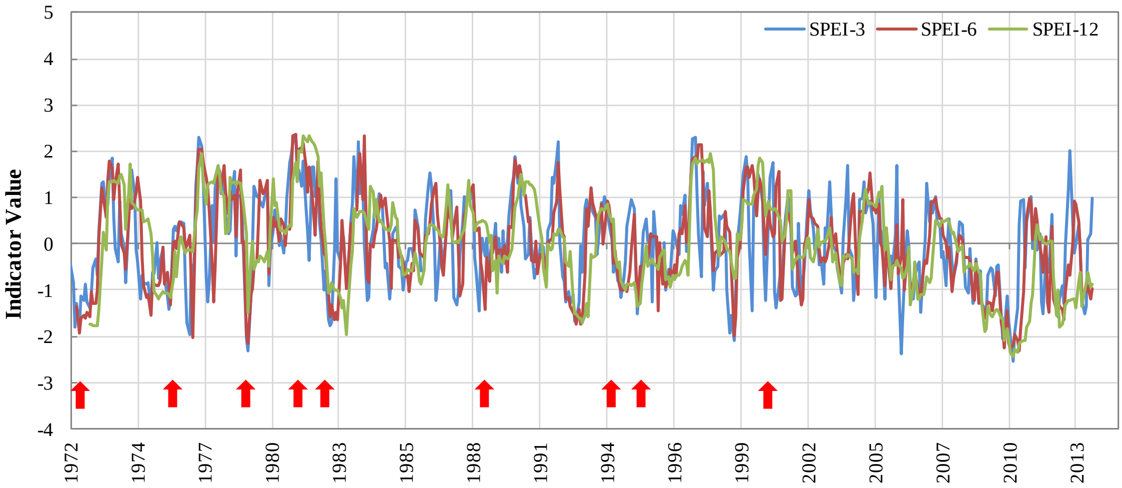

Figure 4. Standardized Precipitation Evapotranspiration Index at Rajshahi

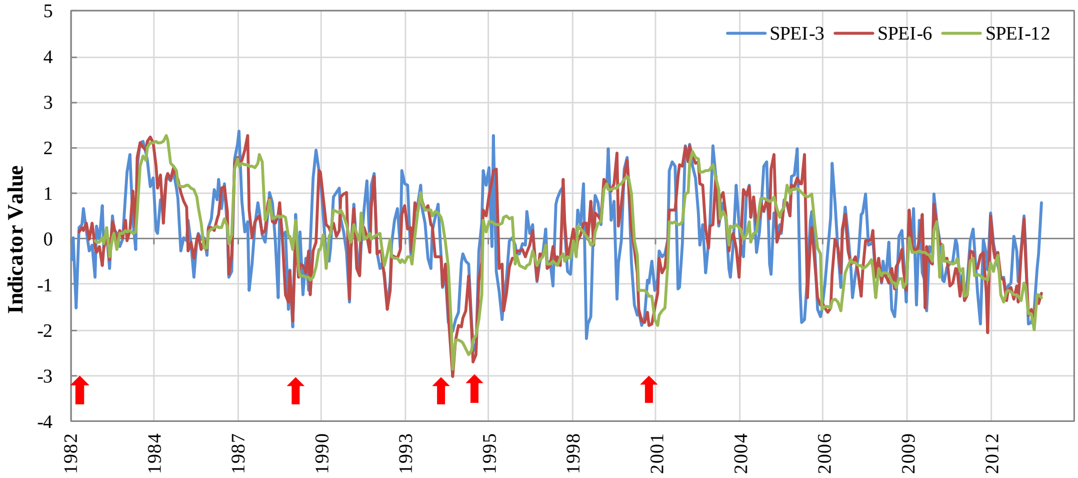

Figure 5. Standardized Precipitation Evapotranspiration Index at Rangpur

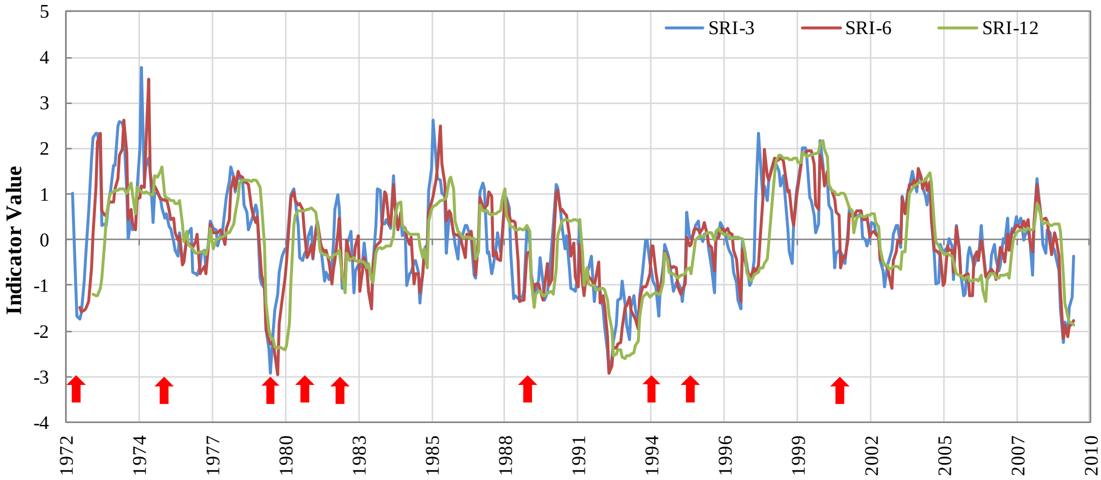

Figure 6. Standardized Runoff Index at Hardinge Bridge

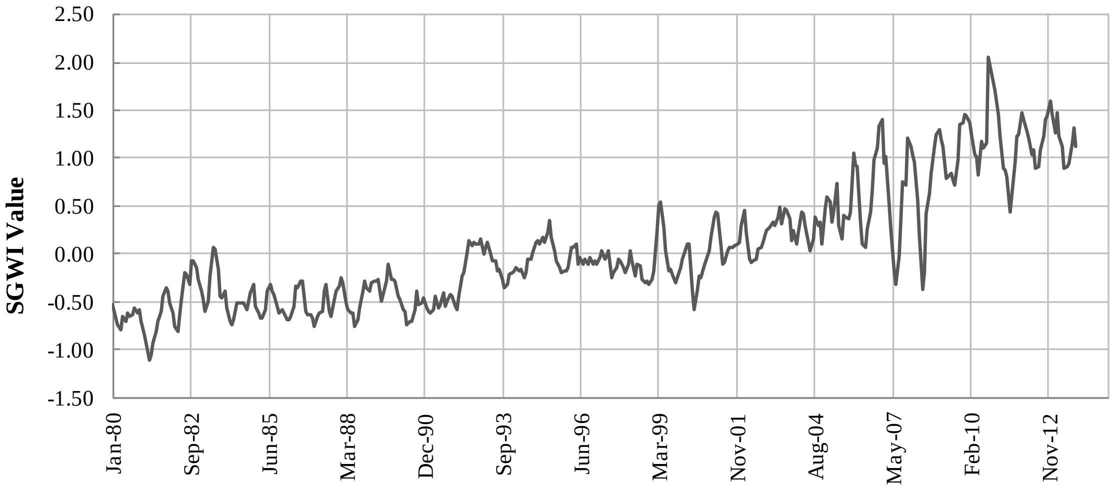

Figure 7. Standardized Ground Water Index at Rajshahi

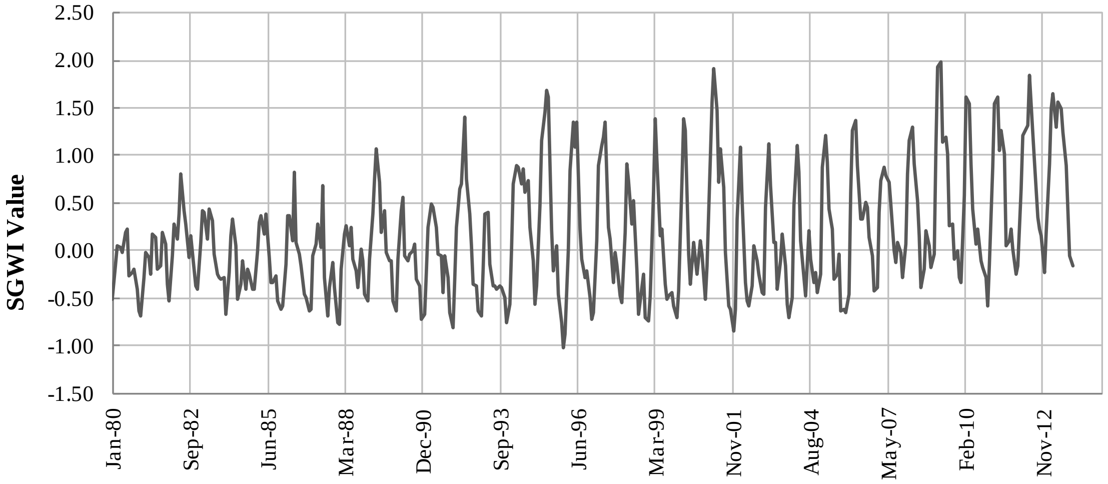

Figure 8. Standardized Ground Water Index at Rangpur

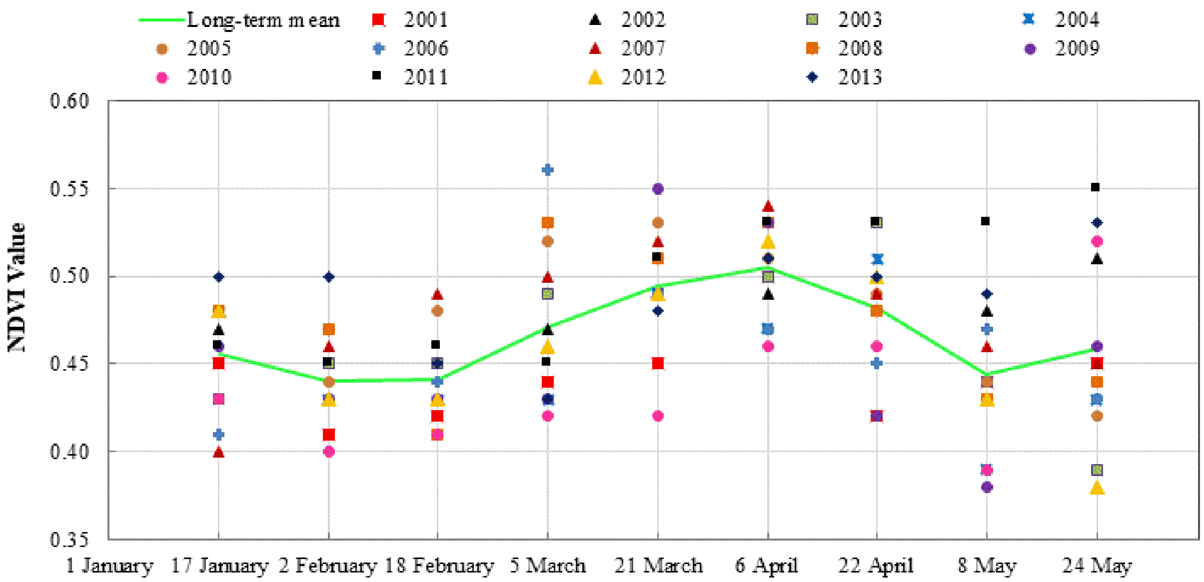

Figure 9. NDVI at Rajshahi during dry season

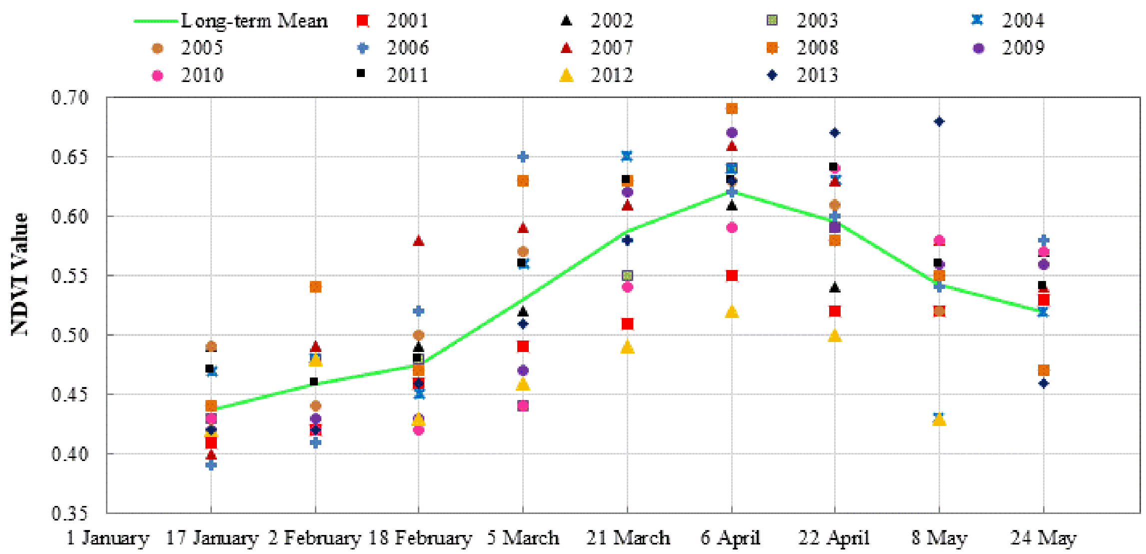

Figure 10. NDVI at Rangpur during dry season

4. CONCLUSIONS

This study presents the effectiveness of the drought indicators in characterizing the past drought events. Results revealed that both meteorological drought indicators SPI and SPEI can effectively identify the past records of drought in the North-Western part in Bangladesh. Both of these indicators shows good correlation between them. The finding of results of SRI does not explain the drought events properly while NDVI analysis gives better result in drought characterization of the study area although this analysis is limited from 2001-2013 and it identifies the observed drought event in 2001. The results from the groundwater analysis explain the depletion of groundwater level in the recent decades as groundwater is being used for irrigation significantly in the dry season and groundwater indicator helps to link with precipitation indicator as groundwater recharge is connected to precipitation in the study area.

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Ganges at Hardinge Bridge: Flow Pattern over Past Hundred Years

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Abstract

Bangladesh is a low-lying deltaic country. Major parts of the country's land mass have been formed by the sediments brought in and deposited by the Himalayan river system: Ganges-Brahmaputra- Meghna. Each of the rivers have origin at a different location of the Himalaya; and each traverse different path catching runoff from vast area with varied topography and vegetation cover before entering into Bangladesh. Inside the country, the rivers join together and discharge into Bay-of - Bengal through a single channel. Flows of these rivers, in combination with local rainfall runoff determine flooding in Bangladesh and determine water availability during the dry period of the year. Water level data for the period 1910-2017 and discharge data for the period 1934-2917 of the Ganges River at Hardinge Bridge station have been analysed statistically. The main finding is that both wet season and dry season flow have decreased since mid-1970s compared to flow over previous 65 years. The reduction of dry season flow appears is drastic relative to average flow condition of that period of year. The wet season flow reduction is much higher in absolute quantity.

Keywords: Ganges, Bangladesh, Flow Regime, Flooding, Hydrological Analysis

1. INTRODUCTION

Hardinge Bridge, located in Bangladesh (24.0663N, 89.0277E) is one of the key hydrological stations on the lower Ganges. Water level measurement had commenced at this point in 1910, and discharge measurement in 1934. Water level is taken twice daily in dry season, 5 times during monsoon season. Discharge measurement is carried out weekly. Mean daily flow rate is computed from weekly measurement data- using rating curve. Under a water sharing agreement with India (1996), discharge measurement is carried out daily during March – May period each year (lean flow months). Over the long period since commencement, huge volume of data has been accumulated.

The Ganges is the river of great economic importance to all the co-riparian countries. It is more true for hugely populated Bangladesh which lacks appreciable natural resources base except water. It is still a predominantly agriculture dependent country. At the same time, rapid industrial expansion is also taking place here. Water is required for consumptive use like irrigating crop fields, livestock rearing, industrial processing, drinking and sanitation; and non-consumptive use like sustenance of aquatice lives, navigation, flushing pollution. However, the availability of water resources is skewed over the annual cycle. On the other hand, demand of use of water is over the same cycle varied and not in phase with availability. Ganges contributes about one third of renewable water resources in the country. In addition to uses mentioned above, Ganges flow is very critical for keeping away the intruding salinity front in the southwest coastal districts. Therefore, good knowledge of flow

characteristics of the river over the annual cycle as well as long-term trend is important for strategic planning.
The author undertook this study on personal initiative with a research aim, taking advantage of the valuable data resources in disposal at no cost. The objective was to examine and analyze the available data to find flow characteristics of the river at this point.

2. THE STUDY

2.1. River Course and Catchment

The Ganges River rises in the Gangotri glacier on the southern slope of western Himalaya (falling within the territory of China) and falls in the Bay of Bengal in Bangladesh. The river has a course length of about 2,500 km from origin to outfall, lying over China, India and Bangladesh. Before entering into Bangladesh from the west, the river traverses a path of about 2000 kilometers, and receives many tributaries both from left and right along this part of course. In Bangladesh, the river flows southward from the entry point for about 110 kilometers, forming the India-Bangladesh border, thereafter, flows completely inside Bangladesh for about another 430 km before meeting the sea. Inside Bangladesh, the river is first joined by Brahmaputra- another Himalayan river and thereafter by Meghna- originating in a foothill of Himalaya.

Catchment area of the river is 1,087,300 km^2 spreading over China (3.1%), India (79.1%), Nepal (13.5%) and Bangladesh (4.3%) (Source: Indo-Bangladesh Joint River Commission, Dhaka, Bangladesh). The vast catchment consists of varied topography including mountains, hills, highlands and plains, varied climate, varied ecosystem and biodiversity; and is inhabited by about 400 million people. The river is fed by snow melt water during April – June period, runoff from monsoon rainfall during July-October period and occasional cyclonic rainstorm in May-June and October- originating from Bay of Bengal. For the remaining period of the year, flow is sustained from the storages in the catchment area.

2.2. Data Availability

The Hardinge Bridge hydrological station is located at about 166 km downstream of Farraka Barrage site in India, about 130 km upstream of the confluence with Brahmaputra. The entire catchment except some part inside Bangladesh lies above this station.

The author collected water level and discharge data from Bangladesh Water Development Board (BWDB), the organization responsible for hydrological measurement in Bangladesh. Mean daily Water level for the period from April 1910 to August 2018 and mean daily discharge data for the period from April 1934 to October 2018 have been made available. Two larger gaps were found in the supplied datasets. Flow measurement for the period from 21 March 1971 to 31 March 1972 remained ceased due to Bangladesh war of liberation. Water level data for the period from January to June 1961 is missing in the collected dataset though discharge data for the same period is available. Perhaps, the water level data for this period exists but somehow not included in the data set supplied to the author.

Besides the above mentioned longer gaps, there exist one 16 day gap, two 7 day gaps and several shorter gaps ranging from 1to3 days. To carry out statistical computation logically, shorter gaps have been filled in by interpolation, and larger gaps through the process of plotting and examining the hydrograph shape for data subset containing the gaps. With gap filling exercise, data availability is as follows:

Table 1. Water level and discharge data availability

Type	Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Flood	Dry	Year
WL	1910-2018	107	107	106	108	108	108	108	108	107	107	107	107	107	108	107
Q	1934-2018	84	84	83	84	84	84	84	84	84	83	83	83	84	84	83

2.3. Data Analysis

In Bangladesh, hydrological year is counted from April to March. On preliminary examination of the collected datasets, it was observed that annual lowest flow in Ganges at Hardinge Bridge occurs mostly in April or May, but in a few years, lowest flow had occurred in March. This implies that sometimes two minima fall in the same hydrological year. To avoid this situation, the author carried out statistical analysis on calendar year basis.

The collected water level dataset consisted of 39,023 data points and discharge dataset consisted of 30,133 data points. As a first step, datasets were examined, and data points were counted to find gaps within the range of time period. After finding and filling the gaps by interpolation where possible, the datasets were examined by plotting in different periodic segment- year, season and even on month window to check consistency.

The collected data comprised of mean daily water level and mean daily instantaneous discharge. From the original datasets, derived datasets have been created on month, season and year window. Statistical parameters such as maxima, minima, mean, median, standard deviation, inter quartile range (IQR), classical skew coefficient, and quartile coefficient has been computed in different time/ period frame. MS Excel 2010 software package have been used in plotting and statistical computations.

There is a general acceptance that the dry season inflow to Bangladesh has decreased since commissioning of Farakka Barrage by India in 1975. In recognition of this fact, a divide line was drawn at this event for analysis purpose. The 84 year long discharge record was imagined as consisted of two segments of equal length: (i) 1934-1975, and (ii) 1976-2017. Statistical parameters were calculated on each sub-dataset separately in addition to calculation on whole dataset.

2.4. Flow Regime and Characteristics

2.4.1 Water Level

Plot of monthly mean, high and low water level is shown in Figure 1. Mean water level for selected months have been plotted against long term mean in the left chart. Solid straight lines in left chart of Figure 1 represents long term mean for respective months. In the right chart, monthly highest and lowest water levels for wet and dry months have been plotted against 'Danger Level' (DL) and long term mean low respectively.

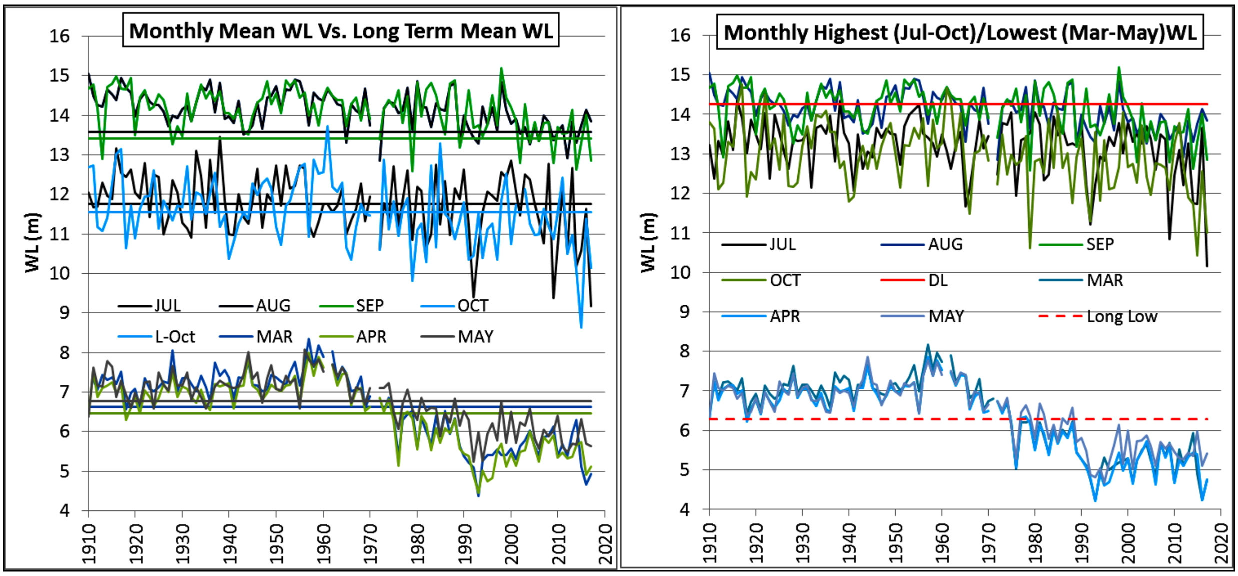

Figure 1. Monthly mean, highest, and lowest water level

High river stage prevails in the months of August and September; the long term mean water level for August is being only slightly higher than that of September. The long term mean of July and October, being close to each other is quite lower than those of August and September. Flow in July falls on the rising limb of yearly hydrograph, and flow of October on the falling limb. Another noticeable characteristic is that mean water levels of July and October fluctuates in greater range over their respective long term mean than those of August and September. In comparison to monsoon season, the water level of dry season is very much lower.

A decreasing trend in water level can be noticed. Lowering of dry season water level after 1970 is conspicuously seen in the graph; lowering trend of level for wet period is not so discernable in the chart. Detailed statistics reveals that yearly mean water level has been reduced by 15-20% in the February-May period and by 2-4% in July-October period.

Danger level at the station has been defined at 14.25 m. It can be seen in the right chart that water level had crossed the DL less frequently in the time period after 1970 than before. Over the recent past 18 year period, water level had crossed the danger mark only once (in 2003). This fact reinforces the notion of decreasing trend. In the latter part of the paper, we will see that persistence duration of high flow also possesses a decreasing trend.

2.4.2 Discharge

A Preview of discharge regime over the period of record is presented in the left chart of Figure 2. The dotted lines represent the long term mean for respective season/ months. Right chart shows a blow up of dry period flow.

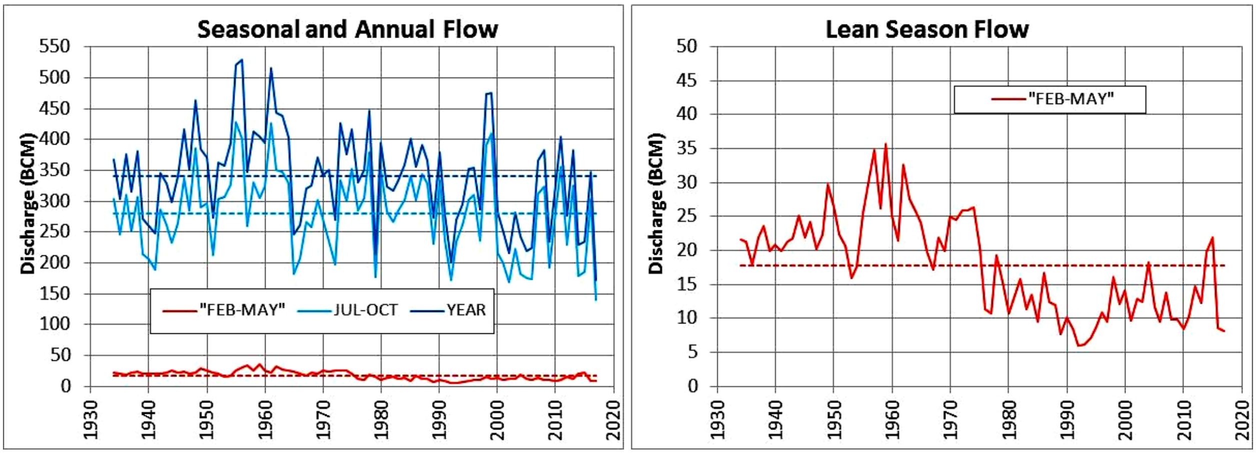

Figure 2. Seasonal and annual flow

The annual flow over the record span ranges from high as 528.52 billion cubic meter (bcm) to low as 172.55 bcm, with a mean of 340.19 bcm. The other statistical parameters are found as follows:

Table 2. Statistical parameters of annual flow

Quartile1 (bcm)	Median (bcm)	Quartile3 (bcm)	Range (bcm)	IQR (bcm)	Std. Dev (bcm)	Classical Skew	Quartile Skew
277.64	347.08	387.53	355.97	109.90	77.21	0.1906	-0.2639

Like water level (and which is obvious), the discharge is highly skewed over the range of year as can be visualized from the right chart of above figure. The long term mean of dry season (February – May) flow is only 5% of long term annual mean while the wet season (July – October) flow constitutes 82% of annual flow on the average.

The annual flow distribution is slightly positively skewed; meaning outliers are on the higher side. However, within central 50%, the flow distribution is negatively skewed meaning that data points in the lower 25% in respect upper in respect of the median are relative more away than data points in the upper 25%.

As mentioned earlier, statistical parameter for flow variables were computed for two segments of the records, from beginning to 1975, and 1976 to 2017. The changes in parameters are as follows:

Table 3 Periodic statistical parameters of annual flow

Period	Mean (bcm)	Median (bcm)	Max^m (bcm)	Min^m (bcm)	Range (bcm)	IQR (bcm)	St.Dev (bcm)	C.Skew	Q.Skew
1934-1975	363.81	359.68	528.52	246.21	282.31	87.57	71.58	0.4458	0.0171
1976-2017	316.58	325.69	475.96	172.55	303.41	109.33	75.51	0.1454	-0.2599
% Change	-12.98	-9.45	-9.94	-29.92	7.47	24.86	5.49	-	-

The mean annual flow has undergone an average reduction of 12.98%. Month wise reduction pattern is as follows:

Table 4 Monthly pattern of flow variation over the two periods under study

Measure	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Absolute	3.48	3.31	3.46	2.79	2.19	1.81	0.58	10.87	7.29	6.03	3.43	3.12
%	42.24	51.03	56.24	52.91	38.03	15.99	1.20	10.65	7.82	12.69	18.74	27.92

The high percentage reduction in lean months when water demand is higher is critical. High reduction in absolute term in wet period may have bearing on ecology.

2.4.3 Flooding

Flooding incident occurs when water spills over the river bank and inundates the surrounding area. ‘Danger Level’ (DL) is usually defined at or near a level of spilling. Thus, attaining danger level or reaching near this level is indicative of high flow condition. It is stated earlier that occurrence of danger level crossing by incoming flow is on decreasing trend. Non-crossing of danger level may be desirable from the view point of flood protection but change of flow regime may have caused or causing negative consequence yet to be evaluated.

An analysis was performed to see the pattern of high flow level persistence over the record period. In addition to DL, two other levels somewhat below the DL were chosen. Durations for which water level remained above those levels were calculated. The result is presented in Figure 3. It is seen that high water stage persistence duration, even for level below the DL is decreasing since 1970.

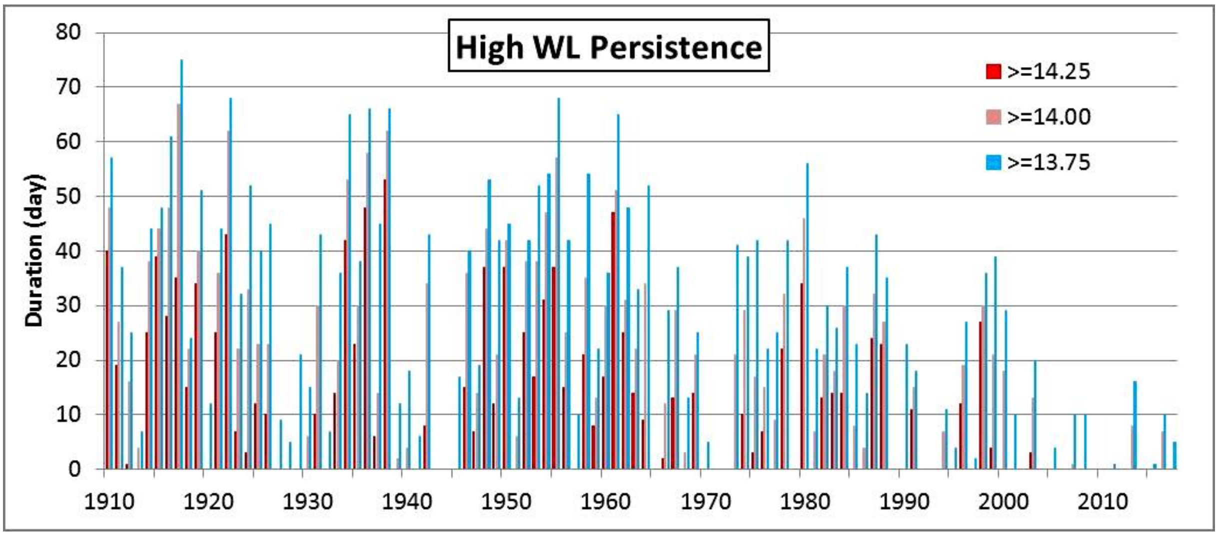

Figure 3. High water level persistence pattern

Usually flood flow comes in two waves, first one in the first half of August and second one in late August or early September. Flood wave arrival time, peaking time and departure time, has bearing on agriculture practice, business, navigation, fisheries, and in general on ecology. Similarly dropping of water level to annual has bearing water use practice. Annual peaking and dipping time have plotted to see the pattern (Figure 4). A little divergence is noticed for the later part of record period.

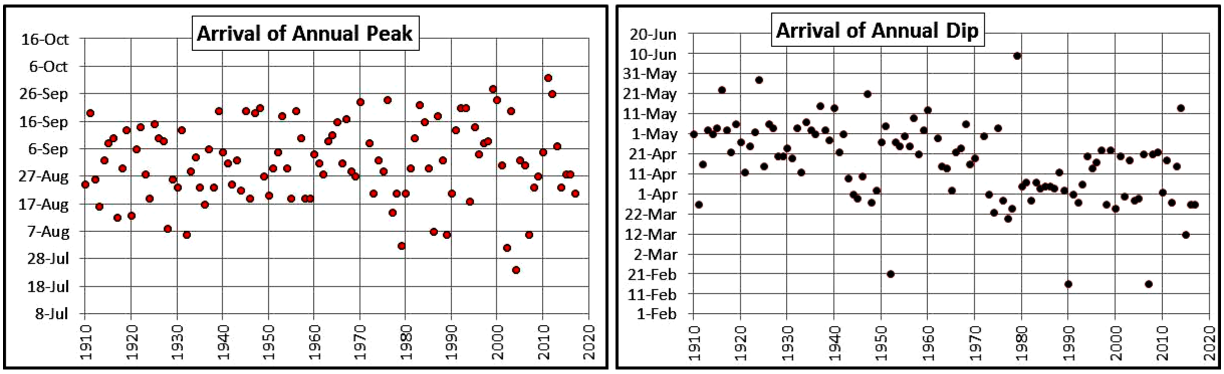

Figure 4. Arrival time for yearly peak and dip level

Some other interesting points based on discharge dataset are as follows:

- Out 10 highest instantaneous discharges, 6 had occurred in the period following 1975 (1st, 2nd, 4th, 5th, 6th, and 7th), 4 had occurred in the period before 1975 (3rd, 8th, 9th and 10th).
- Out 10 lowest instantaneous discharges, 9 had occurred in the period following 1975, and only 1 (10th lowest) had occurred previously.
- Out 10 highest annual discharges, only 3 had occurred in the period following 1975 (4th, 5th, and 7th).
- Out 10 lowest annual discharges, all 10 had occurred in the period following 1975.

These data based facts are also indicative of decreasing flow quantity over time.

3. SUMMARY AND CONCLUSIONS

Time series data extending over more than a century have been analysed. The data as it is, suggest a decreasing trend in the flow situation by all counts since mid-1970s with increased variability in distribution pattern. Flow reduction appears drastic in dry period when considered relative to average flow regime of the period. However, wet season flow reduction is greater in absolute quantity.

The dry season flow reduction is attributed to diversion of flow by India through Farakka Barrage, located at about 166 km upstream. Thus while dry period flow reduction has an evidentiary physical cause, the causes of wet season flow reduction are not so obvious.

Flow reduction at Hardinge Bridge cannot be attributed to precipitation reduction as no such suggestion is found in literature. Rather, various studies suggest that there has been no overall change in precipitation in the Ganges Basin over the past 50 years although localized trends have been observed (Santosh Nepal et al. 2015). Earlier, through a study, Mirza et al (1998) had concluded that precipitation in the Ganges basin is by-and-large stable. Under such context, it might be concluded that flow reduction at Hardinge Bridge have been caused by increased detention and withdrawal along the upper courses.

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Merging Edges: An Approach to Mitigate and Adapt to Flooding and Subsidence in the Dense Urban Context of South-East Asia

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Abstract

With the growth of urbanization, neglect in maintaining the natural dynamics of water gives rise to separation between man and nature. This situation affects the ability of cities to mitigate and adapt to climate change, the effects seen as flooding and subsidence in south-east Asian urban context. The purpose of this paper is to address this growing unsustainability by softening the edges as an exchange zone between communities and infrastructure. By softening the edges between fluid and solid territories, the historic symbiotic relationship where the people, water and natural systems merge, collide and make benefit from each other, can be reinstated. Bangkok, now facing flooding and subsidence, is taken as the site of study, where natural ecosystem is badly damaged by encroachment of modern industrial and hard infrastructure. In our multi-scalar approach at macro, meso and micro level, green and blue network is merged together with the infrastructure and community is enabled by economic upgrading and social stability in a flexible way in this stiff urban context of the city. Our goal is to work as a mediator in bridging this physical and social gap, so that cities can deal with a system of speed and flexibility where people get benefitted from the unwanted flood water by aquaculture, agriculture to transportation, thus, boosting their economy and strengthening social cohesion and equality. In the similar South-East Asian context like Bangladesh, Vietnam, India etc. this design approach can help us to cope with hazards like flood and subsidence by nurturing the elements across boundaries.

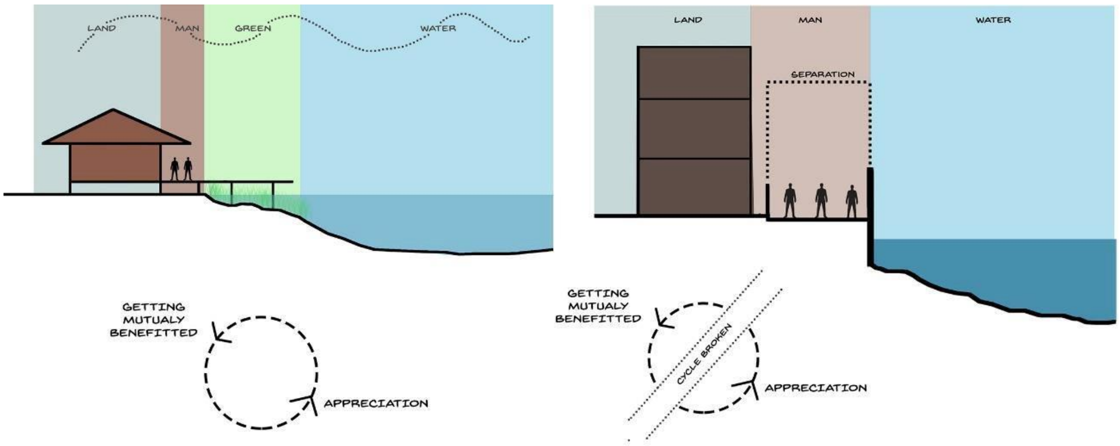
Keywords: Water Sensitive Urban Design, Low Impact Development, Climate Change

1. INTRODUCTION

In the ever-growing urbanization process, one of the most important relationship hampered is that of man and water. In the past there are precedents that dictate a harmonious relationship between man and water, a relationship that has prevailed the sustenance of the society even in the face of yearly floods and natural disasters, especially in South East Asian countries like Bangladesh, Vietnam, Thailand, and India (Figure 1a). So, the main question that we have tried to answer in our work is: What is missing in our dense urban settlements that our sustenance with nature has come to a standstill?

For our study, we have chosen the dense urban area of Bangkok, Thailand by the banks of Chao Phraya river. Once known as the "Venice of the East", Bangkok's natural settings have always been a central feature of its form and mobility. In inner Bangkok today, canals survive mainly as sewers to carry black, putrid water to the river. In the outskirts, most canals have become clogged with garbage and weeds, or have completely disappeared due to unregulated urban planning. When the canals died, the flooding once briefly endured, became a monster out of control (Thaitakoo and Brian 2010). To mitigate the flooding, BMA (Bangkok Metropolitan Administration) resorted to hard infrastructure creating a two tier system, where one land gets protected on the expense of another(Win 2017). Flood walls create uneven exposure to future flooding with urban economic areas protected while marginalized groups such as farmers, fishermen and rural communities are exposed to losses and damage.(Phamornpol 2011) As a result, flood problem worsened while creating social barriers of inequality and breaking the cycle of ecological balance (Figure 1b).

Throughout the process of searching for measures of urban sustainability for Bangkok, we have discussed the problem and solution through macro, meso and micro scales as the problem cannot be solved at just a local scale but has to be addressed keeping the larger context in mind.



(a) **(b)**

Figure 1. Change of Mutual Relationship among Land, Man, Green and Water
(a) Past mutual relationship (b) Present broken relationship

2. CONCEPT AND STRATEGIC APPROACHES

Flooding problem in Bangkok has to be dealt with small scale community driven projects that are flexible and faster, which will impact a broader scale through multiple levels of interaction. Since previous attempts at using hard infrastructures to protect against flood did not fare well in the long run, we propose flood mitigation by using soft infrastructure and community driven landscape interventions, reinstating the historic symbiotic relationship where the people, water and natural systems merge, collide and make benefit from each other (Figure 2).

Rather than working with just area-based intervention for flood mitigation, Bangkok needs a holistic vision for flood management including long term regional scale plans, intervention in city scale plans and short time special area-based plan for flexibility and ease of implementation. Based on the design and site analysis, we focus on three major strategic approaches in our proposal. These strategies are discussed in a three scalar approach suitable for a dense urban city like Bangkok.

- **Blue-Green Edge: Connectivity** between water system and green infrastructure
- **Green-Grey Edge: Adaptability** of communities in different natural conditions
- **Blue-Green-Grey Edge: Community Upgrading** by merging, shifting, crossing and intersecting different boundaries of natural dynamics.

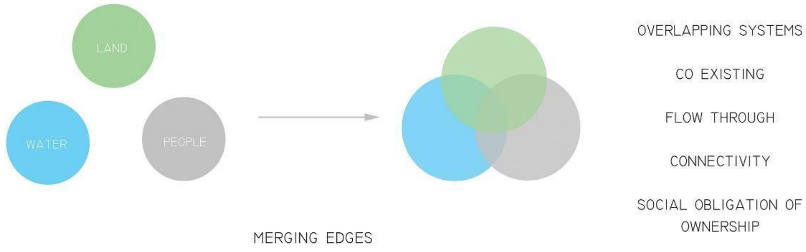


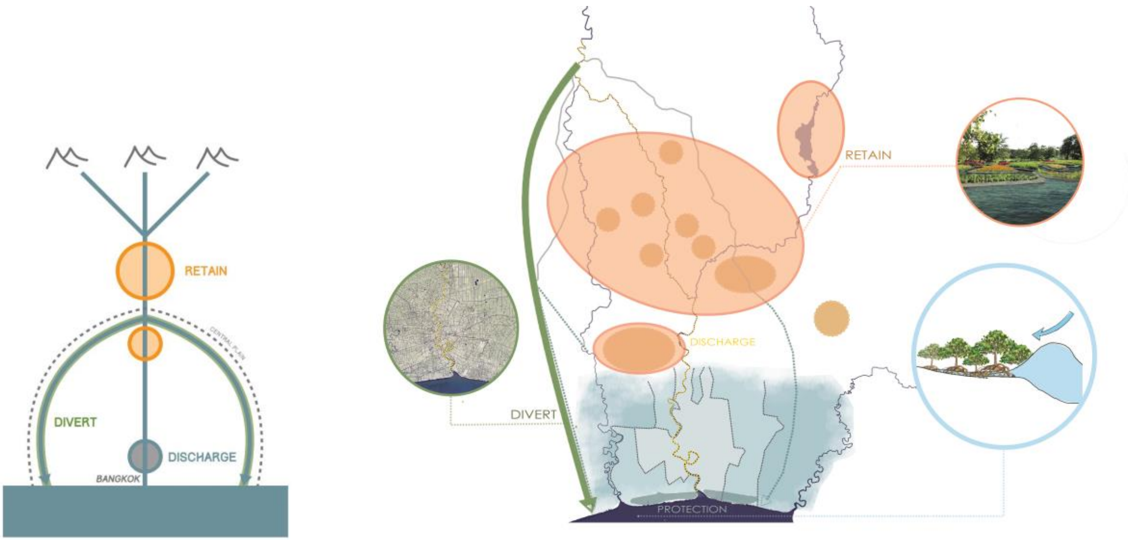
Figure 2. Conceptual Framework: Merging Edge

2.1. Macro Scalar Approach: Delta

Chao Phraya doesn't just flow through Bangkok, it is part of a much larger network and ecology. To increase the connectivity, we have to consider it's beginning in at the confluence of the Ping and ending in the gulf of Thailand. Upstream caused flooding can be mitigated by retaining, diverting and discharging river flow to the south (figure 3a). From the natural topography, it is clear to use natural height difference to retain water upstream. Before reaching the flood prone and most populated areas of central plain, the water should be diverted around the area with bypasses (Figure 3b).
(Ramkisor 2016)

Blue-Green Edge- Connectivity: At the scale of the Greater Bangkok, the solution is to divide the water in as many ways as possible, by making big canals. Then, recreating a real water network, by using the past canals and creating new ones, will give to the city a modern identity linked to its past history. Creating a "green network" that connects to the water network through houses and perpendicular roads, rather than big public parks or walkways. By combined development of blue and green network, the discharge capacity will increase reducing flood risk. The merged areas will also ensure maximum contact between water and the inhabitants.

Green-Grey Edge- Adaptability: Water will be stored in sunken areas for retention in monsoon and it will be slowly discharged into to ground. Water will be diverted through created green and blue network before it reaches the flood prone central plain. The diverted routes will go around the city. The upstream water that reaches Bangkok will be distributed among the various khlong network.



(a) **(b)**

Figure 3. Macro Scalar Approach- Delta
(a) Conceptual diagram of macro scale approach
(b) Retain, divert and discharge zone identification in macro scale map

Blue-Green-Grey Edge- Community Upgrading: Providing canal water for irrigation where it's possible to reduce subsidence related with ground water consumption. As a result, traditional government economy, as well as to rural society for its daily communication and economic activities are improved. Through this process, natural fisheries can be reinstated, re-invigorating the local fishing heritage, improving community food security. New mangroves and their wetlands and estuaries can house boardwalks, bird watching, boating and recreational fishing for local communities and visitors
.

2.2. Meso Scalar Approach: City

In inner Bangkok today, canals survive mainly as sewers to carry black, putrid water to a bigger sewer called the river. In the outskirts, most canals have become shallow, clogged with garbage and weeds, or have completely disappeared due to unregulated urban planning (Department of Environment, Land, Water and Planning 2017) As the canals are veins and arteries of Chao Phraya river, widening and softening edge will not only mitigate flooding but also work to social upgrading by providing for transport, water filtration using phytoremediation method.

Blue-Green Edge- Connectivity: Enlarging the canals enables to increase the capacity of rain collection during monsoon season. Connectivity between the canals, and with the river: enables to support more transport, increase accessibility by creating walkways, with sand to clean the run-off water (Figure 4d). Establishing green network by creating green corridors, bio swales, rain garden and permeable pave reduces rainwater runoff. It collectively reduces the frequency and intensity of flood event (Sitko 2016).

Green-Grey Edge- Adaptability: Integrate 'sunken' areas and overland pathways within green spaces which can occasionally accommodate flood waters but can be used for alternative purposes otherwise. Like,
- Vegetation, providing amenity and habitat (Figure 4a);
- Soil, of adequate volume, nutrient content and drainage characteristics; and
- A link to rainwater, stormwater or recycled water supply, with a frequency and quantity sufficient to support vegetation and soil health (Figure 4c)(Schwab 2009).

Blue-Green-Grey Edge- Community Upgrading: Involve local communities in the design and management of features with urban trees and green space will strongly contribute to a sense of identity and the provision of liveability and create stronger connections between communities and nature (Figure 4e).

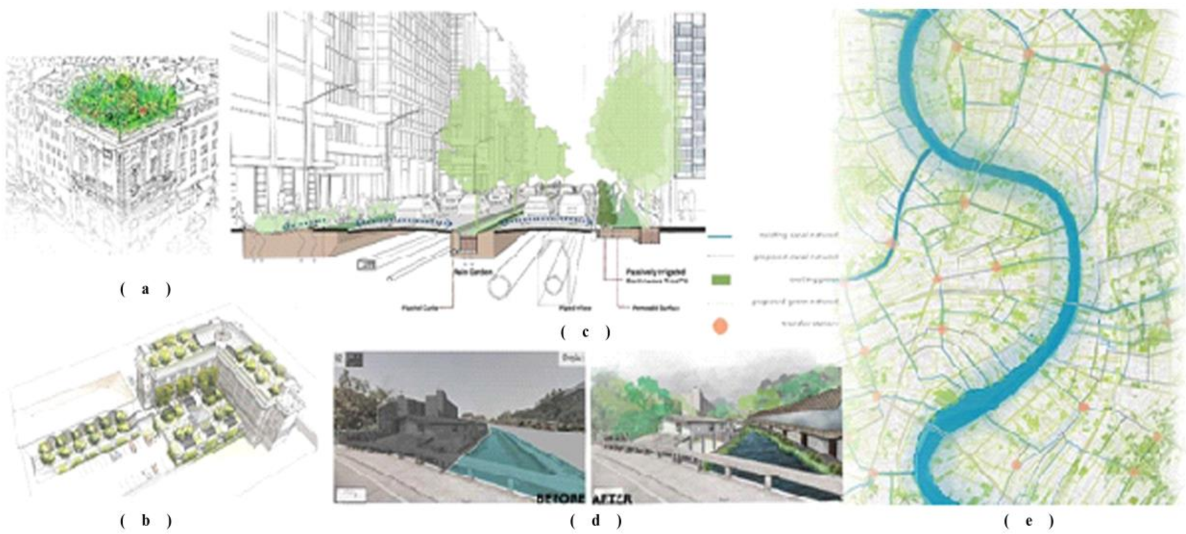


Figure 4. Meso Scalar Approach- City
(a) installing roof garden to increase soakability (b) multilevel vegetation across city
(c) intervention in road for connecting green (d) before-after visualization of intervention in canals
(e) citywide connection of green and blue network

2.3. Micro Scalar Approach: Site

Through land suitability analysis, maps of hydrology, environmental sensitive areas, natural habitats, critical natural corridors etc. are overlapping to identify the preservation areas for nature and build areas for people. In the build areas, constructions are designed for environment friendly, and merged into landscape. Concentrated settlement and zoning strategies are used in this project to prevent urban sprawl. The specific site that we have chosen is from the Saphan Taksin Pier to the Hotel Chatrium on the both side of Chao Phraya river (Figure 6a).

Blue-Green-Grey Edge- Community Upgrading: By enabling the active participation of stakeholders in community gardening and urban farming users, clients, neighbourhood affiliations, local authorities and non-governmental organizations – there is a significant opportunity for strengthening shared values and empowering communities.

Aquaculture plays an increasingly important role in food security and the economy of Thailand. Freshwater aquaculture is mainly for domestic consumption. Small-scale freshwater aquaculture is still very crucial in providing the rural poor with high quality protein food for home consumption. Brackish water aquaculture usually produces high-value products for export.

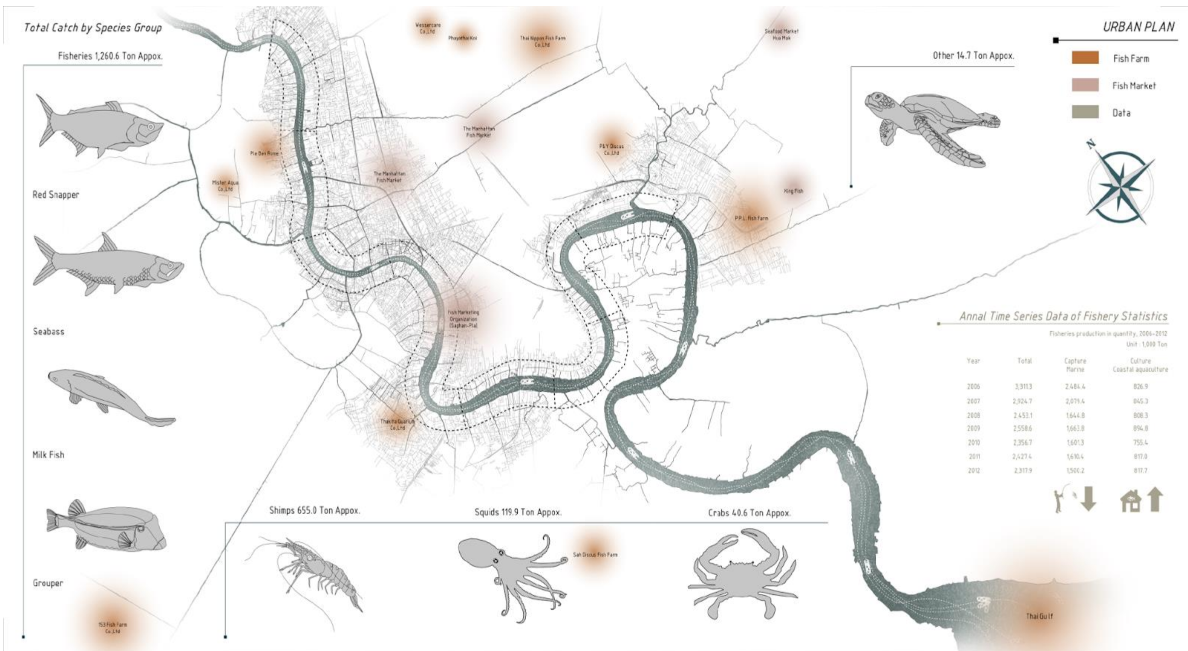


Figure 5. Location of fish production and retail zone (Akkavutwanich T 2015**)**

A lot of the fish in Bangkok that is found for selling now come from far away (Figure 5). Everything is transported to "Saphan Pla Fish Market" in Truck. The meat of the fishes is put in the chill truck that is sharing the road with taxi, concrete truck and other vehicles to reach the market where it gets to be sold to a potential consumer (Akkavutwanic 2015). By expanding the fish market so that the process of produce, process and consumption gets completed in a single place.

Blue-Green Edge- Connectivity: Continuous river walk with connected corridor and mixed structure has been created in the eastern side with green corridors, bio swales and rain gardens to provide. Blue and green network are merged at the edges providing for habitat, water filtration and retention purpose(Atitruangsiri 2017). Using native species as ground covers to slow and treat flood flows promote infiltration and shallow subsurface flows. Trees also enhance bank stability, provide shade and woody debris for in- stream habitats.

Green-Grey Edge- Adaptability: In between the river walk and the area with the traditional temple, Wat Yannawa (Figure 6c), a swelled green corridor alongside the Riverwalk can ensure a buffer zone. It is also a protective measure against the increased water level in the events of storms or flood.

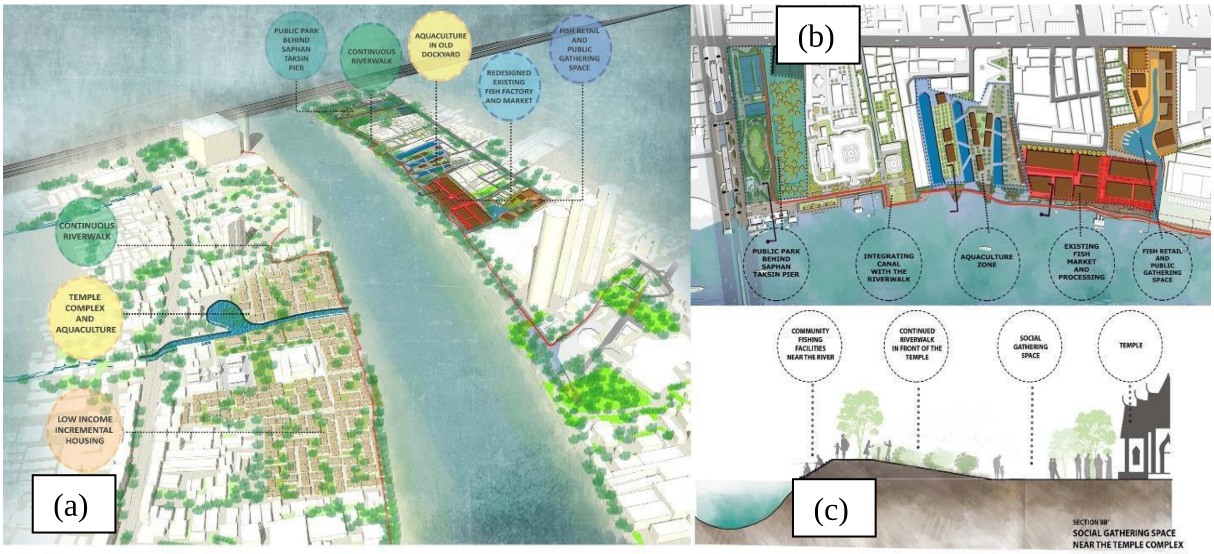


Figure 6. Micro Scalar Approach- Site
(a) bird's eye view of interventions in the specific site
(b) plan of intervention zones from Saphan Taksin pier to Hotel Chatrium
(c) intervention in front of Wat Yannawa

Based on the intervention rules on the three edges, an area on the west side of Chao Phraya river was designed for housing the economically insolvent families who are the worst sufferers of the flood and subsidence (Figure 6a). A low-cost housing unit, with ground floor area for their commercial or productive purposes and first floor area as the living quarters for four persons was designed, abiding by the rules of NHA (Figure 7). As the house is elevated and connected by the elevated pathway, during the flood, the community activities can go on unhampered.

Figure 7. Low-cost Housing Design
(a) visualization of housing area (b) sectional analysis of designed unit

3. CONTEXTUAL RELATIONSHIP

One of the objectives of this study was to observe the similarities in between the context in south-east Asian countries and to propose an approach in building up a sustainable urban relationship with the changing climate Most of the underdeveloped and developed countries in the south-east Asian region suffer in the dilemma of putting priorities of nature over the growing demand of urbanization, and in most of the cases the latter one is given priority(Vojinović 2014). But it can be possible to grow our urban areas by keeping our nature protected, through having a cohabiting and sustainable relationship with our land and water. For example, in Dhaka, Bangladesh, the event of flash flood due to the runoff water resemble the likely condition we see in the 2011 flood in Bangkok (Sitko 2016). So, some of the strategic measures proposed in context of Bangkok, can essentially be applied in Dhaka as well.

4. RESULTS AND DISCUSSION

The goal of the study is to achieve a collective urban resiliency that stems from the community that lives within. The results can be summarised as achieving connectivity, adaptability and community upgrading respectively at the blue-green edge, green-grey edge and blue-green-grey edge, all three working at the macro, micro and meso level. As the community starts to upgrade and adapt themselves to the changing climate scenarios and connect themselves with nature as the interventions directs to, collectively it will have an effect at the city scale and at the regional level.

Lack of acceptance by the civil society, high land value, lack of co-ordination between different authorities, eviction of canal communities etc, are some of the constraints faced in present context. Further discussions can be done to create fast and flexible small-scale community driven interventions that will increase social upgrading and empowering the locals. This approach of merging edges can add value to the process and study of achieving urban sustainability further in the future by pointing out the need to re-establish our connection to nature through different interventions.

5. CONCLUSION

Most of the traditional approaches taken for flood mitigation focuses solely on the water protection using hard infrastructure. As climate change is a daunting fact, relying on hard infrastructure is not enough. We acknowledge the necessity of an integrated approach of structural and non-structural measures where sustainable design solutions such as community gardens, soft embankment solutions can create ownership among communities who in turn participate to cleanse and protect the river and canal system. Revived canals can accommodate flood water and improve transportation system across the city. This water can be used to upgrade the communities by using phytoremediation, urban agriculture, aquaculture and urban place making. Turning the unwanted flood water into strength, the physical and psychological barrier created between water system and people merge creating a mutual beneficial cycle. Dividing the solutions in different scales is necessary for fast and flexible implementation in a dense city like Bangkok.

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Trend Analysis of Shoreline Changes of the Ganges in the North West Region of Bangladesh

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Abstract

The Ganges basin, extending from Tibet to the coast of the Bay of Bengal, is one of largest river basins of Asia and a significant part of it lies in Bangladesh. The temporal change along the left bank of the Ganges flowing through the North West region of the country (Chapainawabganj, Rajshahi, Natore and Pabna district) is the focus of this study. Landsat images from 1980-2018 along with Google Earth historical imagery have been used to delineate approximately 230 km shoreline and Digital Shoreline Analysis System (DSAS), an extension in ArcGIS, has been used for analyses. The Shoreline Change Envelope (SCE) and End Point Rate (EPR) methods have been used to determine the shoreline changes. The SCE method determined a maximum migration of 10,054 m for the study time period of 1980 to 2018 in Chapainawabganj district. During this period, the maximum accretion and erosion rate have been determined 258.5 m/y and -231.8 m/y respectively both in Chapainawabganj district. From the shorelines delineated from historical satellite images, it has been observed that the bank along Chapainawabganj district is more dynamic compared to that of Rajshahi, Natore and Pabna. The analysis also shows in most of the erosion occurred from 1980 to 2000 while in 1990-200 and 2010-2018 accretion was dominant. The balance between eroded and accreted land is the reason behind the stable width of the Ganges.

Keywords: Erosion, Accretion, Shoreline Change, SCE, EPR.

1. INTRODUCTION

Erosion and accretion of river are common in Bangladesh because of its geolgraphical location. Most of the rivers and channels are complex and shifting in nature which make river bank shifting more common (Best and Bristow 1993). Riverbank erosion and accretion are natural geomorphological processes which take place round the year. Both natural and human impacts are responsible for river bank erosion. Dynamicity of streams is the natural cause of erosion and it can produce favorable outcomes such as the formation of productive floodplains and alluvial terraces (Mollah and Ferdaush 2015). Some stable rivers have a healthy amount of erosion; however, unstable rivers and the erosion taking place on those banks are a cause for concern (Mollah and Ferdaush 2015). Riverbank erosion plays a significant role on short and long-term channel adjustment, development of meanders, sediment dynamics of the river catchment, riparian land loss and downstream sedimentation problems (Lawler et al 1997)

The Ganges river system with a catchment of 1.09 million km^2 is one of the largest river systems in the world. Originating from Gangotri glacier of the Himalayas this river in its 2526 km course to Meghna river flows through China, Nepal, India and Bangladesh. Only 4.3% of the catchment area of this river lies in Bangladesh which consists of almost 32% of the total area of the country (Mirza 2004). Ganges river system in Bangladesh, consisting of the Ganges river and Padma river receives an annual rainfall of 1200 mm (Sulser et al 2010). 80% of the total annual discharge volume of the river system occurs during monsoon period (July-October) (Kale 2003). As a result, regions along Ganges experience floods of large magnitude recurrently (Gupta 1995; Sharma 2005). Migration of the river due to erosion and bed scouring is common and many believe that the situation has aggravated with increased human activities (Sharma et al 2010).

Temporal change of riverbanks can be assessed with satellite data using GIS and remote sensing techniques. Ozturk et al (2015) performed a spatiotemporal analysis to study the shoreline changes of the Kizilirmak Delta, Turkey. Bheeroo et al (2016) determined the shoreline change rate and performed erosion risk assessment along the Trou Aux Biches–Mont Choisy beach of Mauritius using GIS-DSAS technique. In the context of Bangladesh, such studies have been performed along the major river systems like Ganges, Brahmaputra and Meghna near different vulnerable erosion zones. Nath et al (2013) studied trend analysis of the river bank erosion of Meghna river for the period of 1980 to 2010 at Chandpur, one of the major erosions and accretion zone of the Bangladesh.

In this study, four districts along the left bank of the Ganges in the North West region of Bangladesh (Chapainawabganj, Rajshahi, Natore and Pabna) have been selected as the study area. The objective of the study is to analyze the trend of change of the left bank of the Ganges in these districts. Landsat images from 1980-2018 along with Google Earth historical imagery have been used to delineate approximately 230 km shoreline and Digital Shoreline Analysis System (DSAS), an extension in ArcGIS, has been used for analyses. The temporal change along the left bank of the Ganges flowing through these districts have been determined and shoreline change rates have been compared both district wise and periodically.

2. METHODOLOGY

With numerous satellite images offering varying levels of spectral, spatial, radiometric and temporal resolution, remote sensing is widely used for monitoring dynamics of coastal areas such as shoreline changes (Alesheikh et al 2007; Schwartz 2005). In this study, multi-temporal Landsat imageries were used to analyze the movement of shorelines from 1980 to 2018. The timeline was divided into four decades and images of 1980, 1990, 2000, 2010 and 2018 were collected from website of United States Geological Survey (USGS). The 1990, 2000, 2010 Landsat-5 Thematic Mapper (TM) imageries and 2018 Landsat-7 with the improved Enhanced Thematic Mapper (ETM) scanner imagery had an image resolution of 30 m pixel size for six of the seven spectral bands, whereas 1990 Landsat-3 Multispectral Scanner (MSS) image had resolution of 60m with four bands. For each year, two Landsat imagery of path 138 and 139, and of row 43 were used to cover the study area. Also, google earth images of the region were collected from google earth historical imagery for extracting the shorelines more accurately.

The Digital Shoreline Analysis System (DSAS) is a statistical analysis tool to compute rate-of-change statistics for a time series of shoreline vector data (Thieler et al 2009). It works within the Environmental Systems Research Institute's (Esri) Geographic Information System (ArcGIS) software. In this study, DSAS v4.4 was used for analyzing shoreline statistics, along with other features of ArcGIS. Landsat imagery had co-ordinate system of WGS 1984 UTM Zone 45N. Historical imagery from google earth for the same year was opened with the Landsat imagery and georeferenced at the exact location with the same co-ordinate system in ArcGIS. With the help of ArcGIS tools, the shoreline for each of the selected years were extracted and matched with the google earth images for accuracy. Thus, five shorelines were extracted for the corresponding years. Each shoreline contained two mandatory fields of date and uncertainty which were necessary for operations in DSAS. A default uncertainty value 4.4 was used in the study.

For determining the rate of change statistics for time series of shorelines, DSAS needs a baseline (Leatherman and Clow 1983). The baseline can be placed onshore or offshore with respect to shoreline. In this study, an onshore baseline with a length of about 190 kilometers was created which stretched from Chapainawabganj to Pabna district. Also, 949 transects were cast at 200 m interval from the baseline. Due to the vibrancy of the shoreline, the baseline was placed a little distant from the shore, hence the length of each transect was 18500 m.

The shorelines were analyzed in four pairs (1980-1990, 1990-2000, 2000-2010 and 2010-2018) and also all together in DSAS. The statistics calculated in DSAS were Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End point rate (EPR), Linear Regression Rate (LRR) and Least Median of Squares (LSM). In this study, only SCE and EPR had been used for trend analysis of the shoreline changes. SCE represents the distance between the nearest and the farthest shoreline from the baseline and is not related to their dates. EPR (m/y) is the rate of change between the oldest and most recent shoreline and the computation of EPR uses only these two shorelines. The landward shifting of the shoreline with respect to the baseline is erosion and seaward shifting is accretion of land. The statistical values in transects were denoted negative (-) for erosion and positive (+) for accretion (Anders and Byrnes 1991). Also, to represent the erosion and accretion in amount of area, eroded and accreted area in hectares (ha) had been determined. To determine the area eroded and accreted, polygons between shorelines were created in ArcGIS for each decade. The areas of polygons representing erosion and accretion were calculated separately to determine the lost and gained lands for each timeframe.

3. RESULTS AND DISCUSSION

Shoreline along the left bank of Ganges changes significantly, moderately and a little in Chapainawabganj, Pabna-Natore and Rajshahi respectively during the time period of 1980-2018.Figure 1 shows the shorelines in the left bank of the Ganges from 1980 to 2018.

Figure 1. Historic Shorelines along Left Bank of the Ganges

In Chapainawabganj, shoreline has changed the most during 1980-2018 time period with a maximum SCE of 10054.42 m. Most of transects of Chapainawabganj have higher value of SCE indicating significant dynamicity. In Pabna, the second largest SCE has been observed (9528.72 m) near the confluence of the Ganges, Brahmaputra and Padma river. Other areas in Pabna, except the confluence zone, show moderate change in terms of SCE. In Natore, district has relatively small river side area and most of transects indicate a moderate change. Rajshahi has the lowest value of SCE (5175.29 m) among these four districts. Transects in Rajshahi are stable in terms of SCE comparing with changes in other three districts. Figure 2 shows SCE(m) graph for 1980 to 2018 time period for the four districts.

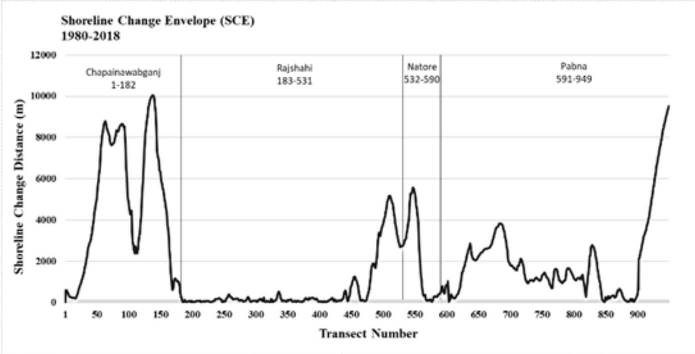

Figure 2. SCE (m) Graph between 1980 and 2018 for the Study Area

According to the results shown in table 1, Chapainawabganj has the greatest erosion rate as well as accretion rate for all periods according to minimum and maximum value respectively. The mean values of EPR also show that Chapainawabganj has the highest erosion rate (-85.9 m/y, 1980-1990) while Natore has the highest accretion rate (258.3 m/y, 2010-2018). The percentage of transects shows that Pabna has highest percentage (81%) of erosion transects in 1980-1990 while Rajshahi has the highest percentage (73%) of accretion transects in 2010-2018.

Table 1. Shoreline Change Rate According to EPR Method

Period (Year)	**1980-1990**	**1990-2000**	**2000-2010**	**2010-2018**
Chapainawabganj (Number of Transects=182)				
Mean Value	-85.9	40.0	-51.4	-5.9
Max Value	121.5	864.7	170.8	124.2
Min Value	-386.7	-554.9	-269.3	-244.5
Erosion Transects, Number (%)	138 (76)	100 (55)	152 (84)	63 (35)
Stable Transects, Number (%)	0 (0)	0 (0)	0 (0)	1(1)
Accretion Transects, Number (%)	43 (24)	81 (45)	29 (16)	117 (64)
Rajshahi (Number of Transects=349)				
Mean Value	-12.1	2.7	7.8	53.1
Max Value	23.4	113.1	338.7	730.2
Min Value	-173.4	-23.6	-108.3	-145.1
Erosion Transects, Number (%)	250 (72)	175 (50)	179 (51)	93 (27)
Stable Transects, Number (%)	0 (0)	0 (0)	0 (0)	0 (0)
Accretion Transects, Number (%)	99 (28)	174 (50)	170 (49)	256 (73)
Natore (Number of Transects=59)				
Mean Value	-16.0	0.5	6.3	258.3
Max Value	9.2	38.7	131.6	794.1
Min Value	-34.4	-24.2	-13.4	-24.9
Erosion Transects, Number (%)	27 (46)	26 (44)	35 (59)	25 (42)
Stable Transects, Number (%)	0 (0)	0 (0)	0 (0)	0 (0)
Accretion Transects, Number (%)	6 (10)	33 (56)	24 (41)	34 (58)
Pabna (Number of Transects=359)				
Mean Value	-45.2	61.0	4.6	111.8
Max Value	32.0	739.6	137.5	546.9
Min Value	-232.0	-100.7	-87.2	-41.3
Erosion Transects, Number (%)	291 (81)	150 (42)	184 (51)	123 (34)
Stable Transects, Number (%)	0 (0)	0 (0)	0 (0)	0 (0)
Accretion Transects, Number (%)	68 (19)	209 (58)	175 (49)	236 (66)

According to the graph shown in Figure 3, Chapainawabganj has the highest erosion rate (- 231.84 m/y) as well as accretion rate (258.5 m/y). Shoreline of Rajshahi is stable in terms of EPR. Most of transects in Natore have seen accretion within 1980-2018. Pabna has seen most accretion in study time period with a maximum value of 251.6 m/y near the confluence of Ganges, Padma and Brahmaputra.

Overall the results of shoreline change rate indicate that bank along Chapainawabganj is highly dynamic with most of its length undergoing erosion. The shorelines of other three districts are going through mostly accretion in the recent years.

Table 2 shows the area of land eroded and accreted during 1980-2018. Higher accretion (28857 ha) has been observed then land erosion (18813 ha). Maximum erosion is observed during 1980-2000 and maximum accretion is observed during 1990-2000 and 2010-2018. Rajshahi division was affected severely during the floods of 1988 and 1998 which might be the reason of major erosion in this region during 1980-2000 period.

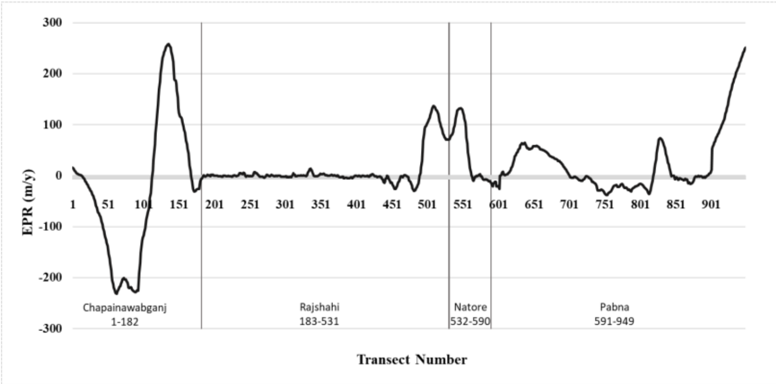

Figure 3. EPR (m/y) Graph of the Study Area for 1980-2018

Table 2. Eroded and Accreted Area in Left Bank of Ganges in the Study Area from 1980-2018

Period (year)	**1980_1990**	**1990_2000**	**2000_2010**	**2010_2018**	**Total**
Erosion (ha)	8424	6133	3446	811	**18813**
Accretion (ha)	418	14023	3006	11410	**28857**

4. CONCLUSION

Traditional studies of riverbank changes require conventional surveys, repeated measurements to identify and to evaluate changes. In this study, a combination of GIS and remote sensing technique along with statistical analysis in DSAS has been used to determine the change of shoreline along the left bank of the Ganges. Using a GIS integrated statistical tool like DSAS has helped to evaluate the change in shoreline using various parameters in a more comprehensive manner.

Analysis performed in this study shows that shoreline along Chapainawabganj district is the most unstable among the four districts of the study area. To protect the eroding bends of Chapainawabganj, river protection structures like spurs were constructed in the 2000s. As a result, decrease in erosion rate has been observed from 2000 to 2018. The study also showed that Rajshahi has the most stable shoreline in the study area which is the result of revetment and groyne construction in 1970s to protect Rajshahi town. Due to river protection works in the Upstream at Rajshahi, no significant erosion has been observed in Natore. The riverbank in Pabna is also comparatively stable due to the river protection work near Hardinge Bridge. Moreover, highly and moderate erosion resistant bank material is abundant along the left bank of Ganges river. Stability of bank in Rajshahi district is also due to presence of old Pleistocene sediment from Barind Tract which is highly erosion resistant bank material (Hossain 2006).

Detecting shoreline change is a vital task for in many disciplines specially related to management and planning of river systems. Trend analysis helps to predict the future scenario of the region also allows simulations and planning to be performed (ozturk et al 2015). GIS and remote sensing approach also allows a synoptic viewing to predict changes in a large region (Lam-Dao et al 2011). It is expected that quantitative results of this study will help the planners to assess the current situation of the region and take steps for the future.

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Production Performance of a Triangular Solar Still

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Abstract

People along the southern coast of Bangladesh have great difficulty accessing safe drinking water due to insufficient infrastructure, such as sanitary facilities, and water and power supply. This is a particularly urgent issue during the dry season. To overcome this water shortage, we designed a triangular solar still (TrSS) to produce distilled water and tested it in Khulna, a coastal area of Bangladesh. The TrSS mainly included polyolefin film, bamboo sticks, and plywood, offering important advantages of low running cost, easy assembly and maintenance, light weight, and portability compared with other desalination technology such as multistage flash and reverse osmosis systems. To identify basic TrSS production properties, we performed a production test during April 2018 in the Khulna distinct, Bangladesh. Local people were able to assemble TrSS within 10 minutes and could produce distilled water without requiring special skill. Average daily TrSS production water was 433 and 298 g for sunny and cloudy days, respectively, hence estimated production cost would be lower than standard water cost (1.0 BDT/L) in remote and rural areas of Bangladesh.

Keywords: Triangular solar still, Production, Solar energy, Drinking water, Distillation

1. INTRODUCTION

The United Nations reported that water related diseases cause approximately 80% of all illnesses and deaths in developing countries (United Nations, 2003). Therefore, simple technologies to produce fresh water are urgently required. Multistage flash and reverse osmosis systems are currently the most common desalination technologies and can provide large fresh water volumes at a reasonable price. However, these plants require high initial investment, high maintenance costs, high power, and high level of expertise due to their maintenance and operation complexity. Consequently, they are difficult to quickly implement for developing and less developed countries.

Bangladesh is the most densely populated country in the world, 46% of the population living low elevation coastal areas with high flooding risk (CIESIN 2007). In particular, Southern Bangladesh wells suitable for drinking have been decreasing due to sea water intrusion landward associated with sea level rise by global warming and flooding (Mahmuduzzaman et al 2014). Consequently, people have great difficulty accessing safe drinking water and often must resort to unsanitary water, such pond water, and women and children commonly require approximately half an hour every day to harvest drinking water (Umemura et al 2014).

Several solar distillation techniques have been developed to solve serious these water problems (Shafiul et al 2006; Ahsan et al 2010a; Ahsan et al 2010b; Yamaji et al 2013; Ahsan et al 2012; Fukuhara et al 2013). A tubular solar still (TSS) was developed to provide potable water for a family or small village. Previous TSS studies have focused on enhancing water production and performance in dry climates or humid subtropical area, but few studies have considered performance in Bangladesh (Shafiul et al 2014; Terasaki et al 2014). An initial survey confirmed that reducing TSS and water production costs would be essential to allow TSS uptake in this region. Therefore, we re-designed the TSS into a triangular solar still (TrSS).

This paper presents the design, production performance, and water production cost for the TrSS. Production tests were performed in Khulna, Bangladesh and we estimated water production cost for 10 years.

2. TRIANGULAR SOLAR STILL

2.1. Design and structure

The TrSS consists of a bamboo frame, triangular cover, and rectangular trough, as shown in Fig. 1. The frame comprises six bamboo sticks arranged in triangle shape with three bamboo sticks for support. The bamboo sticks were approximately 20 mm in diameter or larger and 0.4 or 1.0 m long. Hemp rope was used to firmly tie the bamboo and strengthen the frame structure. The cover was agricultural polyolefin film (0.15 mm thick) and 1.0 m long. The cover was constructed by heat welding the polyolefin film according to the assembly diagram, to prevent water leakage. The trough was constructed from black painted 10 mm thick plywood, 0.19 m wide, 0.97 m long and 0.06 m high, and then wrapped with polyolefin film to make it waterproof. Painting the trough black greatly increased solar radiation absorption, increasing water temperature rise in the trough.

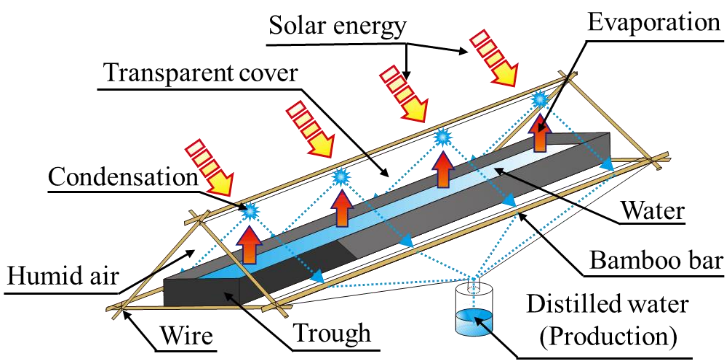

Figure 1. Proposed triangular solar still

2.2. Water production

Figure 1 also shows the TrSS water production principle. Solar radiation transmits through the cover and is largely absorbed by the water in the trough, with the remainder absorbed by the cover and the trough itself. Thus, the water in the trough heats, increasing water vapor density due to evaporation from the water surface. The water vapor then condenses on the inner surface of the cover, releasing latent heat due to evaporation. The condensed water naturally trickles down the inside of the cover due to gravity and collected at the bottom.

2.3. Fabrication process

The proposed TrSS fabrication process can be described as follows.
(1) Draw and cut polyolefin films following the assembly diagram.
(2) Heat weld overlaps between the cut sections to construct covers.
(3) Cutting bamboo sticks and tie them together.
(4) Cutting plywood following the templates.
(5) Assembling the frame and the trough.
(6) Cover the frame and the trough with constructed covers.
(7) Install the trough and place it on the triangle frame base.

The constructed TrSS weighs approximately 2.5 kg/m, which can be easily carried, and the film (imported from Japan) and local bamboo have approximately 10 and 5 year effective life, respectively (see Table 1). Older bamboo frame sticks can be easily exchanged for new ones as required, since they can be sourced locally. Thus, the proposed TrSS is very easy to move and assemble without requiring special techniques or tools. Trials showed that local people could assemble a TrSS unit within 10 minutes. Since the TrSS incorporates locally acquired lightweight materials, villagers can design and construct the most favorable TrSS for each family or village, etc.

Table 1. Fabrication cost of TrSS

Item	Specifications	Durability	Unit cost
Cover (polyolefin film)	Thickness: 0.15 mm, Area: 2.9 m^2	10 years	196 BDT/m^2
Trough (ply wood)	Thickness: 10 mm, Area: 0.3 m^2	10 years	488 BDT/m^2
Frame (bamboo stick)	Diameter: 20 mm, Total length: 2.4 m	5 years	5 BDT/m

3. PRODUCTION TEST

A simple production test was performed in Khulna city, Bangladesh from 14 – 24 April, 2018, as shown in Fig. 2. Atmospheric temperature, T_a (°C), and illuminance, E (klx) were measured using temperature-humidity and illuminance-UV sensors (TR-74Ui, T&D corporation), respectively. Solar radiation, I (W/m^2), was calculated using a regression relationship between solar radiation and illuminance that was derived in advance. Daily production, M_{day} (kg), was measured using an electric balance with 0.1 g minimum reading after sunset. Water depth in the trough was kept at approximately half. All data except M_{day} was automatically downloaded to a data logger at 30 min intervals.

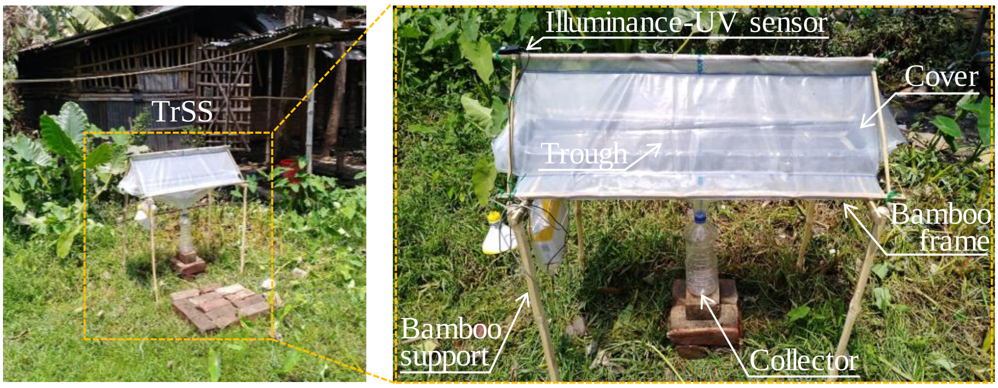

Figure 2. Production test in Khulna

4. RESULTS AND DISCUSSION

Figure 3 shows typical daily water production during the test period. Daily production was M_{day} = 0.24–0.50 kg. Average M_{day} = 0.43 kg for sunny days, which is approximately 1/4 daily minimum drinking water consumption per capita.

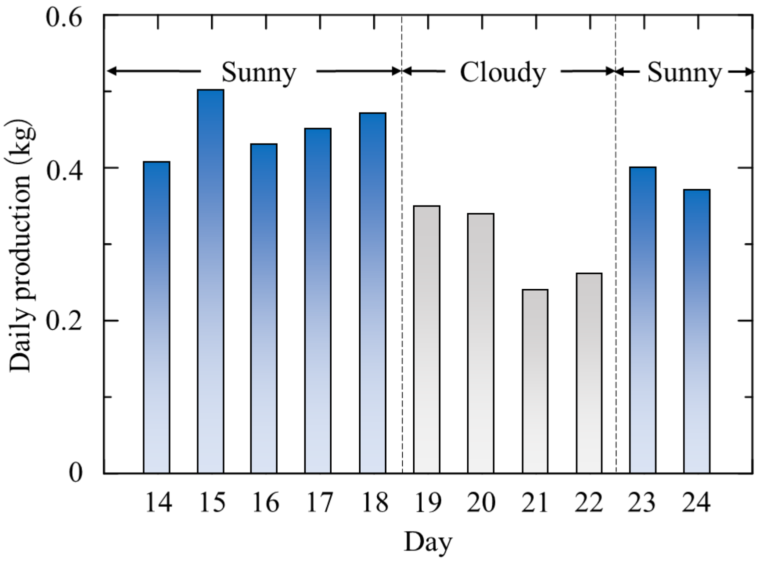

Figure 3. Daily production variation during the Khulna production test

Ambient temperature $T_a \approx$ 22–38°C with maximum at approximately 13:00. Maximum $E \approx$ 116 klx also occurred at approximately 13:00 and solar radiation was approximately 650–900 W/m^2 around noon. The collected production and meteorological data showed that daily production per water surface area M_{pd} (kg/m^2/day) was proportional to daily solar radiation flux, R_{sd} (MJ/m^2/day), as shown in Fig. 4. Shafiul et al. (2007) showed that solar radiation flux has major impact on M_{pd}. Equation (1) was obtained from data at Khulna and Japan from August to October, 2018.

$$M_{pd} = 0.20 R_{sd} - 0.19 \tag{1}$$

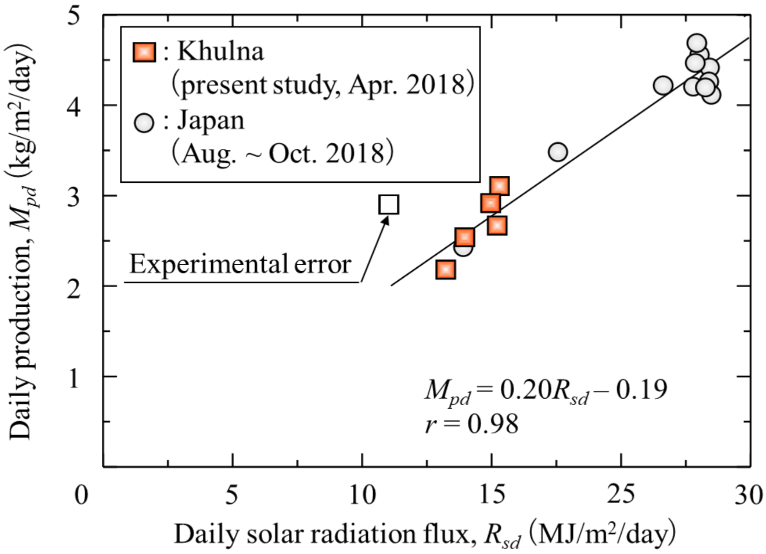

Figure 4. Daily production and solar radiation flux recorded during this study

We estimated TrSS water production cost including fabrication cost and following assumptions:
(1) polyolefin film was available in Bangladesh at the same price as Japan,
(2) transport cost from Khulna to target village were not included.
(3) Equation (1) accurately expresses the relationship between M_{pd} and R_{sd}.
(4) Monthly production was calculated based on monthly average solar radiation data from the data set (See NASA data sets).

Figure 5 shows estimated annual water production cost during the dry season was initially ≈ 9.0 BDT/L, decreasing sharply for the first 3 seasons, eventually falling below 1.0 BDT/L, the average current drinking water cost for residential customers.

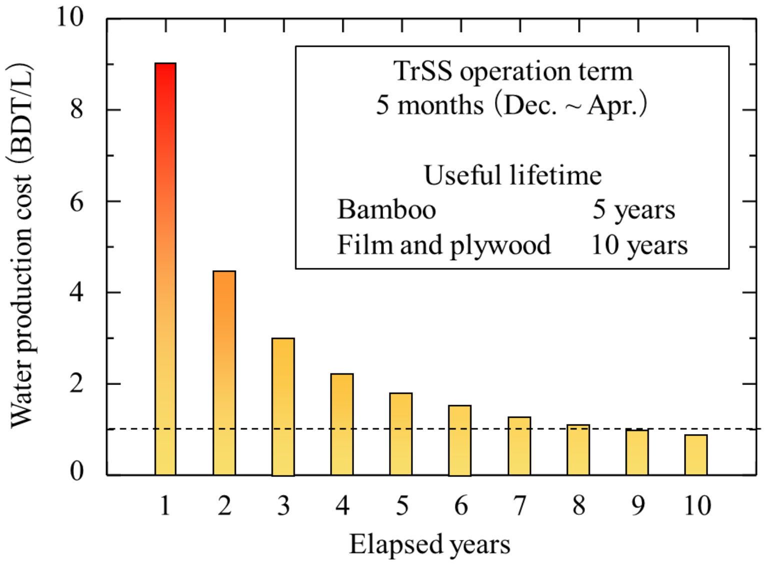

Figure 5. Estimated annual TrSS water production costs

5. CONCLUSIONS

To overcome severe potable water supply problems in remote and coastal areas in Southern Bangladesh, we designed a triangular solar still (TrSS) incorporating cheap and locally acquirable lightweight materials, such as bamboo. We performed a production test during April, 2018 in Khulna city, Bangladesh to estimate daily production performance, providing the basis to estimate water production costs for 10 years.

We found average daily water production for sunny days ≈ 0.43 kg, with daily production being proportional to daily solar radiation flux. Consequently, estimated TrSS water production for 10 years was less than 1.0 BDT/L. Thus, the proposed TrSS is an appropriate solution to provide potable water for local people in remote areas of Bangladesh. Further research will reduce TrSS cost and examine the produced water quality.

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Statistical Analysis of Rainfall Trend and Variability due to Climate Change in Bangladesh

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Abstract

Climate change is a dominant environmental factor that has been affecting Bangladesh by causing a significant shift in the rainfall trend of the country. A study period from 1965-2015 has been taken in which daily rainfall records of 8 stations, distributed all over the country has been examined. The objective of the study is to analyse historic annual rainfall data of different locations from all over the country and observe the trend. Seasonal and annual rainfall variation has been assessed. Mann-Kendall test and Sen's Slope model is used to detect the trend and estimate the magnitude of change, respectively. It has been observed that about 69% of rainfall occurs in the Monsoon season throughout the country. Monsoon and Post-Monsoon season shows a significant increasing trend whereas Pre-Monsoon and Dry season shows significant decrease. Mean annual rainfall is highest in Sylhet, whereas, Rajshahi has the least mean annual rainfall. It has been revealed that Khulna has a significant increase in mean annual rainfall trend. Annual mean rainfall in Bangladesh is found to be 2388 mm/year from this study. Moreover, a non-significant trend has been found in annual mean rainfall all over the country. Monthly mean and extreme event indices are also analyzed where the trend is decreasing for the extreme event.

Keywords: Climate change, rainfall trend, Mann-Kendall, Sen's Slope.

1. INTRODUCTION

Climate change is the change in earth's climatic pattern. Global warming and climate change are recognized worldwide as the most crucial environmental dilemma that the world is experiencing today. Rahman et al (2017**)**. It has been indicated that rainfall is changing due to global warming on both the global Hulme et al (1998); Lambert et al (2003); Dore (2005) and the regional scales Rodriguez-Puebla et al (1998); Gemmer et al (2004); Kayano and Sansigolo (2008). The climate of a region is determined by the long-term average, frequency and extremes of several meteorological variables, most notably temperature and precipitation.Rutherford and Maarouf (2005).The objective of the study is to evaluate trends in the rainfall pattern from all over Bangladesh. The results can be used to check whether further analysis is required, and, if so, serve as a necessary input for predicting, decision-making, and planning processes to mitigate any adverse consequences of changing climate. Bangladesh is one of the most affected country in the Asian region due to change in climate, this is down to its geographical location which is highly vulnerable to natural disaster such as floods, landslides, waterlogging, salinity, erosion etc. Moreover, Dottori et al (2018) reported that the future flood impacts are likely to have uneven regional distributions with the highest losses are to occur in Asia. Furthermore, the climate of Bangladesh is greatly influenced by the presence of the Himalayan mountain range and the Tibetan plateau in the north, the Bay of Bengal in the south. Rahman et al (2017). Bangladesh relies heavily on agriculture which is the single largest producing sector of the economy since it comprises about 18.6% of the country's GDP and employs around 45% of the total labor force. Bangladesh Bureau of Statistics (2010). Rainfall is the most important factor that determines the agricultural production in Bangladesh. Shahid (2010). The importance of the study is to analyze the extreme rainfall indices as the extreme event directly affects the flood risks and also to predict the future scenarios of rainfall pattern throughout Bangladesh. In case of annual, seasonal and extreme rainfall, most of the stations have negative trend so it is seen that the rainfall is decreasing all over the country in the 51 years study period.

2. STUDY AREA AND DATA USED

Bangladesh is a low-lying plain of about 143,998 km^2, situated on deltas of large rivers flowing from the Himalayas**.** Geographically, it extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. The daily rainfall data were extracted from Bangladesh Meteorological Department (BMD) of 8 stations (Dhaka, Cox’s Bazar, Khulna, Mymensingh, Rajshahi, Rangpur, Sylhet, Barisal) from 1965-2015. The locations of the stations are being displayed in figure 1. When the data were arranged, it was found that in total of one or two years of rainfall data were missing from each station. The missing rainfall data were not taken into considerations. For this article the seasons were divided into four parts, Pre-monsoon (March-May), Monsoon (June-September), Post-monsoon (October-November), Dry (December-February).

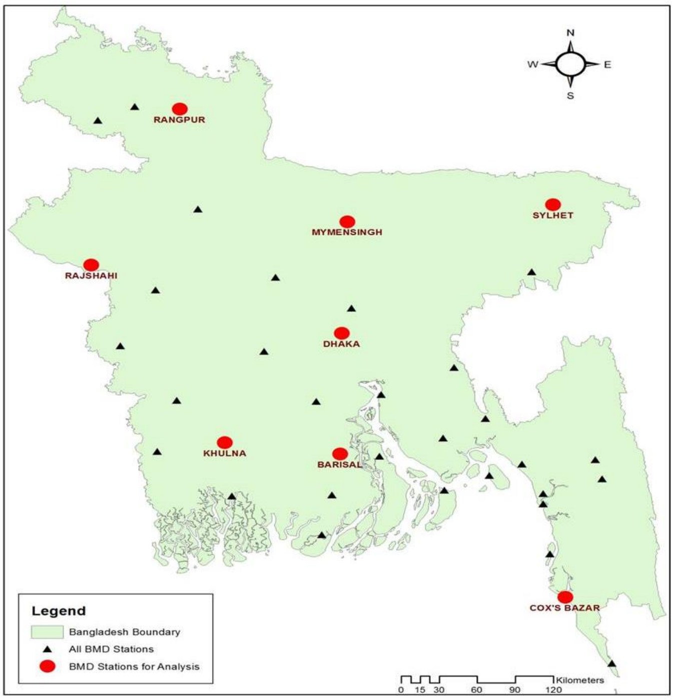

Figure 1: BMD station locations

3. METHODOLOGY

In this article the methodology followed is Trend analysis using the statistical non-parametric tests i.e. Mann-Kendall test and Sen’s Slope Estimator test on the annual, extreme event and seasonal rainfall. The collected data have been compiled, tabulated and analyzed by MS Excel and Excel template “MAKESENS” Application.

3.1. Mann-Kendall

The Mann–Kendall (MK), commonly known as the Kendall's tau statistic, is a non-parametric test used for trend analysis. Mann (1945) first used this test and Kendall (1975) derived the test statistic distribution. Rustum et al (2017)

The Mann-Kendall statistic S is given as Swain et al (2016):

$$\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \quad (1)$$

A time series x_i that is ranked from i = 1, 2, 3,……, n-1 and x_j, which is ranked from j=i+1,2,….,n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$\text{sgn}(x_j - x_i) = \begin{cases} +1, > (x_j - x_i) \\ 0, = (x_j - x_i) \\ 1, < (x_j - x_i) \end{cases} \quad (2)$$

For n > 8, S follows approximately normal distribution with mean i.e. E(S) =0. The variance statistic is given by,

$$\text{Var}(S) = \frac{n(n-1)(2n-5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \quad (3)$$

Where t_i is considered as the number of ties up to sample i.
The test statistic Z_{mk} (Mann-Kendall co-efficient) is computed as,

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{Var(s)}}, & S < 0 \end{cases} \quad (4)$$

Z_{mk} here follows a standard normal distribution. A positive and negative value of Z_{mk} indicates an upward trend and downward trend respectively.

3.2. Sen's Slope Estimator Test

To estimate the true slope of an existing trend(as change per year) and in cases where the trend can be assumed to be linear the Sen's Slope nonparametric method is used. The trend line equation is

$$f(t) = Qt + B \quad (5)$$

Where Q is the slope and B is the constant.
To evaluate the slope estimate Q in equation 5 we first calculate the slopes of all data value pair

$$Q_i = \frac{x_j - x_i}{j - i} \quad (6)$$

Where j > k.

If there n values x_j in the time series we get as many as N= n(n-1)/2 slope estimates Q_i. The median of these N values of Q_i is the Sen's estimator of the slope. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is

$$Q = Q_{[(N+1)/2]}, \text{ if N is odd} \quad (7)$$

$$Q = 1/2\ (Q_{[N/2]} + Q_{[(N+2)/2]}), \text{ if N is even} \quad (8)$$

4. RESULTS AND DISCUSSIONS

The results of the study on the trends of rainfall of the 8 stations located all over Bangladesh have been analyzed and discussed. The Mann-Kendall Statistic and Sen's Slope values of annual rainfall and extreme rainfall events for each of the stations over a period of 51 years are represented below in Table 1 and Table 2 respectively.

Table 1: Mann-Kendall and Sen's Slope values of annual rainfall

Station	Annual average (mm/yr)	Z_{mk}	Trend	Q (mm/yr)	B
Khulna	1731.37	1.30	+	5.657	1698.38
Cox's Bazar	3567.97	-0.28	-	-1.889	3739.22
Barisal	2052.32	-1.22	-	-4.083	2088.28
Dhaka	2034.30	-0.90	-	-4.078	2098.88
Mymensingh	2046.75	0.44	+	3.279	1948.09
Rajshahi	1449.39	-2.11	-	-6.880	1640.71
Rangpur	2105.96	0.93	+	4.909	1962.14
Sylhet	4031.57	-0.64	-	-3.933	4005.37

Table 2: Mann-Kendall and Sen's Slope values of extreme rainfall events

Station	Z_{mk}	Trend	Q (mm/yr)	B
Khulna	-0.21	-	-0.08	119.63
Cox's Bazar	-1.29	-	-0.75	214.13
Barisal	-1.78	-	-0.89	152.34
Dhaka	-3.21	-	-1.37	156.78
Mymensingh	-0.84	-	-0.36	135.43
Rajshahi	-1.71	-	-0.67	120.03
Rangpur	1.52	+	1.18	133.03
Sylhet	-0.55	-	-0.36	185.80

It was found out from analysis that annual average rainfall trend throughout Bangladesh is following a downward trend (Z_{mk} = -0.16) and the change in magnitude of rainfall is -0.421 mm/yr.

In case of yearly seasonal variation in Bangladesh the rainfall trend in monsoon and post-monsoon is increasing at a rate 1.44 mm/yr and 1.10 mm/yr respectively. However, for dry and pre-monsoon season it shows a decreasing trend at a rate 0.25 mm/yr and 2.02mm/yr respectively. The change in rainfall during the course of the season of the 8 stations is shown in Table 3.

Table 3: Stations showing the rainfall trends over the course of the season

Seasons	Stations	
	Positive trend	Negative trend
Monsoon	Khulna, Mymensingh, Rangpur, Cox's Bazar	Barisal, Dhaka, Sylhet, Rajshahi,
Post-monsoon	Khulna, Mymensingh, Rangpur, Cox's Bazar	Barisal, Dhaka, Sylhet, Rajshahi
Dry	Khulna, Mymensingh,	Cox's Bazar, Barisal, Dhaka, Sylhet, Rajshahi, Rangpur
Pre-monsoon	Mymensingh, Rajshahi, Rangpur, Sylhet	Cox's Bazar, Barisal, Dhaka, Khulna

The maximum mean monthly rainfall was found in Cox's Bazar at an amount of 885.1 mm/yr occurring in the month of June whereas in Mymensingh the minimum mean monthly rainfall was found in December at an amount of 4.5 mm/yr. The bar chart showing the mean monthly rainfall throughout the country is represented below in figure 2.

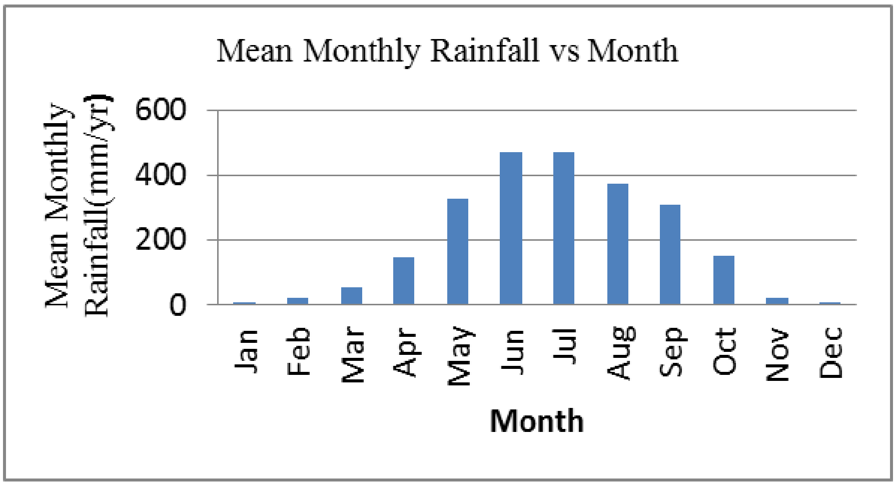

Figure 2: Mean monthly rainfall

5. CONCLUSIONS AND RECOMMENDATIONS

Our main focus was to find the rainfall trend and variability. The data were carefully checked before analyzing. The trend analysis showed significant increase in annual rainfall for Khulna whereas Rajshahi had a significant decrease in annual rainfall over the course of these 51 years. In case of extreme rainfall event, Dhaka registered the significant decrease in trend due to temperature rise and land use factor. However, unlike the rest of the stations, only Rangpur had an increase in extreme rainfall event trend. Further studies are recommended to be conducted in which analysis should be done in hourly basis and investigate other rainfall characteristics at temporal and spatial resolution such as dry days, rain days, and other climate change parameters. Identifying the rainfall trends could have a wide range of applications in hydrological and climatic research.

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Hydropower Development along Teesta River Basin: Opportunity for Cooperation

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Abstract

The aim of this research is to examine the hydropower development potentials and identifying major hydropower projects along Teesta river basin that is shared by Bangladesh and India. The upstream of Teesta river basin is located mostly in hilly areas of Sikkim where India plans to produce electricity of over 6,500 MW by exploiting hydropower potentials of the basin. India also plans to exploit remaining untapped hydropower potentials of Teesta river basin. But the lower part of the basin is densely populated, mostly flatland and has no hydropower potential. Negotiations on how to share Teesta river's water have been going on since 1979. In July 1983, an ad-hoc agreement was reached between India and Bangladesh to share the Teesta water at the ratio of 39% (India): 36% (Bangladesh) that was extended until 1987. As of today, both countries failed to reach any agreement to share water and, unfortunately, all subsequent negotiations on Teesta river basin management only focuses on sharing water rather than sharing the benefits from water resources including hydropower and other related resources. This paper identified the existing, ongoing and upcoming hydropower development projects along with a Teesta river basin map showing the locations of the major projects. Finally, it assesses the hydropower sharing opportunity between the two riparian countries and argues that hydropower sharing between Bangladesh and India might help both countries to reduce tension and appreciate reaching a sustainable agreement for integrated development of Teesta river basin.

Keywords: Integrated Teesta river basin, Hydropower development, Cooperation, Bangladesh, India.

1. INTRODUCTION

In many parts of the world, the international political boundaries were drawn without considering the water courses and basins. Presently, about 261 rivers water have used by two or more riparian states. Transboundary rivers basins cover about 45% of total earth surface shared by 145 countries (Tiwary, 2006). Teesta is a transboundary river shared by Bangladesh and India. It has steep slope and high seasonal variability of flow that causes flash flood in the monsoon (May - September) period, but in the non-monsoon (October - April) period the flow of the river decreases significantly (Mullick et al 2010).

The Teesta river originates from Chombo Chu at an elevation of 5,280 m in the north-eastern part of Sikkim, India (Prasai and Surie 2013; EnvIS 2018). Some authors also considered Jongsong peak and Chho Lhamo as the sources of water of Teesta river (Meetei et al 2007; Rahaman and Varis 2009; Singh and Goyal 2016). At Chungthang, two rivers namely Lachen Chu and Lachung Chu join together and, from the confluence, starts flowing as the name Teesta. After that, Teesta increase its width with wide loop and drop to Singhik with an elevation of 1550 m to 750 m from mean sea level. At Singhik, Teesta joins with Talung Chu which originated from Khangchendzonga range and Rangpo

Chu joins at Rangpo. Then Teesta river gradually increase its width and joins with Rangit river at Teesta Bazar (Goyal and Goswami 2018).

At Shevok, Teesta comes to the flat land and starts more spreading its width. Teesta river entered into Bangladesh and flows through Lalmonirhat, Nilphamari, Rangpur and finally joins with mighty Brahmaputra river at kamarjani village in Kurigram (Islam, 2016). Teesta river travels about 414 km before joining with Brahmaputra river and it has a catchment area of about 12,370 km^2 (Rudhra, 2018).

Before 1787, the Teesta was a part of the Ganges river system and it flows south direction through Jalpaiguri district of west Bengal, instead of present south-east direction. The name “Teesta” come from the Sanskrit word “Triosta”, which indicate the three led channels of Teesta of that time, i.e. Karatoa, Purnabhaba, and Atrai (Prasai and Surie 2013). According to Hindu mythology, flow of Teesta come from the breasts of the goddess Parvati. (Jain et al 2007). Teesta river and most of its tributaries flow with high velocity, carry boulders and suspended sediments (Goyal and Goswami, 2018). Velocity of water of Teesta river is about 6 m/sec and average suspended sediment load is about 15.89 million ton (Roy 2011; Acharjee and Barat 2013). The Teesta floodplain is the most active floodplain of North Bengal which is bounded with the Himalayan terraces in the northern and north-western region, the Barind tract in the western and south-western region, the Ganges floodplain in the southern region and the Jamuna river in the eastern region (Islam 2016).

The upper portion of the basin is mostly covered with snow and glaciers. But lower portion is mostly flat land and some part has covered with forest (Singh 2018). Sikkim and some part of West Bengal (Darjeeling) has huge amount of hydropower potential. It is expected that within a few years Sikkim-Darjeeling region of India could produce over 6000 MW of Hydropower (Khawas 2016). The upper part of the basin has very low population density, but it has all the hydropower potential, unlikely the lower part of the basin is densely populated but suffer for electricity. To date, both riparian country (Bangladesh and India) have proposed a number of plans for an effective negotiation of the issues related to Teesta river. But most of those only focuses on water sharing rather than sharing the benefits from water resources including hydropower and other related resources.

1.1. Objectives of the Research

This research has two objectives: (i) to examine the hydropower development potentials and identify the existing, ongoing and upcoming/ proposed hydropower development projects, (ii) to assess the hydropower sharing opportunity between Bangladesh and India within the basin which could be helpful for integrated development of Teesta river basin.

1.2. Data and Information Sources

Data has been collected both from primary and secondary sources. Primary data has been collected from relevant Government report, official websites of Government organizations and other international organizations. Secondary data has been collected from various international, national and local organizations as well as published articles, books, document and reports. The data of hydropower projects has been collected and cross matched from CEA (2016), EDPS (2018), India-WRIS WebGIS (2018), NHPC (2018) and NTPC (2018). To improve the accuracy of the schematic diagram of Teesta river system (Appendix 1) and the locations of the hydropower projects, data have been collected from several sources, e.g. EnvIS (2018), BWBD (2011), SANDRP (2018) etc. Great emphasis has been placed on the accuracy and reliability of the data.

2. HYDROPOWER DEVELOPMENT ALONG TEESTA RIVER BASIN

The earliest concept of power generation using water power comes from china during the Han Dynasty between 200 BC and 9 AD. (IHA 2018). Hydropower is the largest source of renewable electricity in the world. It contributes about 17% of the total production of electricity which is over 1,200 GW. The cumulative capacity of generation of electricity is still expected to increase by an additional of 119 GW by 2022 (IEC 2018). Hydropower is expected to remain the world’s largest source of renewable electricity generation by 2022 and it will play a critical role in decarbonizing the power system and also improve the system flexibility. According to World Energy Council report 2016, the China is the top most country who have the hydropower potential about 2,140,000 GWh/year from which 59% (about 1,013,600 GWh/year) is still unutilized. Similarly, India (18%), Nepal (2%), Pakistan (16%), Myanmar (4%) have used only a little portion of its total hydropower potential (WEC, 2016).

In 2004, Central Electricity Authority of India prepared a preliminary feasibility report of new 162 hydroelectric schemes of total potential of over 50,000 MW, where Sikkim have 10 schemes with an installed capacity 1,469 MW (CEA 2015). In 1974, a committee was formed to study the hydropower potential in Sikkim. Sikkim welcomes private developers for developing and exploiting its hydropower potential, which has been assessed to 8000 MW peak with a firm base of 3000 MW. Total hydropower potential in the state so far is 5352.7 MW and they are in different stages of implementation (EPDS 2018). About 50 hydropower development projects are in different stages. Hydropower development of Sikkim and West Bengal are listed in Table 1, Table 2, and Table 3. The location of hydropower projects has been shown in Figure 1.

Table 1. Existing hydropower projects along Teesta river basin (as of 05.11.2018)

Project Name	Location	Installed Capacity (MW)	River	Latest Status/ Remarks
Ramman II	West Bengal	50	Ramman	In operation. Project completed on 1995.
Ranjit III	West Sikkim	60	Ranjit	In operation. Commissioned on February 2000. Project completed by NHPC.
Teesta Low Dam III	West Bengal	132	Teesta	In operation. Commissioned on March 2013. Project completed by NHPC.
Teesta Low Dam IV	West Bengal	160	Teesta	In operation. Commissioned on August 2016. Project completed by NHPC.
Teesta Stage V	East Sikkim	510	Teesta	In operation. Commissioned on March 2008. Project completed by NHPC.

Source: CEA (2016), EDPS (2018), India-WRIS (2018), NHPC (2018)

Table 2. Ongoing hydropower projects along Teesta river basin (as of 05.11.2018)

Project Name	Location	Installed Capacity (MW)	Latest Status/ Remark
Bakchachu	North Sikkim	40	Project under survey & investigation by Sanvijay Power and Allied Industries Ltd.
Bhasmey	East Sikkim	51	Project under construction by Gati Infrastructures Ltd. As per MoU, date of commissioning was December 2013. Project progress is around 28%.
Chuzachen	East Sikkim	99	Project under construction by Gati Infrastructures Ltd. As per MoU, date of commissioning was June 2013.
Dikchu	North/ East Sikkim	96	Project under construction by Sneha Kinetic Power Projects Ltd. As per MoU, date of commissioning was December 2013 and project declared COD on March 2017.
Jorethang	South Sikkim	96	Project under construction by DANS Energy Pvt Ltd. As per MoU, date of commissioning was June 2013 and project declared COD on September 2017.
Paanan	North Sikkim	300	Project under construction by Himagiri Hydro Energy Pvt Ltd. As per MoU, date of commissioning was September 2013 and only preliminary construction works started.

Rahi Kyoung	North Sikkim	26	Project under survey & investigation by Sikkim Engineering Pvt Ltd. DPR is under preparation. Public hearing has been concluded by SPCB.
Ramman III	West Bengal	120	Project under construction by NTPC.
Ranjit II	West Sikkim	66	Project under construction by Sikkim Hydro Ventures Ltd. As per MoU, date of commissioning was May 2013. Project progress is around 12%.
Ranjit IV	West Sikkim	120	Project under construction by Jal Power Corporation Ltd. As per MoU, date of commissioning was July 2015. Project progress is around 49%.
Ronginichu	East Sikkim	96	Project under construction by Madhya Bharati Power Corpora. As per MoU, date of commissioning was December 2013. Project progress is around 64%.
Tashiding	West Sikkim	99	Project under construction by Shiga Energy Pvt Ltd. As per MoU, date of commissioning was September 2015. Project declared COD on September 2017.
Teesta Stage III	North Sikkim	1200	Project under construction by Teesta Urja Limited. As per MoU, date of commissioning was December 2013 and Project declared COD on February 2017.
Teesta Stage IV	North Sikkim	520	Project under construction by NHPC. Only preliminary construction works started. First stage environment clearance is obtained.
Teesta Stage VI	North/ South Sikkim	500	Project under construction by Lanco Energy Pvt Ltd. As per MoU, date of commissioning was July 2013. Project progress is around 48%.

Source: CEA (2016), EDPS (2018), NHPC (2018), NTPC (2018)
Note: COD: Commercial Operation Date, DPR: Detailed Project Report, SPCB: State Pollution Control Board, MoU: Memorandum of Understanding.

Table 3. Upcoming/ Proposed hydropower Projects along Teesta river basin (as of 05.11.2018)

Project Name	Location	Installed Capacity (MW)	Latest Status/ Remark
Bhimkyong	North Sikkim	99	MoU/IA was terminated on June 2012. High Court of Sikkim has given a new timeline up to 2018 the development of the project to Teesta Hydro Power Pvt. Ltd.
Bop	North Sikkim	99	MoU/IA was terminated on June 2012. High Court of Sikkim has given a new timeline up to 2018 the development of the project to Teesta Hydro Power Pvt. Ltd.
Chakhungchu	North Sikkim	50	The project was allotted on 2002. An arbitration case is underway with Sikkim Govt. and Amalgamated Trans Power India Ltd.
Kalez Khola I	West Sikkim	27.5	MoU/IA terminated due to non-performance of the West Sikkim Cosmic Infra Powergen Pvt Ltd on September 2016.
Kalez Khola II	West Sikkim	54	MoU/IA terminated due to non-performance of the Pentacle Power Pvt Ltd on February 2017.
Lachung	North	99	MoU/IA was terminated on June 2012. High Court of

	Sikkim		Sikkim has given a new timeline up to 2018 for development of project to Lachung Hydro Power Pvt. Ltd.
Lethang	West Sikkim	96	Project not granted clearance by National Wild Life Board, Govt. of India. Project cancelled vide Notification No. 12/Home/2012.
Lingza	North Sikkim	120	Project cancelled/not taken up as this area fell within Dzongu area and in the vicinity of Kanchanjonga National Park.
Ramman I	West Bengal	48	MoU/IA signed with NHPC on July 2015.
Manul and Mangan	North Sikkim	30	MoU/IA terminated due to non-performance of the Higen on September 2017.
Ralang	South Sikkim	40	The project was allotted on 2002. An arbitration case is underway with Sikkim Govt. and Amalgamated Trans Power India Ltd.
Rangyong	North Sikkim	80	Project cancelled/not taken up as this area fell within Dzongu area and in the vicinity of Kanchanjonga National Park.
Rathangchu	West Sikkim	30	Projects scraped due to Religious sentiments.
Rechu-Meyongchu	North Sikkim	26	MoU/IA terminated due to non-performance of Planet Infra Projects Pvt. Ltd.
Ringpi	North Sikkim	320	Project cancelled/not taken up as this area fell within Dzongu area and in the vicinity of Kanchanjonga National Park.
Rolep	East Sikkim	36	The project was allotted on 2002. An arbitration case is underway with Sikkim Govt. and Amalgamated Trans Power India Ltd.
Rukel	North Sikkim	33	Project cancelled/not taken up as this area fell within Dzongu area and in the vicinity of Kanchanjonga National Park.
Sada-Mangder	West/South Sikkim	71	MoU/IA terminated due to non-achievement of the stipulated milestones by Gati Infrastructures Ltd on February 2017.
Suntaleytar	East Sikkim	40	MoU/IA terminated due to non-performance of Moser Baer Electric Power Ltd / Shreya Powertech Pvt Ltd on February 2017.
Teesta Low Dam I & II (Combined)	West Bengal	81	MoU/IA signed with NHPC on July 2015.
Teesta Low Dam V	West Bengal	80	MoU/IA signed with NHPC on July 2015.
Teesta Intermediate Stage	West Bengal	84	MoU/IA signed with NHPC on July 2015.
Teesta Stage I	North Sikkim	280	MoU/IA cancelled as this area fell within the vicinity of Kanchanjonga National Park.
Teesta Stage II	North Sikkim	330	MoU/IA terminated on September 2018 due to non-performance of Him Urja Infra Pvt. Ltd.
Ting Ting	West Sikkim	99	Project cancelled vide Govt. Notification No. 12/Home/2012 as milestones as per MOU not achieved by

			T.T. Energy Pvt. Ltd.
Upper Rolep (Nathangchu)	East Sikkim	30	MoU/IA terminated on September 2016 due to non-performance of Cosmic Infrapowergen Pvt Ltd.
Upper Rolep (Tshanguchu)	East Sikkim	30	MoU/IA terminated on September 2016 due to non-performance of Cosmic Infrapowergen Pvt Ltd.

Source: CEA (2016), EDPS (2018), NHPC (2018)
Note: IA: Interagency Agreement

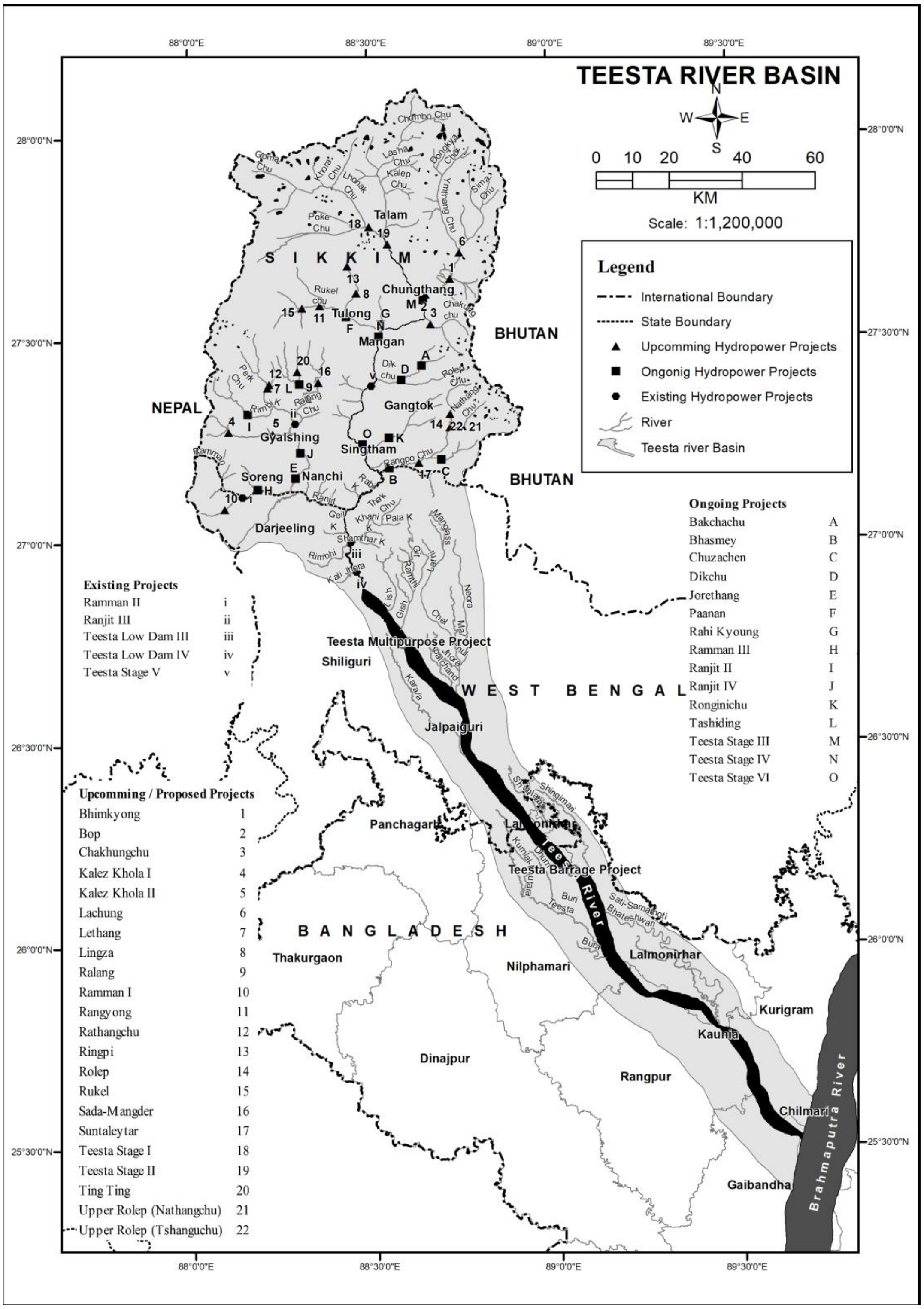

Figure 1. Location of hydropower projects along Teesta river basin

3. CONCERN FOR FUTURE ELECTRICITY DEMAND: BANGLADESH - INDIA

3.1. Electricity consumption and accessibility

As on 2014, the electricity consumption per capita of Bangladesh and India is about 311 KWh and 806 KWh respectively (WB 2018). As both countries are part of developing world, the consumption of electricity increases rapidly (Table 4). In every five years, the percentage of increasing electricity consumption varies from 120% to 135% from the previous five years. To fulfill the increasing demand both countries have taken several initiatives.

Table 4. Electricity consumption and accessibility

Year	% of population with access to electricity		Electric power consumption (kWh per capita)	
	Bangladesh	India	Bangladesh	India
1990	8.54	43.29	48.37	273.05
1995	20.76	51.50	75.90	360.05
2000	32.00	59.40	101.49	394.96
2005	44.23	66.93	170.68	469.45
2010	55.26	76.30	239.83	642.11
2014	62.40	81.24	310.39	805.60

Source: WB (2018)
Note: KWh: Kilowatt-hour

3.2. Present Production and Future Demand of Electricity

In, 2017, the electricity production of Bangladesh and India is about 57.28 TWh and 1206.31 TWh (Table 5). Currently, the main source of electricity production of Bangladesh is gas (58.89 %) (BPDB, 2018). On the other hand, India depends on coal (56.9%) based power plant (MoP, 2018). India has taken some initiatives to switch their main source of electricity from coal to renewable energy (hydropower, wind, solar etc.) to fulfil the future demand of electricity. About 47 major hydropower projects (each above 25 MW) throughout India are under construction. It is expected that these projects will contribute to around 14,000 MW additional electricity in Indian national grid within 2022 (CEA 2018b).

Table 5. Electricity production of Bangladesh and India (TWh)

	Thermal (Coal, Oil, Gas)	**Hydro**	**Nuclear**	**Import**	**Total**
Bangladesh (as of 2017)	51.64	0.98	0	4.66	57.28
India (as of 2017-2018)	1037.06	126.12	38.35	4.78	1206.31

Source: BPDB (2017), CEA (2018a)
Note: TWh: Terawatt-hour

Mondal et al (2010) forecasted that, the electricity demand of Bangladesh will be 131.58 TWh within 2035 in low GDP growth scenario which is about 8 times higher than the electricity consumption of 2005. In the average and high GDP growth scenarios the demand will increase about 11 to 16 times that 2005. Saravanan et al (2012) forecasted that, within 2030, the electricity demand will be 2755.45 MW (Table 6). To meet the future demand of electricity regional cooperation is needed.

Table 6. Forecasted demand of electricity of Bangladesh and India (TWh)

	2015	2020	2025	2030
Bangladesh	48.6	74.86	107.3	146.3
India	1036.96	1414.82	1950.34	2755.45

Source: Mondal et al (2010), Saravanan et al (2012)

4. COOPERATION: HYDROPOWER SHARING COULD REDUCE TENSION

4.1. Electricity trade in South Asia

Quite a few electricity trade agreements are already available in South Asia. Under CASA-1000 project, Afghanistan and Pakistan have imported electricity from Central Asia. The transmission line of CASA could be extended up to India and Bangladesh. After fulfilling own demand, Bhutan exports about 75% of its total electricity generation to India (Singh, 2013). India invested in several power projects of Bhutan. Under the agreement between Bhutan and India, India committed to import minimum of 5,000 MW electricity from Bhutan (Singh et al, 2015). Under a high growth scenario, by 2027, the power development projects of Nepal will earn huge revenue by developing a total hydropower capacity of 22,000 MW including 15,000 MW for exports (Srivastava and Misra, 2007). Sri Lanka is expected to import around 1000 MW of electricity from India. Bangladesh and India have an agreement to share electricity from India to Bangladesh that includes about 500 MW electricity which could be extended up to 1000 MW within 2018 (Table 7).

Table 7. Recent regional cooperation for sharing of electricity in South Asia.

Participant countries	Description
Afghanistan-Central Asia	In 2011, Afghanistan imported about 2,246.2 GWh electricity for Iran, Uzbekistan, Turkmenistan, and Tajikistan. CASA-1000 has expected to increase the electricity trade.
Bangladesh-India	In 2013, Bangladesh imported about 500 MW (expandable to 1000 MW in future) electricity from India.
India-Bhutan	In 2013-2014, India imported 5556 GWh electricity from Bhutan. India and Bhutan has signed an agreement form which India will minimum of 5000 MW electricity import by 2020.
Nepal-India	In 2013, Nepal Imported 793GWh electricity from India.
Sri Lanka-India	A feasibility study has conducted by Sri Lanka for importing up to 1000 MW electricity from India.
Pakistan-India	Pakistan submitted a draft MoU to India for importing about 1200 MW electricity. CASA could be extended up to India.
Pakistan-Iran	In 2014, Pakistan imported 419 GWh electricity from Iran.

Source: Singh et al (2015)
Note: CASA-1000: Central Asia-South Asia power project

4.2. Why hydropower sharing (Sikkim-Bangladesh) along Teesta river basin?

Hydropower sharing between Bangladesh and Sikkim (India), along the Teesta river basin, India could be beneficial for both countries for following reasons:

- The electricity Demand of Sikkim is about 264.7 kWh per capita (as of 2016-2017) (EnvIS, 2018). It is expected that within 2022, the hydropower projects that are under construction and under survey and investigation will be completed (Table 2 and MoP 2018). This will add about 3500 MW electricity to their grid. After fulfilling State of Sikkim's local demand, India could export electricity which will give a strong base to the economy of State of Sikkim.
- Due to close proximity, exporting electricity from Teesta river basin to Nepal, Bhutan and Bangladesh are feasible for the State of Sikkim (India). However, Bhutan already export electricity and Nepal is also expected to be an electricity exporter within 2022. Hence, the first choice could be Bangladesh to export electricity.
- According to international law, as a stockholder of Teesta river basin, Bangladesh deserve the first priority to import the hydropower of Sikkim (Helsinki Rules 1966).
- Government of State of Sikkim, India, aims to export hydropower to Bangladesh. Power Trading Corporation (PTC) has been tasked to explore possibilities for exporting electricity to Bangladesh from Teesta III (1,200 MW) hydropower project (Dahal 2016).
- This is an excellent opportunity for Bangladesh to improve existing capacities and use clean energy to meet the climate change and other environmental targets. It could reduce tension due to future demand of electricity in Bangladesh.

5. CONCLUSION AND RECOMENDATION

Hydropower is a low cost and clean energy source which could fulfil the increasing electricity demand of South Asia. For that, cross boundary electricity trade could play an important role. This paper assessed the present condition of hydropower development along teesta river basin. The total hydropower potential of the basin is over 8,000 MW, mostly located in States of Sikkim and West Bengal of India. Currently, total 47 hydropower projects of Sikkim and West Bengal within the Teesta river basin are in different stages which have a total installed capacity of around 6753.5 MW (see Tables 1, 2 and 3). Governments of the States of Sikkim and West Bengal, India, are taking numerous initiatives to explore more hydropower potential along the Teesta river basin.

To have an effective hydropower sharing agreement, Governments of Bangladesh and India should consider following issues:

- After fulfilling own electricity demand, State Government of Sikkim could export electricity to Bangladesh which will improve the economic condition of Sikkim.
- State of Sikkim, India, should have a clear policy to export hydropower to Bangladesh.
- The cost of electricity should be based on market price, which will ensure both parties are in win-win condition.
- Agreement should be for longer term as short-term agreement often does not produce effective cooperation due to lack of continuous commitment.
- Socio-economic and socio-political condition of both countries should be considered.
- Feasibility study should be conducted, which will reduce the risks to financial investment, environment and society.

Bangladesh and India already have an agreement for electricity sharing. The effectiveness of the agreement could influence the future hydropower sharing opportunity of Bangladesh and India. The findings of this study should be interpreted with care. If political leadership shows a strong will and strengthens regional cooperation and electricity trade, hydropower development along the Teesta river basin could significantly contribute to economic development in the riparian countries, i.e. Bangladesh and India.

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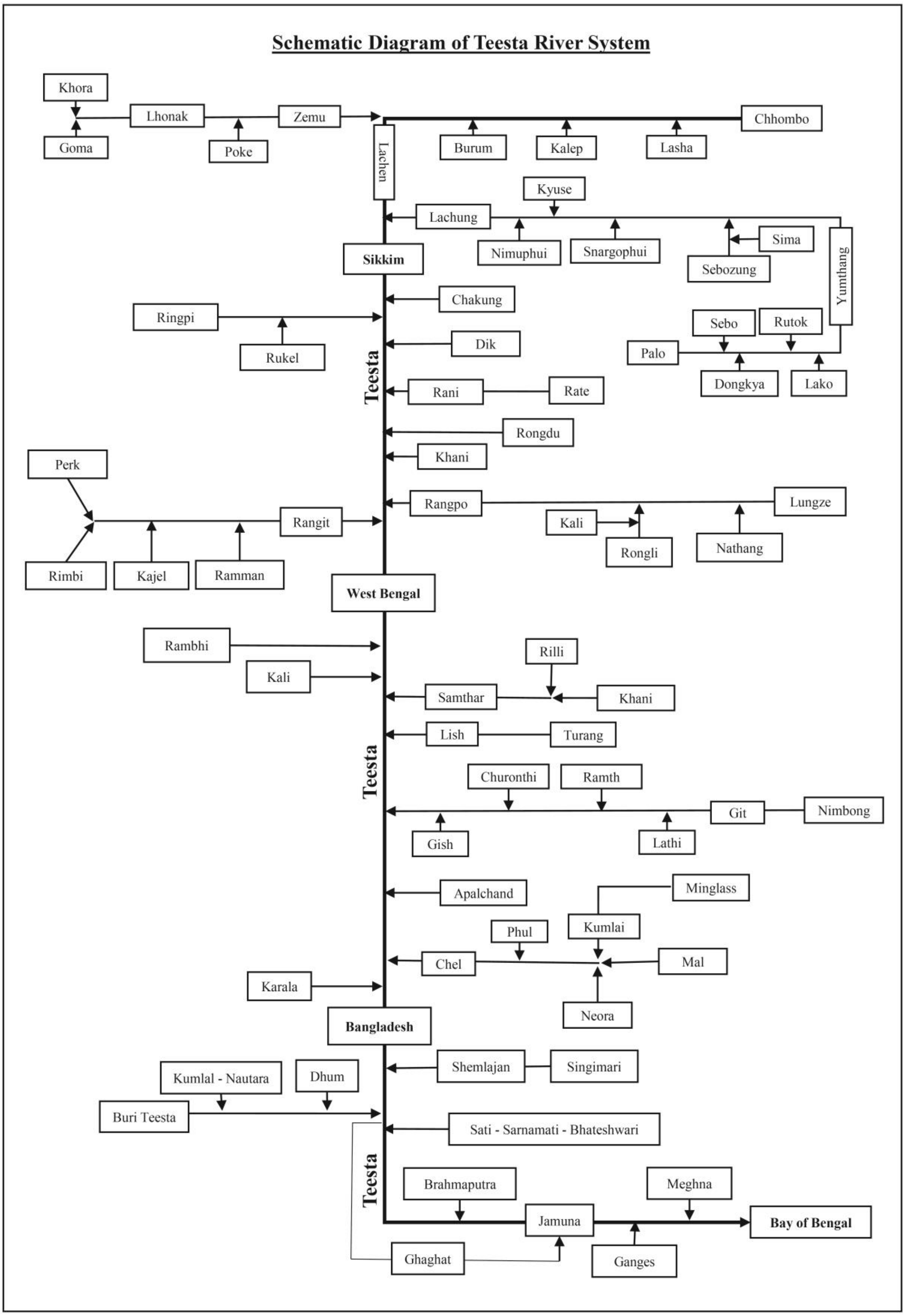
Appendix 1

Schematic Diagram of Teesta River System



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Stromwater Management Technologies in Australia

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Abstract

The main purposes of stormwater management in Australia are flood protection, decreasing water scarcity and reducing pollutant loads. Rainwater harvesting (RHW), managed aquifer recharge (MAR) and detention basin (DB) are commonly used technologies in Australia for stormwater management. These are not merely supplementary to each other; they mainly contribute through reducing peak floods and its volumes. This reduction mainly depends on rainfall intensity, duration and catchment size. RHW helps in preserving water to use during insufficiency of rainfall. On the hand, MAR recharges aquifer both naturally and artificially which ultimately recovers groundwater and protects aquifer and aquitard. BD is a common conventional method of managing stormwater in Australia which collects stormwater and releases it slowly at a controlled rate to protect the downstream areas from flood, erosion, and contamination. Among all available technologies of stormwater management, RWH is practiced mainly at household level in Australia. Government is also encouraging installation of RWH tanks through offering rebates. On the other hand, the government is solely responsible for installing MAR and DB. Groundwater quality improves through MAR. In the Australian context, stormwater harvesting is not an economically attractive water supply option when considered purely from a cost perspective; rather it becomes environmentally attractive when water quality is in consideration.

Keywords: Flooding, managed aquifer recharge, detention basins, rainwater harvesting, stormwater management.

1. INTRODUCTION

Stormwater is the water draining off rain from a site from that falls on the roof and land. It carries materials such as soil, organic matter, litter, fertilizers from gardens, oil residues from driveways, etc. The volume of stormwater runoff increases by urban development which replaces large areas of vegetated ground with impervious surfaces like roads and buildings. Increased urbanization also influences the reduction of baseflow and as a consequence enhances local flooding.

Water demand increases by the growth in population and urbanization, intensive agricultural development and rapid growth of the industry increases. On the other hand, stormwater, a potential source of water is commonly considered as an under-utilized resource in Australia. Stormwater also degrades water quality of waterways through carrying pollutants. Thus, proper management of stormwater is essential for flood mitigation and to improve water quality in downstream waterways.

Australia has been experiencing climatic stress at present. On top of that climate change projections are expecting this situation will continue with some extremities. As the demand for water increases, it is vital to ensure that alternative water sources meet the long-term water demand. The alternative water supplies could be in the form of reuse of rainwater (rainwater harvesting), stormwater, greywater, treated sewage and managed aquifer recharge (MAR). Fit-for-purpose water use prioritizes the appropriate quality of alternative water sources for different demands. Closer the match in the quality of the water to the level needed for end users, the less treatment is required. Reducing water treatment is both energy and cost efficient (City of Melbourne 2018). Along with other stormwater collection methods, rainwater harvesting, MAR and detention basins could be options to manage urban flooding as well as to face the climatic challenge of scarcity of water in dry season.

This study will report the stormwater management techniques in Australia to manage floodwater as well as to reduce demand on mains water supply, especially during drought situations. Few case studies in Australia will be reported together with the benefits and costs involved in recycling stormwater with respect to Australian practices.

2. STROMWATER MANAGEMENT TECHNOLOGIES

The conventional stormwater management requires the construction of an expansive and expensive centralized infrastructure system to carry runoff efficiently and rapidly which often results in financial and environmental liability in the forms of infrastructure flooding damage and the externalization of possible stormwater pollution costs (Vargas 2009). Starting in the 1920s, stormwater management and flood prevention were implemented in a linear fashion, assuming that stormwater was a waste and not a resource (Durrans 2003). Today it is seen as an under-utilized resource. The impact of flooding has necessitated upgraded drainage infrastructure and increased community resilience. The need to better manage water has led to some ingenious and cutting-edge water capture and recycling techniques being implemented by the private sector, government, residents and major cities in Australia. Currently, the City of Melbourne practices integrated water cycle management which is a coordinated management of all components of the water cycle including water consumption, rainwater, stormwater, wastewater, and groundwater, to secure a range of benefits for the wider catchment (City of Melbourne 2018).

The following projects in the City of Melbourne are worth mentioning in which stormwater harvesting systems capture, treats and stores stormwater for irrigation reuse in a park. Figure 1 depicts the schematic diagram of a typical stormwater harvesting system that collects water from drains, cleans it using biofiltration and stores it for irrigating the garden.

1. Birrarung Marr stormwater harvesting system (City of Melbourne 2018)
2. Stormwater harvesting in Alexandra and Queen Victoria Gardens (City of Melbourne 2018)
3. Fitzroy Gardens Stormwater Harvesting System. (City of Melbourne 2018)

In all three projects, the harvesting system diverts stormwater from the exit point to be treated and stored for reuse. The treatment process begins with a gross pollutant trap that removes large pollutants, such as litter and leaves. The water is then pumped to storage tanks or retrofitted ornamental ponds (in case study 2) via a sedimentation chamber, which removes small particle pollution matter such as fine sands and oils. This water is pumped to the biofiltration bed on the surface for treatment. The biofiltration bed contains indigenous plants. As the water drains through the soil and roots, these plants naturally remove soluble pollutants such as phosphorus and nitrogen. The treated water filters back down into the secondary storage tank, where millions of liters are stored for irrigation. Table 1 depicts the size of the catchment that stormwater is captured, the size of the park where treated water is used for irrigation and the potable water savings from each project.

Table 1. Water saving details of three stormwater harvesting projects in Melbourne

Project	Catchment Size (ha)	Park Size (ha)	Potable water saving (million liters)	Potable water saving (%)
Birrarung Marr	37	8.3	35	70%
Alexandra and Queen Victoria Garden	34	10	20	55%
Fitzroy Gardens	67	26	70	60%

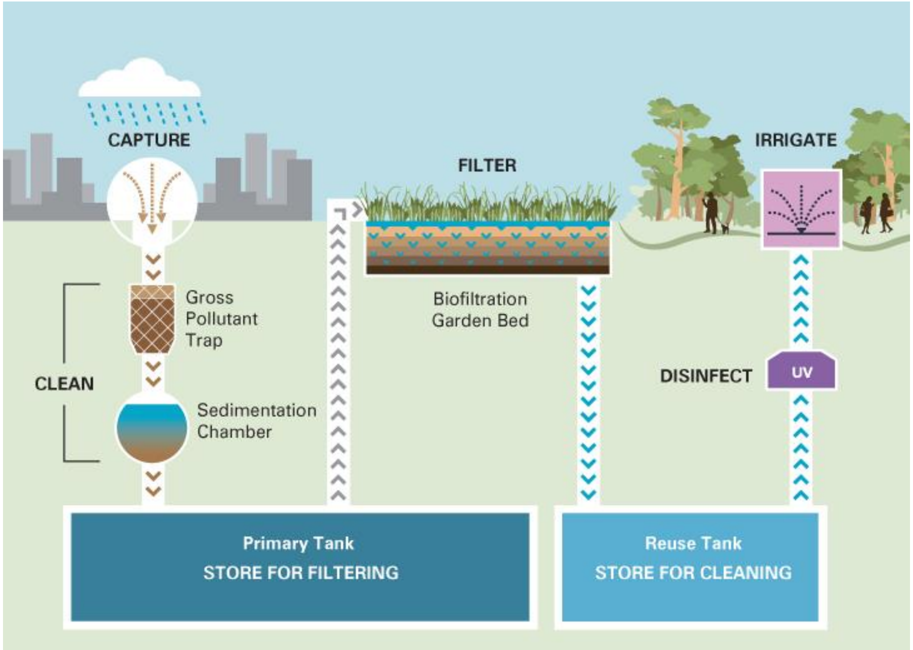

Figure 1. The schematic diagram of a stormwater harvesting system (Source: City of Melbourne 2018)

The followings three methods are the most commonly used stormwater management technologies practiced in Australia.

2.1. Rainwater Harvesting

In response to droughts with consequent water shortages and improved science, local authorities throughout Australia encourage the use of rainwater harvesting systems in urban areas to supplement mains water supplies and to manage urban stormwater runoff. In Australia, urban households mostly rely on treated (mains) water supply but can significantly lower mains water usage by installing a rainwater harvesting system. In 2013, about 26% of all Australian households (2.3 million people) used rainwater tanks (ABS 2013a). The use of rainwater could vary from industrial purposes to domestic uses. Rainwater harvested from roofs in houses can be used for multiple household purposes such as gardening, laundry, toilet flushing and in hot water systems, which constitutes about 80% of the water consumed within a residential property (Coombes 2002).

The size of the rainwater collection tank depends on the purposes of water to be used. Also, it varies with the rainfall in the location as well as the roof size (catchment area). Hence, there is a significant difference in the tank size required to meet a similar demand and to provide the same supply reliability. The Water Sensitive Urban Design Manuals provide some guidance when selecting tank sizes for different sates in Australia. Khastagir and Jayasuriya (2010a) presented a methodology and a relationship for optimal sizing of rainwater tanks for Melbourne metropolitan area considering the annual rainfall at the geographic location, the demand for rainwater, the roof area and the desired supply reliability.

However, YourHome (2016) also gives guidelines for selecting rainwater tank sizes for a four-person household with mains water and evenly spread rainfall in the area for different end uses (Table 2).

Table 2. Size of the water tank for different purposes (Source: YourHome 2016)

Rainwater to be used	Target volume of tank (liter)
Toilet flushing and use on a small garden	2,000–3,000
Toilet flushing, clothes washing and small garden	3,000–5,000
The whole of house water supply	5,000-20,000

2.2. Managed Aquifer Recharge (MAR)

The concept of Managed Aquifer Recharge (MAR) is to use the high storage capacity of underground aquifers to remove the need for new surface storages, such as dams. MAR replenishes groundwater aquifers which supply about 20% of total water consumption in Australia. Aquifer storage can be utilized to provide a new ‘reservoir’ or ‘bank’ for water, which can be utilized during droughts or high demand periods.

Common elements of MAR scheme are presented in Figure 2.

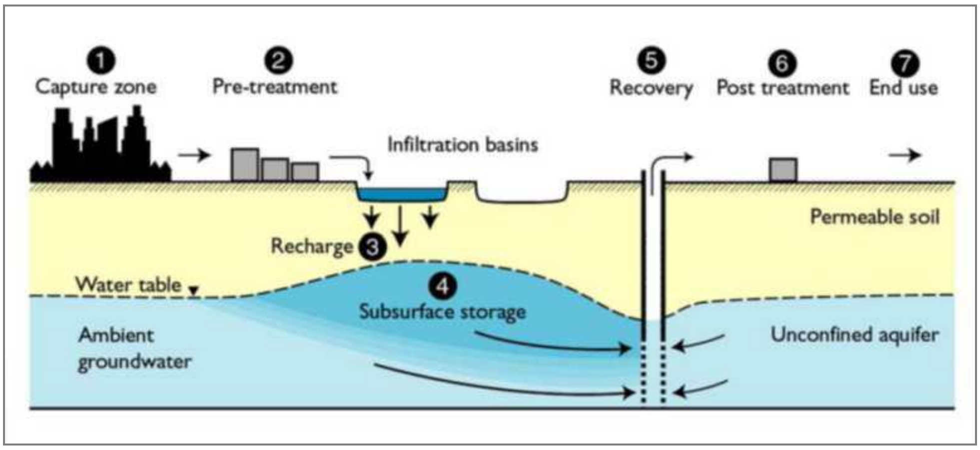

Figure 2. Schematic diagram of a MAR scheme (Source: NWC 2009)

Main sources used in MAR are stormwater harvesting, treated wastewater, excess surface water and potable water (in rare cases). Ideally, water source should be easily available and close to the target aquifer. In Australia, this is commonly known as Aquifer Storage and Recovery (ASR). For ASR, it needs to follow ASR Code which is to ensure the quality of water, protect aquifer and aquitard, and maintain e-flow at downstream surface water (EPA 2004).

MAR could be in two ways: naturally and artificially. The natural process involves filtration of rainwater through the soil profile, pass the vegetation root zone and down to permeable rocks known as aquifers (Figure 2). The artificial process involves gravity feeding or injecting water into a suitable underground aquifer for storage and later reuse. Artificial recharge is mainly to refill depleted underground water supplies. This also recycles the excess stormwater. For artificial aquifer recharge, excess stormwater is usually stored in a wetland, detention pond, dam or tank which is ultimately injected into the aquifer containing groundwater. Before injecting water, it is essential to ensure water quality is to be no worse than the quality of water already in the aquifer (EPA 2004).

In Melbourne, the City West Water (CWW) began investigating the use of Aquifer Storage and Recovery with treated wastewater from the Western Treatment Plant in Melbourne and supplied this to customers in new residential housing estates in Melbourne’s West. The water was injected and stored in the confined Werribee Formation aquifer, a regionally extensive and highly permeable aquifer. CWW believes the aquifer is a better water storage option than tanks or surface dams (CCW 2018).

There are large-scale initiatives in Australia for artificial aquifer recharge. For instance, in South Australia, stormwater has been filtered and cleansed at the Kaurna Park wetlands and stored in aquifers, for use in irrigation (DoAFF 2004). In Western Australia, a project for a groundwater aquifer in Cottesloe is to filter stormwater to replenish the aquifer (DoAFF 2004).

2.3. Detention Basin

A common conventional method of managing stormwater is a stormwater basin. Basins are meant to collect stormwater and they slowly release it at a controlled rate so that downstream areas are not flooded or eroded. While effective for flood control, these practices have significant limitations for water quality treatment and to prevent impacts to stream systems.

Detention basins (DBs) are one type of flood control structure. For instance, the DBs constructed during 1970's-1990's in New South Wales helped to alleviate more frequent flooding. They also have the potential to act as an end-of-the-pipe best management practice (BMP) for water quality control. Sedimentation is the primary pollutant removal mechanism employed by DBs. Total suspended solids (TSS) and associated pollutants such as phosphorus settle out within a DB during the retention time. Sedimentation, if enhanced, can allow DBs to act as an efficient BMP for phosphorus and sediment removal from stormwater (Amina et al. 2014).

3. BENEFITS OF STORMWATER MANAGEMENT

3.1. Flood Prevention

Recycling stormwater reduces the load on stormwater drainage network systems, thus preventing flooding of existing infrastructure by decreasing the peak runoff (Fewkes and Warm 2000). This increases the life cycle of the stormwater management system by extending the service life of the infrastructure assets and decreasing replacement costs (Coombes et al. 2000).

Vargas (2009) found that RWH can reduce the peak flow up to 50% from Penn State University Park, depending on rainfall intensity, duration, and catchment size. Kim *et al.* (2014) have found that the flow and the peak volumes reduced by 18% and 20%, respectively by installing storage tanks of 10 m^3 to a roof area of 100 m^2 in all buildings in a small region. In another study, Palla et al. (2017) found RHW to reduce the peak and volume reduction by 33% and 26% on an average. Zhang et al. (2012) obtained a reduction in the flow volume of 13.9%, 30.2%, and 57.7%, for 207.2 mm, 95.5 mm and 50.0 mm of daily precipitation, respectively. Steffen et al. (2013) evaluated the benefits of RWH systems in 23 cities located in seven different regions of the USA. The results indicated that the rainwater harvesting could reduce the stormwater volume by 17%. Buffon (2010) obtained a maximum average value of 20.3% of flow reduction, based on the number of rainy days.

On the other hand, MAR offers numerous benefits such as storage to improve the security of water supply, natural treatment, a low-cost, low-energy water supply option, replenishing over-exploited aquifers, etc. So far, less than 60 GL/ yr of water is supplied via MAR in Australia, and opportunities are likely to exceed 300 GL/yr (Dillon 2009).

Ferguson (1998) found that detention basins are capable of removing sediments up to 80%. A University of New Hampshire bioretention basin, comprised of a 30" (750 mm) depth of sandy soil, and a 16" (400 mm) depth of gravel, displayed 82% reduction in peak stormwater flow and a 92-minute delay in the storm peak (UNHSC 2007).

3.2. Reduces Depletion of Water Resources

In addition to managing issues with stormwater runoff quantity and peak flow, rainwater harvesting and MAR also reduces demand on public water supplies. This, in turn, reduces the need for construction of a new reservoir and wells (Lallana et al. 2001; Leggett et al. 2001) to meet the demand due to population growth. A study conducted in Southern Australia by Coombes et al. (2001) reported that having rainwater tanks can decrease the demand for potable water by 50%.

3.3. Reducing Pollutant Loads in Receiving Waters

Rainwater collection acts as a buffer for stormwater quality control. A study conducted by Khastagir and Jayasuriya (2010b) showed the effectiveness of rainwater tanks in improving the stormwater runoff quality that will flow on to urban drains. The flow and Total Nitrogen (TN), Total phosphorus (TP) and Total Suspended Solids (TSS) reduced up to 75%, 80%, 93%, and 90% respectively. Above authors identified that the % reduction in water quality parameters increases with the tank size. However, the roof area connected to the tank is inversely proportional to the % reduction in flow, TSS, TP, and TN as the spillage of rainwater from the tank will increase. For DB, Kadlec (2009) has reported that multi batches ponds are more efficient than a single batch detention pond when removing pollutants. A detention basin with six ponds is capable of removing pollutants by 80% whereas a single volume pond can remove only 20% of the pollutant load.

4. COMMUNITY ACCEPTANCE

In Australia, RWH has a high level of community acceptance. Regardless of high capital cost, long payback periods and potential health risks, 26% of the households in Australia own a rainwater tank just because of positive mind set-up of the community (ABS 2013b). Smith (2014) reported that among the users, 47% harvest rainwater to save water and 23% to avoid water restrictions. On the other hand, one driver for developing MAR with recycled water is its high level of public acceptance, especially for drinking water supplies, with respect to other forms of water recycling Dillion et al. (2009). Groundwater recharge with reclaimed water has been practiced since the 1960s in the USA for recovery for non-potable and drinking water supplies.

5. COST INVOLVED IN STORMWATER HARVESTING

Stormwater harvesting is an alternative source of non-potable water source where potable quality water is not required for use. Philp et al. (2008) identified costs of stormwater harvesting systems was a constraint to uptake due to the lack of a method to assess the costs and benefits associated with stormwater recycling systems against conventional systems. According to Philp et al. (2008), Cardno (2006) estimated the cost of supply of harvested stormwater in greenfield developments at between $1.30 and $2.80 per kL. This cost of supply, however, does not take all aspects of the stormwater use system into account especially the water quality benefits. WBM (1999) also concluded stormwater harvesting is not an economically attractive water supply option when considered purely from a cost perspective. However, Philp et al. (2008) concluded that when other issues such as water quality benefits are factored in, the option becomes both environmental and economically attractive.

Khastagir and Jayasuriya (2011) carried out a cost-effectiveness analysis to estimate the payback period, cost-effectiveness ratio and the levelized cost of installing rainwater tanks in different geographical locations with significantly varying mean annual rainfall (MAR). The study showed that the payback period was as low as 14 years for a 5kL tank in an area where the mean annual rainfall is around 1000 mm (discount rate of 10% and an inflation rate of 4.2%). The payback period varied considerably with the tank size, especially in low rainfall areas. The above authors emphasized the importance of selecting an optimum tank size to ensure maximum use of the rainwater to maximize the return on the initial investment. The Australian government encourages rainwater harvesting through offering rebates for installing rainwater tanks in houses.

Rahman et al. (2012) have found that the rainwater harvesting system is not financially viable at the current water prices in Australia, which is highly subsidized and in the current high-interest regime. They have also found on the same study that the capital cost represents the highest component in the whole life cycle cost of a rainwater harvesting system followed by the maintenance cost. Vieira et al. (2014) found in their study that RWH systems with pumps installed are less energy-efficient than conventional systems. Hajani and Rahman (2014) conducted another study on Peri-Urban Regions of Greater Sydney, Australia which was mainly to assess the performance of a rainwater harvesting system of different sizes of water tanks. This study reveals that a 5 kL tank has the highest benefit-cost ratio (ranging from 0.86 to 0.97) among the eight possible tank sizes examined in this study. Sharmeen et al. (2013) had a similar finding from another research on greater Sydney. They found that a 5 kL tank was preferable to 2 kL and 3 kL as that could offer 20% to 64% more water savings.

According to Dillon et al. (2009), ASR and dams generally have similar unit capital costs if the cost of land is neglected. Tanks and earthen impoundments have higher unit capital costs and land area requirements. Taking account of land area, especially where land value is high, such as in or near urban areas (~$1000/m^2 is common in capital cities), ASR has potential to have the least total capital costs per unit of water storage of alternatives given above.

6. CONCLUSION

The stormwater flow rate and volume could be reduced by rainwater harvesting as well as Aquifer Storage and Recovery and Detention Basins. Stormwater management could play a major role in facing water scarcity, protecting flooding and improving water quality . The Australian government has encouraged installing rainwater harvesting technology at household level by providing a rebate to promote RHW as part of its strategy related to water deficiency caused by frequent droughts. Though there are different stormwater technologies in Australia, they are not supplementary to each other; rather an integrated management approach needs to be adopted to manage stormwater properly using all available technologies here in Australia.

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Bank Line Migration Pattern along Padma River in Naria Upazila, Shariatpur District

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Abstract

The Padma River is one of the largest rivers in Bangladesh characterized by frequent bank erosion leading to channel pattern changes and shifting of bank line. In Bangladesh several studies have been conducted the analysis of river bank erosion but there are very few studies in Shariatpur district regarding river bank erosion. This research paper represents channel migration along the Padma River in Naria Upazila of Shariatpur District; one of the most vulnerable regions due to river bank erosion. This study is based on both primary and secondary data. Required data for calculation were collected from Google Earth. Left bank of Padma River along Naria upazila was digitized using Google Earth for the period 1984-2017. Arc-GIS was used for bank line shifting analysis. Perpendicular lines and overall shifting calculation were also done. With the help of Microsoft Excel; calculation of year wise bank line shifting, maximum bank line shifting and eroded areas were done. From this analysis it has been found that river bank erosion in Naria Upazila is increasing at an alarming rate. It means this area is highly vulnerable for river bank erosion.

Key Words: Padma River, River Bank Erosion, Bank line Migration, Shariatpur.

1. INTRODUCTION

People around the globe recognize Bangladesh not only as a country of overpopulation but also as a geographical area prone to all kinds of hazards. River bank erosion is a very quotidian phenomenon among all the hazards in alluvial floodplain regions. It is one of the most frequent but the most unpredictable disaster which causes less loss of lives but severe damages in various fields such as agriculture, infrastructure and livelihood for which it is often referred to the title "silent disaster" (Hassan and Syed 2015).

The main objective of this study are:

- Analysis the pattern of channel migration along the Padma River in Naria Upazila, Shariatpur District.
- Analysis the area destroyed by river bank erosion along the Padma River Naria Upazila, Shariatpur District.

River bank erosions are more devastating and very precipitous in compared to other hazards. The consequences of river bank erosion is rather slow but continuous. In order to redeem the loss caused by the hazard, affected families require a longer period. There are no specific indicators to measure the loss of river bank erosion. Even there is no early warning system to make people conscious before river bank erosion which ultimately results in an instant damage suddenly. Channel migration and severe bank line erosion and shifting also takes place almost every year due to river bank erosion

(Banglapedia 2018). So, channel migration and destroyed area evaluation is needed to be analyzed. Chinmoyee and Dulal (2013) did a research on bank erosion and bank line migration pattern of the SUBANSIRI RIVER in ASSAM using REMOTE SENSING AND GIS TECHNOLOGY. They have used satellite images of IRS LISS-III of 1995 and Landsat 5 TM of 2010. Bank lines of those two years were digitized from the geo referenced satellite imageries using the GIS. Rahman and Islam (2017) stated that the river Padma showed different platform pattern with the changes from meandering to braided, which varied spatially and temporally. So analysing bank erosion pattern by delineation of course migration of the Padma river at Hari-Rampur, they used a time-series of dry season satellite images from the time “1860-2009” to visualize the historical changes in morphology and to provide the basis for the long-term bank erosion process of the Padma River a Sequential left bank line migration. Nazneen (2013) in one of her research found that climate change is likely to play a significant role in riverbank erosion. On an average, due to climate change consequences, the riverbank erosion along the major three rivers will be increased by 13% by 2050 and it will be increased by 18% by 2100. All of the researchers calculated accretion pattern, no one calculates bank line shifting and area destroyed due to river bank erosion using google earth pro and ArcGIS. Every year due to river bank erosion hundreds of lands gets lost. The phenomena is more acute in the Naria Upazila of Shariatpur district. The area is on the critical region of river bank erosion which makes it highly vulnerable but very few researches focused on river bank erosion in this area. Examples regarding river bank erosion induced human displacement in Naria Upazila is very rare whereas the people of this area are continuously suffering due to river bank erosion. In this study the bank line shifting pattern and destroyed area has been estimated in Padma River along Naria Upazila in Shariatpur district.

2. METHODOLOGY

2.1 Study Area

Padma River is the most erosion prone river of Bangladesh and Shariatpur is the most affected area near Padma River. Naria Upazila is considered as the most affected and vulnerable area for river bank erosion of Shariatpur District. The upzila occupies an area of 50306 acres (BBS 2011). It lies between 23º01´ and 23º27´ north latitudes and between 90º13´ and 90º36´ east longitudes. The upazila is bounded on the north by the river Padma and Lohaganj Upazila and Tongibari of Munshiganj Zila, east by Munshiganj Sadar Upazila of Munshiganj Zila and Bhedarganj Upazila, south by Bhedarganj Upazila and Shariatpur Sadar Upazila and west by Shariatpur Sadar Upazila and Janjira Upazila (Figure1).

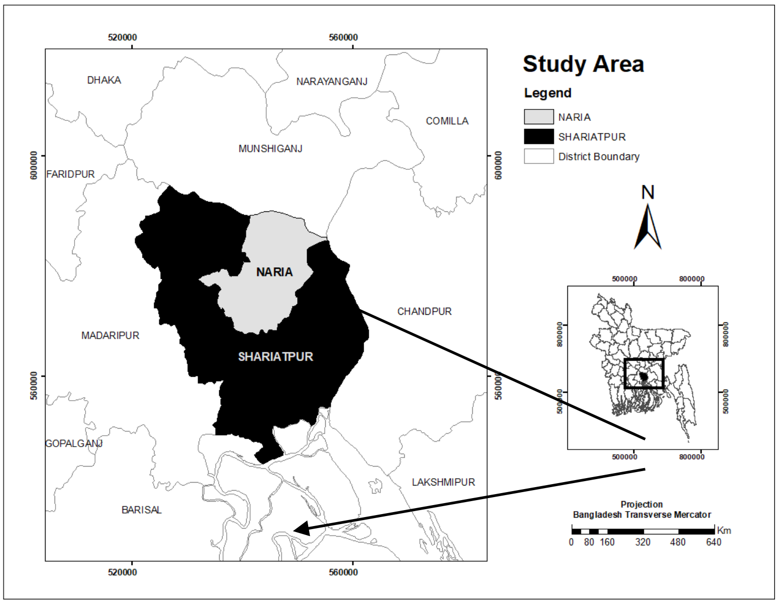

Figure 1: Location Map of Naria Upazila in Shariatpur District

2.2 Data and Material

This study is based on secondary data. Bank lines data were collected from Google Earth pro. Arc-GIS10.3 was used for bank line shifting analysis. With the help of Microsoft Excel 2010; areal information of erosion in different year and channel migration calculated.

2.3 Methods

To fulfil the objectives of the research processing and to calculate the channel migration over the time period of 1984-2017, digitizing the bank lines of the study area along the Padma River using Google Earth pro has been done. Arc Map 10.3 has been used to calculate the channel migration. Microsoft Excel 2010 used for bank line shifting analysis.

2.3.1 Bank line Migration and Eroded Area Calculation

Bank line Creation and Analysis: For this process, bank lines of left bank of Padma River along Naria upazila for 1984-2017 were digitized using Google Earth pro. Perpendicular lines and overall shifting calculation were done in Arc-GIS10.3. Calculation of year wise bank line shifting, maximum bank line shifting and eroded area were done using Microsoft excel 2010.

Key Informant Interview (KII): Key informant interviews usually a qualitative interview. Interviews were taken from many experts like Upazila Mayor, Social welfare Officer, Upazila land officer, Bangla Vision Reporter, Field Organizer, UNO, and Commissioner of 4 No. Ward, Brother of Chairman etc. regarding the scenario of river bank erosion.

3. RESULT AND DISCUSSION

3.1 Bank Line Migration and Eroded Area

Bank lines were created in Google earth pro and then analysis was done by ArcGIS10.3. In Figure 2 bank line migration from 1990 to 1995 has been shown. In the same process bank lines for 1984 to 1989, 1989 to 1990, 1995 to 2004, 2004 to 2010, 2010 to 2017 has been calculated. From Figure 2 erosion of 1990 to 1995 can be easily identified. A huge amount of migration occurred in the bank line due to river bank erosion.

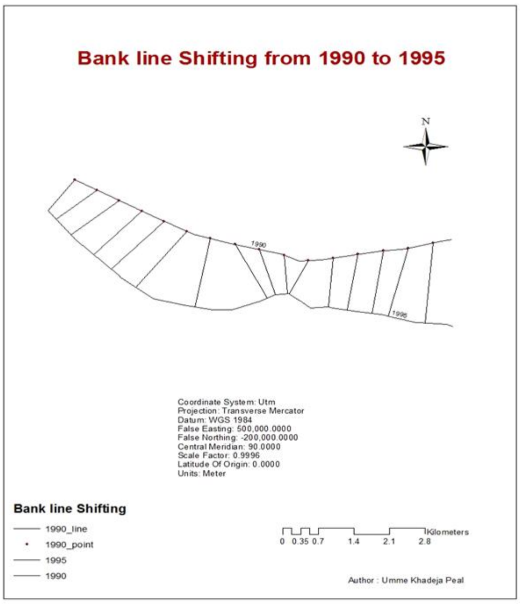

Figure 2: Bank line Migration from 1990 to 1995

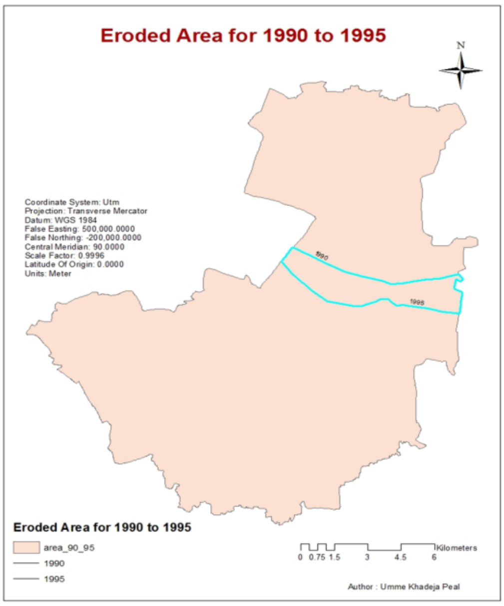

Figure 3: Eroded Area for 199

In Figure 3 eroded area for 1990 to 1995 has been shown. In the same process eroded area for 1984 to 1989, 1989 to 1990, 1995 to 2004, 2004 to 2010, 2010 to 2017 has been calculated. From Figure 3, erosion for 1990 to 1995 can be easily identified. A significant amount of area has been eroded in the period 1990 to 1995 due to river bank erosion.

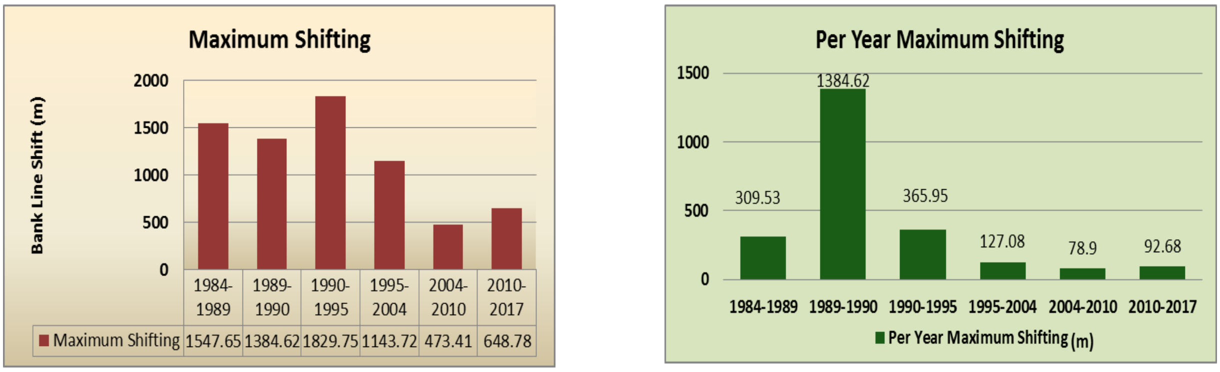

Figure 4: Maximum Shifting

In Figure 4, we can see maximum bank line migration from 1984 to 2017. In the left side of the Figure, it is seen that bank lines of Padma River along Naria Upazila has been shifted in a high rate from 1990 to 1995 which is about 1829.75 meters. In the right side of the Figure, per year maximum shifting has been shown. We can see from the right side of the Figure that huge amount of erosion has occurred in 1989 to 1990. It is seen that left bank of Padma River along Naria upazila has been shifted by 1384.62 meters in just one year.

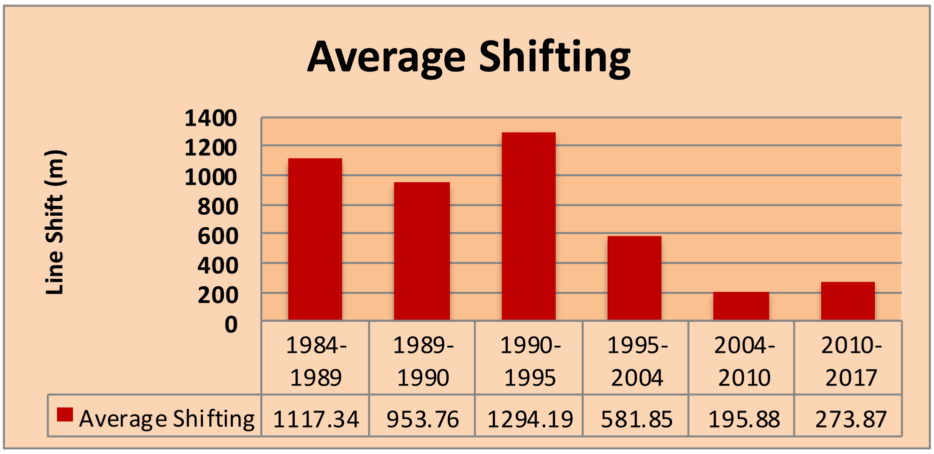

Figure 5: Average Shifting from 1984 to 2017

In Figure 5 Average shifting of Padma River along Naria Upazila for 1984 to 2017 has been indicated. From the Figure, it can be identified that river bank erosion rate was pretty high in 1984 to 2004 but has decreased over 2004 to 2010. Again from 2010 to 2017 the erosion rate is increasing. It is also noticed that the highest river bank erosion occurred in 1989 to 1990 because in just one year the migration was 953.76 meters. But migration for 1990 to 1995 was 1294.19 meter which is the highest among all other durations of the year.

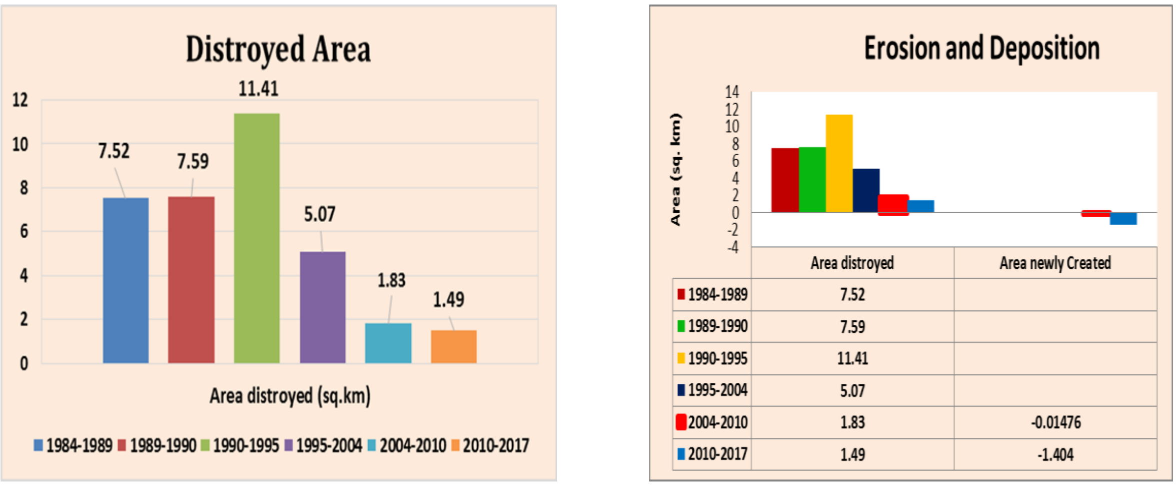

Figure 6: Eroded and deposited Area from 1984 to 2017 (Minus sign (-) means erosion and plus sign (+) means deposition)

In Figure 6, eroded and deposited area for 1984 to 2017 has been shown. From the left side of the Figure, it is seen that high rate of erosion occurred in 1990 to 1995 among all other duration of the year as 11.41 square kilometers have been eroded. Again, in the right side of the Figure, eroded area and deposited area has been shown. Negative sign defines erosion whereas positive sign defines deposition. In the above Figure, it is seen that from 1984 to 2004 only erosion has been occurred but from 2004 to 2017 both erosion and deposition has been occurred. From 2004 to 2010, eroded area was 1.83 square kilometers and deposited area was 0.01476 square kilometers. From 2010 to 2017, eroded area was 1.49 square kilometers and deposited area was 1.404 square kilometers.

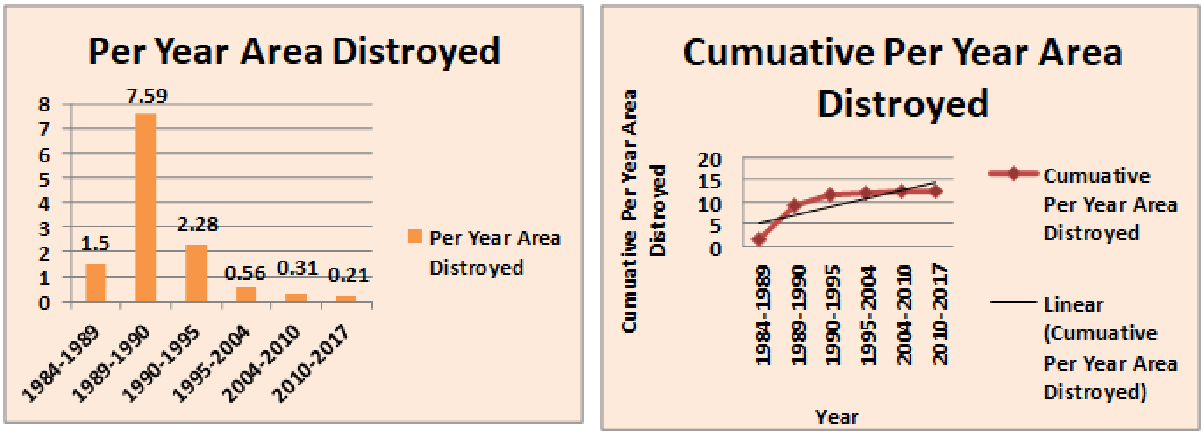

Figure 7: Per Year Area Erosion

In Figure 7, per year erosion has been shown. In the left side of the Figure, it can be identified from per year eroded area calculation that the highest erosion occurs in 1989 to 1990. Again, in the right side of the Figure, cumulative per year erosion has been shown. It is seen that overall erosion rate is on the rise. From the KII, it is also found that river bank erosion is increasing in the recent years. 10 years ago, river bank erosion rate was also very high.

5. CONCLUSION

Bangladesh being a riverine country comprising of numerous rivers, it can be expected that river bank erosion is likely to affect in any region we think about. But areas near rivers are likely to be more prone than the areas far from the river. Again, the people are highly vulnerable due to lack of education & awareness. Also, there is less development issues mostly because of less focus being given in these not so popular regions. The study was mainly focused on bank line migration pattern. It is found from the study that river bank erosion rate is significant here which indicates the area is highly vulnerable for river bank erosion in future. If not controlled in due time, the consequences may become vaster in such unfocused region (Naria Upazila). As a result, the government should focus on required adequate measures & encourage more developments not only in the urban areas but also in this unknown region to intervene in the ongoing devastating consequences of river bank erosion until it is too late.

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Assessment of Quantity and Quality of Condensate Water from Air Conditioners

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Abstract

The demand of fresh water is increasing day by day in big cities especially for Dhaka city where the groundwater table depletion rate is about 2 m to 3 m per year. Air Conditioning (AC) condensate water could be explored as an alternative water source, which could be considered within the global calculations of the water supply. Recovering of the Air Conditioning (AC) condensate water has been recently developed as a new technology which efficiently contributed to the water resource management. The objective of this study is to better understand the possible reuse of condensate water from air conditioning systems. The aim of this study was mainly to evaluate this water source in terms of quality and quantity. The study was conducted on 19 air conditioning systems of various types (such as variation in cooling capacity, variation in brand of AC) at various locations in Gazipur and Dhaka cities (13 in Gazipur and 6 in Dhaka). Sample AC water was collected, and its volume was measured with time. Various water quality parameter tests were conducted on collected sample. This study obtained the average concentration of condensate water from air conditioners for Iron, Copper, Lead, Conductivity, Turbidity, Chloride, pH, Hardness, Manganese, and TDS were about 0.02 ,0.006, 0 mg/L, 30.6 µs/cm,1.11 NTU, 10.74 mg/L, 7.60, 54.11 mg/L as $CaCO_3$, 0.0012 mg/L and 25.04 mg/L respectively. It was also found that the condensate water was good, which satisfied the Bangladesh standards for drinking as well as WHO standards. Average discharge rate of water per ton was observed 1.10 L/hour. Ultimately, this study disclosed that the reuse of this condensate water has no potential risk for drinking, washing and other household purposes, irrigation and fisheries purposes.

Key words: AC, Condensate, Quality, Quantity, Reuse

1. INTRODUCTION

Rapid population growth in urban centers is creating enormous pressure on their water supplies in the context of the scarcity of suitable freshwater resources and the ever- increasing costs of the water supply systems. The problem is acute for Dhaka city.

Water supply problem in some newly developed areas and some areas of the old city is becoming more acute, because the existing facility of DWASA cannot keep pace with the growing demand for safe water supply. Both quantity of water produced and water distribution facility are inadequate to serve the present population of the city. The magnitude of the problem is greater during the extreme dry and hot season. Most of the consumers do not get the required quantity of water.

The daily water demand for the city of about 9 million people is 165 crore liter at present and will rise up to about 2.5 times by 2030 (IWM 2007). DWASA demands that it produces 144 crore liter daily

(DWASA, 2005). Currently, the physical leakage in the water distribution system stands between 30-40% (IWM 2007). The water demand at the drought season grows roughly by 25%. Then the shortage becomes about 100-120 crore liter daily. In the last 5 years, DWASA has managed to increase the daily production by 3.5 crore by installing some deep tubewells. Due to poor recharge of the aquifers of the city, heavy abstraction of the groundwater is causing continuous declination at an alarming rate. As a result, many deep tubewells have become non-functional. DWASA is planning to augment the water supply by implementing the second phase of Saidabad Surface Water Treatment Plant and by establishing well fields outside the metropolitan area. Even after implementation of these programs, water crisis will continue.

In Bangladesh, the need for water is increasing with the current political situation, population growth, and high rate of urbanization. The depletion of fresh water resources keeps continuing as the demand for drinking, household works, irrigation, industrial and municipal water keeps escalating. In big cities of Bangladesh, the available present conventional water resources are hardly sufficient to be maintained for the current quality of citizens‟ life and economy. The majority of the supplied fresh water in Dhaka and other cities come from scarce groundwater resources. This places the future population and its associated water demands, under severe pressure with these limited groundwater reserves (Al-Salaymeh et al 2011). Exploring alternative sources of water play a vital role in water supply, when fresh water including the surface and the ground water become limited. Therefore, saving, reusing/recycling/recovering and developing new water technologies will improve the water resources management.

Dhaka city water supply authority (Dhaka WASA) is therefore putting more emphasis on use of surface water sources for potable water supply. However, widespread pollution of surface water bodies surrounding Dhaka is a major obstacle in utilization of these water sources (Alam et al. 2012). The situation is similar in many major cities of Bangladesh. In this situation, rainwater harvesting and reuse of grey water are gaining importance for sustainable water supply. However, use of condensate water generated from air conditioning system has not received much attention, although condensate water has been successfully recycled in commercial and public buildings in a number of countries (Bryant and Ahmed, 2008), (Guz 2005). Due to hot and humid weather, significant quantity of condensate water is expected to be generated from air conditioning systems in Bangladesh, which can be used in different ways. Condensate water harvesting is one of the main approaches that could enhance efficiently the water management that contributes in stabling the Bangladesh convoluted context. Also, drinking water source and other household purposes water source may be generated by reusing AC water if possible. This study focuses on estimation of condensate water quantity of water produced from different types of air conditioners and quality analysis of discharged water from this source.

The overall objective of this study was to find out Air Conditioning (AC) condensate water as a new source of fresh water and some specific aims of the study were to determine the quantity of water produced from different types of air conditioning system; to assess the AC water quality and to identify the possible reuse of AC water.

2. METHODOLOGY

The overall study method used in this study was based on an interdisciplinary and integrated approach comprises of a combination of directions. This study was both desk-based and field based. Scholarly articles and books consist of literature studies of published materials and data in line with the area of interest were reviewed and considered as secondary source of information. The secondary sources were concerning the condensate water assessments, water quality assessments, water standards, and generated water quantities produced by cooling systems. In addition, the primary source of data on condensate water quality and quantity was collected through sampling campaigns in Gazipur summer time. Semi-structured Interviews were also carried out with the main actors in the air conditioning system as an aid to reveal essential primary data.

A questionnaire survey was conducted towards19 users, to restate selected results and to provide the additional user perception on safety aspects to the discussion of water conservation. Figure 1 shows the key steps of the study.

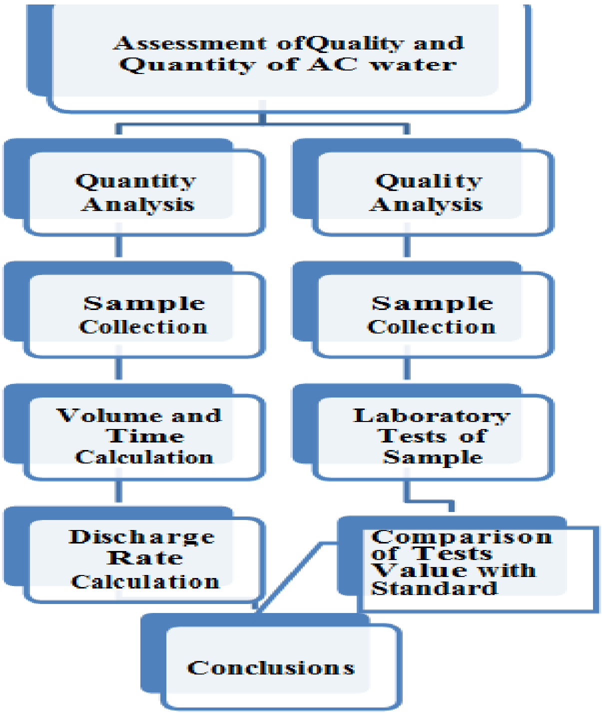

Figure 1. Key steps of the research process

2.1 Data and AC Water Collection

Secondary data was primarily collected through desk-based study, where data was obtained from electronic databases, libraries, and scholarly articles and books concerning the condensate water quality and previous experiments quantifying the volume of this water source.

The literature review was designed based on the exploration of the current knowledge including substantive findings and strategies such as national frameworks developed worldwide. This process also outlook the guidelines set the water balance through explaining the baseline water footprint and in relation to the condensate water collection. In order to give a handy guide in the completion of this study, the methodology followed in proceeding with the literature review, was reviewing the baseline as well as the past theoretical and methodological technical contributions which were implemented particularly to serve the objective of condensate water efficiency. Air Conditioning Condensate Water was collected in the plastic bottle shown in Figure 2.

Figure 2. Collection of Air Conditioning Condensate Water

2.2 Water Quality Analysis

The prime parameters which were tested for Condensate Water quality analysis were Turbidity, Copper concentration, Iron concentration, Lead concentration, Manganese concentration, Conductivity, Chloride concentration, pH, Hardness, TDS etc.

The quality parameter tests were performed by using Hach DR 2800 UV Spectrophotometer, DRB 2000 Reactor, pH and TDS meter, Turbidity meter (Hach 2100Q) in the environmental engineering laboratory, Department of Civil Engineering, DUET, Gazipur.

2.3 Water Quantity Assessment

In order to formulate an overview about the condensate water yield generated from the air conditioning systems, a quantity assessment process was conducted in the two cities of Dhaka and Gazipur. Therefore, similar to the quality sampling campaign presented in the previous section, water samples were also collected following a systematic quantifying method:

Samples were collected from different kinds and types of locations including, commercial building, residential households and building offices.

From the two locations of Dhaka and Gazipur about 19 samples of Air Conditioning Condensate Water capacity plastic bottles were collected in two liter capacity plastic bottles. Table 3.1 shows the number of the collected samples from different capacities of air conditioning units.

The collected water samples were accompanied by the filling an appropriate form, clearly indicates: Location, sample site, type, date, and time, the capacity air conditioning unit (1 Ton, 1.5 Ton, 2 Ton, and 5 Ton).

Table 1. Condensate Water Quality Samples

City	1 ton	1.5 ton	2 ton	5 ton
Dhaka	-	1	1	4
Gazipur	4	6	3	-
Total	4	7	4	4

3. RESULTS AND DISCUSSIONS

This section discusses the results of the generated condensate water quality and quantity analysis which was carried out for the Dhaka and Gazipur cities.

3.1 Condensate Water Quality Assessment and Evaluation with Standard

The primary purpose of the condensate water quality assessment is to identify a specific understanding of the elements that could occur in this source of water and are of concern to public health. The results are presented in Table 2, were undergone to detect the condensate water quality in regard to the selected parameters. The selected parameters are necessary for water quality monitoring programs. The values of the tested parameters for the condensate water generated by the air conditioning units are presenting the results of the tests for the 19 samples (A1-C5), for the main chemical parameters. Table 2 shows the detailed data analysis for the condensate water tests and Table 3 shows the evaluation status with drinking water standards (WHO and ECR 1997).

Table 2. Chemical and Physical quality Analysis for the condensate water samples

SL. Id	Iron (mg/L)	Copper (mg/L)	Lead (mg/L)	Conductivity (µs/cm)	Turbidity (NTU)	Chloride (mg/ L)	pH	Hardness (mg/L)	Manganese (mg/L)	TDS (mg/L)
A1	0.01	nil	nil	22.2	1.05	7	8.02	20	0.004	11.2
A2	nil	nil	nil	44.8	0.56	20	7.50	160	nil	25.4
A3	nil	0.05	nil	24.8	1.22	18	7.40	160	nil	1.40
A4	nil	nil	nil	51.9	0.59	10	7.40	160	nil	25.9
A5	0.03	nil	nil	26.9	1.69	8	7.60	32	nil	34
A6	0.01	nil	nil	22.4	1.35	10	7.50	60	0.002	14.2
A7	0.02	nil	nil	26.2	1.03	15	8.05	30	nil	12.2
B1	0.04	nil	nil	42.1	1.68	10	7.30	22	nil	52
B2	0.03	0.06	nil	25.4	0.82	10	7.40	16	nil	50
B3	0.06	nil	nil	59.6	1.69	07	6.53	16	nil	87
B4	0.02	nil	nil	17.12	1.39	13	7.50	22	nil	22
B5	0.02	nil	nil	28.2	1.08	12	7.80	60	0.003	18.2
B6	nil	nil	nil	15.2	1.15	08	8.01	40	0.001	16.2
B7	0.02	nil	nil	18.2	1.25	10	7.80	30	0.001	16.4
C1	nil	nil	nil	28.3	0.89	08	8.01	50	0.002	19.1
C2	0.01	nil	nil	22.2	0.82	10	7.50	60	0.001	18.6
C3	0.01	nil	nil	59.6	1.05	07	8.04	30	0.004	17.3
C4	0.03	nil	nil	13.7	0.82	09	7.30	20	nil	17
C5	0.01	nil	nil	33.2	0.87	12	7.50	40	0.002	17.60

The concentration ranges for 19 condensate water sample for Iron, Copper, Lead, Conductivity, Turbidity, Chloride, pH, Hardness, Manganese, and TDS were about 0-0.06 mg/L, 0-0.06, 0-0, 13.7–59.6 µs/cm,0.56 – 1.69 NTU, 7 – 20 mg/L, 6.53 – 8.05, 16 – 160 mg/L as $CaCO_3$, 0 - 0.004 mg/L and 1.4 – 87 mg/L. Reflecting the heavy metals occurrence in the collected condensate water, no particular risk was concluded for the drinking water and irrigation water too. It was also found that the condensate water was good, which satisfied the Bangladesh standards for drinking water as well as

WHO standard. Ultimately, this study revealed that the reuse of this condensate water has no potential risk for drinking, washing and other household purposes, irrigation and fisheries purposes.

Table 3. Chemical and Physical qualities of condensate water and evaluation with drinking water standard

Parameters	Reading Ranges	Reading Average	WHO (2004)	ECR, 1997	Compliance Achieved
Iron Concentration	0-0.06 mg/L	0.02	0.3 mg/L	0.3-1 mg/L	Ok
Copper Concentration	0-0.06 mg/L	0.006	2 mg/L	1 mg/L	Ok
Lead Concentration	0	0	0.01 mg/L	0.05 mg/L	Ok
Conductivity	13.7–59.6 µs/cm	30.6 µs/cm	-	-	Ok
Turbidity	0.56 – 1.69 NTU	1.11 NTU	10 NTU	5 NTU	Ok
Chloride	7 – 20 mg/L	10.74 mg/L	250 mg/L	150-600 mg/L	Ok
pH	6.53 – 8.05	7.60	6.5-8.5	6.5-8.5	Ok
Hardness	16 – 160 mg/L as $CaCO_3$	54.11 mg/L as $CaCO_3$	500 mg/L as $CaCO_3$	200-500 mg/L as $CaCO_3$	Ok
Manganese	0 - 0.004 mg/L	0.0012 mg/L	0.4 mg/L	0.1 mg/L	Ok
TDS	1.4 – 87 mg/L	25.04 mg/L	1000 mg/L	1000 mg/L	Ok

3.2 Condensate Water Quantity Assessment

In this section, it may be represented volume and discharge rate of air conditioning condensate water from various type of AC and their variations with different parameters. As explained previously, different types of targeted locations were visited in Dhaka and Gazipur cities, where condensate water quantities were observed with respect to time. The commonly used air conditioning split units are with the capacities of 1, 1.5, 2 and 5 tons.

Table 4. Shows volume and discharge rate of condensate water with collection time for various types of AC.

Sample Id.	AC Capacity (tons)	Collection Time (hr.)	Volume of Water (Liter)	Discharge Rate (L/hr.)	Remarks
A1	1.0	1 .00	1.28	1.28	After 5 minutes discharge started
A2	1.5	0.583	2.00	3.53	After 4 minutes discharge started
A3	2.0	0.45	2.00	4.44	After 3 minutes discharge started
A4	1.5	0.30	0.62	2.07	After 4 minutes discharge started
A5	1 .0	3.70	2.00	0.54	After 8 minutes discharge started
A6	1.5	2.50	2.00	0.80	After 7 minutes discharge started

A7	1.0	3.60	2.00	0.55	After 8 minutes discharge started
B1	2.0	0.30	1.00	3.75	After 3 minutes discharge started
B2	1.5	0.70	1.00	1.43	After 4 minutes discharge started
B3	5.0	0.38	1.50	3.92	After 5 minutes discharge started
B4	1.0	0.33	1.20	3.64	After 4 minutes discharge started
B5	5.0	0.38	1.50	3.94	After 6 minutes discharge started
B6	5.0	0.26	1.00	3.92	After 5 minutes discharge started
B7	5.0	0.31	1.20	3.93	After 6 minutes discharge started
C1	1.5	0.33	0.50	1.52	After 2.5 minutes discharge started
C2	1.5	0.33	0.47	1.44	After 2.5 minutes discharge started
C3	1.5	0.33	0.48	1.45	After 2.5 minutes discharge started
C4	2.0	0.93	2.00	2.15	After 3 minutes discharge started
C5	2.0	0.91	2.00	2.20	After 3 minutes discharge started

Average of discharge rate per ton was computed using this arithmetical mean formula "Σ (discharge rate)/Σ cooling capacity" and the obtained result was 1.10 L/hr. After observing the data from Table 4 required plotting for discharge rate vs. other parameters were plotted because of perceiving air conditioning condensate water discharge behavior with respect to other parameters. Figure 3 it can be shows the variation of discharge rate with cooling capacity of AC. It may be revealed that discharge rate increases with an increase in cooling capacity.

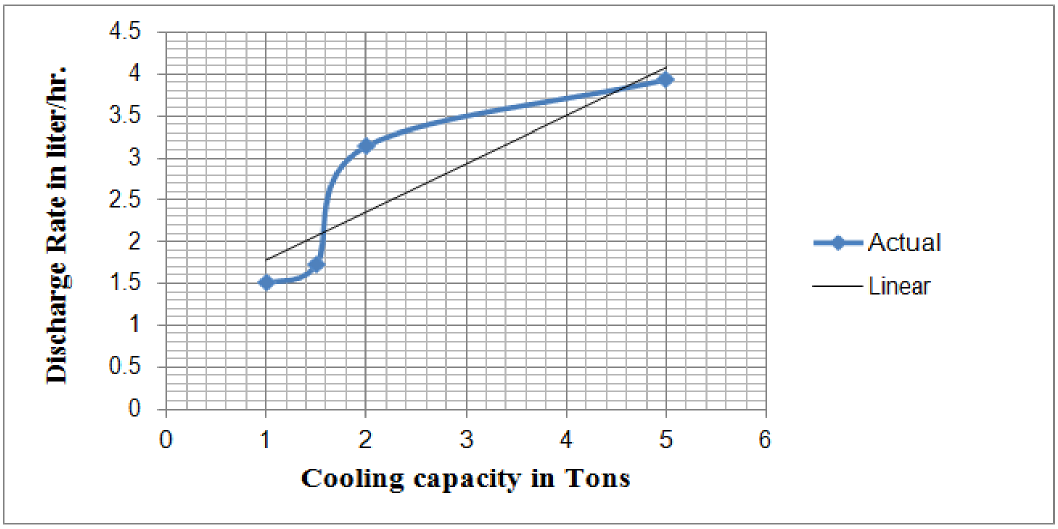

Figure 3. Variation in Discharge rate with cooling capacity of AC

Figure 4 represents the variation of discharge rate of C1 AC condensate water with collection time. This study observed that the initiating discharge of condensate water from AC took 2.5 minutes after starting AC. After that point discharge rate was increased linearly with collection time. After 20 minutes discharge rate remains constant.

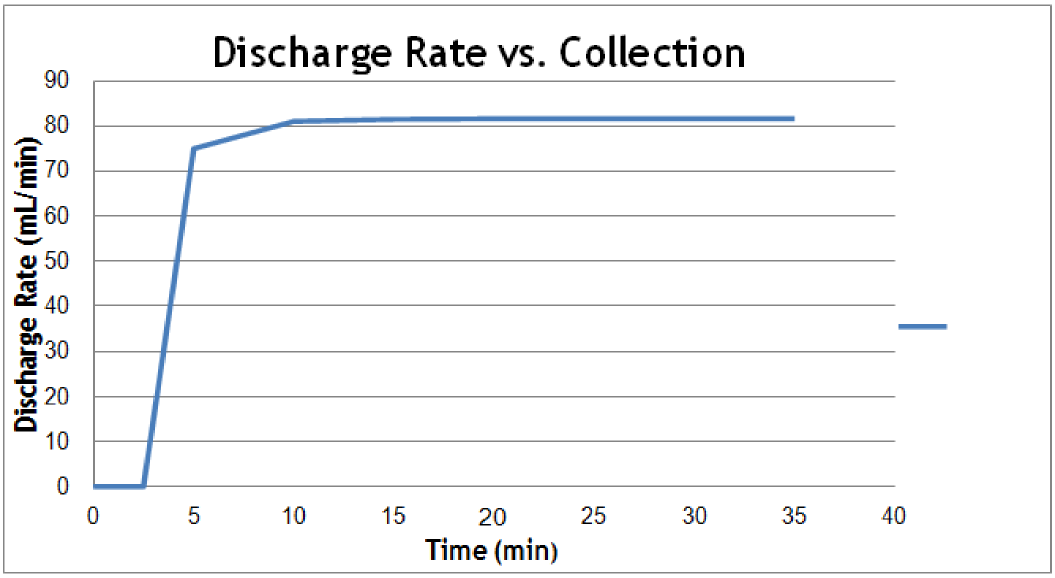

Figure 4: Relation between Discharge Rate and collection time for (C1 Sample)

Figure 5 shows the relation between cumulative discharged in volume against time. At 35 minutes, the cumulative discharge was 3500 ml. From the slope of tangent, the discharge in volume may be 153.18 liter for 24 hours collection time. To prevent dehydration, we need to drink adequate amounts of water. There are many different opinions on how much water should be drinking every day. Health authorities commonly recommend eight -ounce glasses, which equals about 2 liters, or half a gallon. Therefore, 1 day collected water from C1 sample may be enough for 76 adult peoples for drinking purposes.

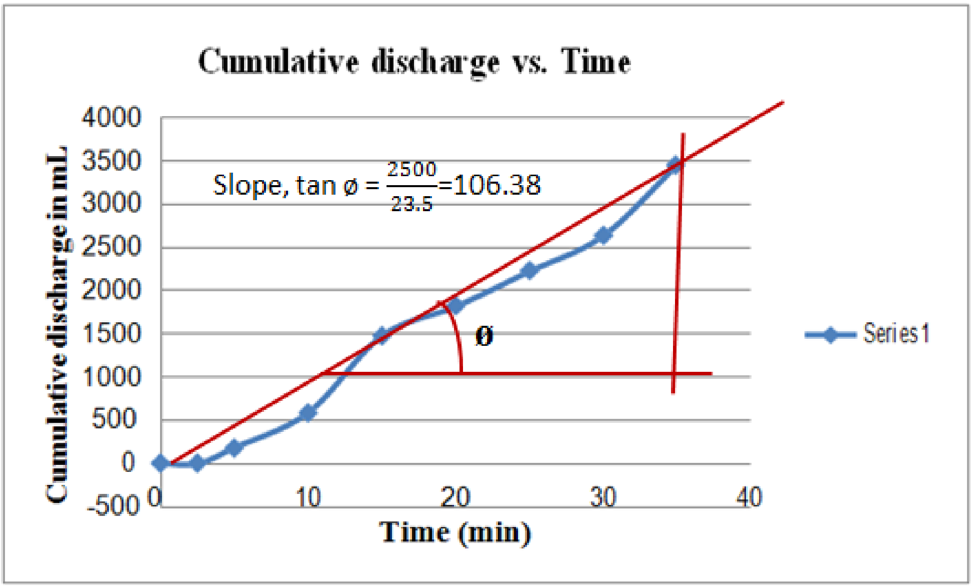

Figure 5. Relation between Cumulative discharged volume with collection time for (C1 Sample)

Figure 6 represents the variation in discharge with the variation in AC brands. The maximum discharge was observed in Panasonic brand (3.64 L/hr.) than Jamuna, Walton, General and Transtec.

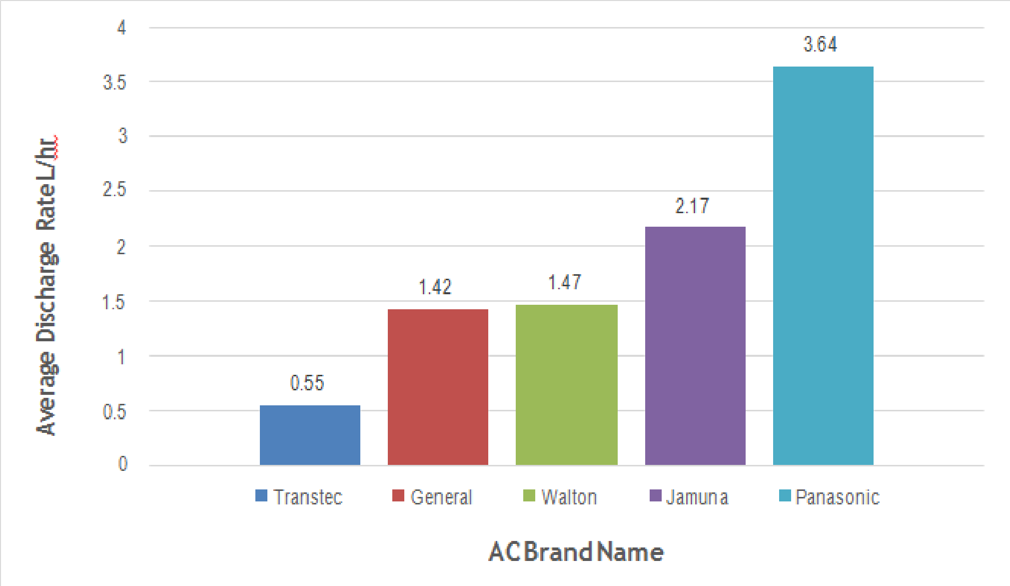

Figure 6. Variations in Discharge Rate with the variation in AC brands

4. CONCLUSIONS

In Bangladesh, almost in all modern buildings, air conditioning cooling systems are used to provide conditioned indoor environment. These cooling systems generate significant and under-utilized source of fresh water. This source of water is mostly drained to the streets and sewage systems. In light of the water resources scarcity in Bangladesh, the condensate water could be considered as an alternative source of water, which plays a vital role in water supply, when fresh water become limited.

Major conclusions from this study may be summarized as follows:

i. The average concentration of condensate water from air conditioners for Iron, Copper, Lead, Conductivity, Turbidity, Chloride, pH, Hardness, Manganese, and TDS were about 0.02 ,0.006, 0 mg/L, 30.6 µs/cm,1.11 NTU, 10.74 mg/L, 7.60, 54.11 mg/L as $CaCO_3$, 0.0012 mg/L and 25.04 mg/L respectively.

ii. It was also found that the condensate water was good, which satisfied the Bangladesh standards for drinking as well as WHO standards.

iii. Discharge rate varies with different variables such as: Cooling Capacity of AC, Time duration after starting AC, AC Brands etc.

iv. Average discharge rate of water per ton was observed 1.10 L/hour

v. Ultimately, this study disclosed that the reuse of this condensate water has no potential risk for drinking, washing and other household purposes, irrigation and fisheries purposes.

ACKNOWLEDGEMENT

Authors would like to express our sincere gratitude to our supervisor, Dr. Md. Akramul Alam, Professor, Department of Civil Engineering, DUET, for giving us an opportunity to work on such an important topic. His continuous guidance, important suggestion and invaluable acumen are greatly acknowledged. His keen interest on the topic and enthusiastic support on my effort was a source of inspiration to carry out the study. Thanks to the technical staff of the Environmental Engineering Laboratory, DUET, for their assistance and cooperation during the study.

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Grey Water Treatment Using Glass Filter Media

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Abstract

The water demand is increasing due to rise in the world's population which also generates too much grey water. Recycling grey water can be a significant source of water that could potentially cover the demand portion of water. The main objective of the study was treatment of grey water using glass filter media and its performance observation. In this study Tempered Glass (TG) filter media and Soda Lime Silicate (SLS) glass filter media were used. The grey water samples have been collected from DUET student's Hall and teacher's quarter. After filtering grey water samples, efficiencies of different filter media were observed and compared with BD standard (ECR,1997) and WHO standard. The removal efficiencies were obtained 95% for color, 89% for chloride, 95% for COD, 93% for BOD5, 44% for Hardness, 96% for turbidity and 16% for TSS by using SLS filter media. When TG filter media was used, removal efficiencies was obtained 88% for color, 21% for chloride, 74% for COD, 88% for BOD, 45% for Hardness, 92% for turbidity and 23% for TSS. This study revealed that grey water treatment process using SLS glass filter could be more effective for removal color, BOD, COD, Turbidity, hardness than TG glass filter media. It has also been observed that treated parameters value with in safe limit except BOD, COD and TSS according to WHO guide line and Bangladesh Standards for drinking water parameter.

Key words: Grey water, Filter, Glass, Quality

1. INTRODUCTION

Bangladesh is world's 8th (eighth) most populous country with residents of more than 156 million people in an area of 56977 sq. mile (BBS, 2014). The WHO estimates that 97% of the people of Bangladesh have access to water and only 40% have proper sanitation. With a staggering, approximately 60% of the population has to endure unsafe drinking water, the nation is in danger. The statistics even did not reflect scenario. People of many of Bangladesh suffer from water crisis all the year around. With the bulging of the population, demand for water is growing fast but the supply of water does not increase accordingly. The sources of freshwater used today are in threats due to over exploitation and pollutants load from untreated discharge of wastes from different sources. To reduce the pressure on freshwater sources and stop using freshwater where it may not mandatory, such as for irrigation, fish culture gardening, recreation, etc., waste water use or reuse can be an attractive solution (Al-Jayyousie 2003; Redwood 2007).

Water is becoming a rare resource in the world as well as Bangladesh. It is therefore essential to reduce surface and ground water use in all sectors of consumption, to substitute fresh water with alternative water resources and to optimize water use efficiency through reuse options.

These alternative resources include rainwater and grey water. Grey water is commonly defined as wastewater that is discharged from a house, excluding black water (toilet water). This includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines. It commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair etc. (Redwood 2007). Grey water makes up the largest proportion of the total wastewater flow from households in terms of volume. Typically, 50-80% of the household wastewater is grey water. If a composting toilet is also used, then 100% of the household wastewater is grey water (Birks and Hills 2007).In terms of basic water quality parameters for non-potable uses (TSS, TDS, BOD, Turbidity, FC), Grey water is considered to be comparable to a low or medium grade wastewater. For the purpose of successful implementation of grey water recycling different countries of the world have already started the quantification and characterization of grey water. Due to rapid industrialization and development, there is an increased opportunity within wastewater, as grey water reuse in developing countries such as Bangladesh. Consequent to rapid growth in population and increasing water demand, stress on water resources in Bangladesh is increasing and per capita water availability is reducing day by day. This study focuses on grey water characterization, treatment and have been changed the water quality parameters. The overall objective of the study was treatment of grey water using glass filter media. Specific objectives of the study:

- To assess the removal efficiencies of Color, Turbidity, pH, COD, BOD, DO, TS, TDS, TSS, Alkalinity, Hardness, Chloride etc. of grey water using recycling glass filter media and sand filter media.
- To evaluate which filter media is more effective for grey water treatment.
- To compare the result with the standard value of water quality.

This study observed that grey water treatment process using SLS glass filter could be more effective for removal color, BOD, COD, Turbidity, hardness than TG glass filter media. It has also been disclosed that treated parameters value with in safe limit except BOD, COD and TSS according to WHO guide line and Bangladesh Standards for drinking water parameter.

2. MATERIALS AND METHODOLOGY

In this study two types of filter media, one glass filter media and other one sand filter media was used to observe the comparative treatment efficiency of grey water. Glass filter media were two types one Soda Lime Silicate (SLS) another Tempered Glass (TG). The whole processes are shown in figure below.

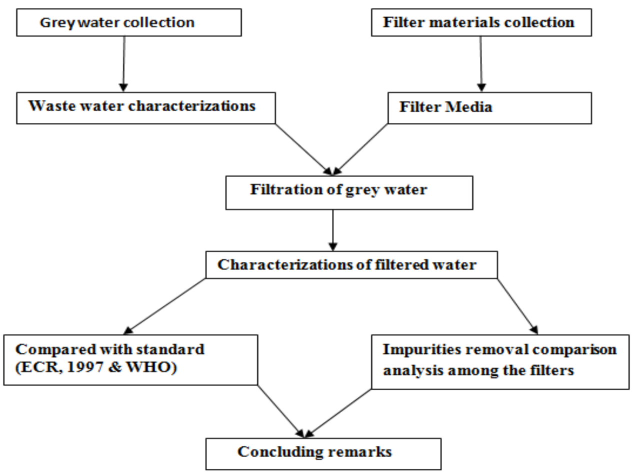


Figure 1. Showing methodology of the study

2.1 Preparation of Glass Filter Media

2.1.1 Glass Collection and Cleaning

Recycled glass was collected from local outlets (Joydevpur market, Gazipur). The collected waste glasses were soaked in water in a large sink for cleaning till the complete removal of impurities in visual observation.

2.1.2 Grinding

The different colored cleaned glasses were placed inside a thick plastic bag separately and tied with rope. Then the glass was crushed with a hammer by impacting the bag. The bigger pieces of glass (approximately size>4.75 mm) were used for grinding. The glass collector bucket was cleaned and hung within the grinder carefully. Then the crushed glass was stored for sieving.

2.1.3 Sieve Analysis of Glass

The glass particles were sieved using 4.75 mm, 2.36mm, 1.18 mm, 600µmm, 300 µmm and, 150 µmm mesh sieves. Sieves were made of brass and the mesh was made of stainless steel. Sieving was done manually (Shown in figure below). The sieve was covered with a lid to avoid dust formation. Glass sizes from 4 mm to s<150 µmm were separated for experimental use.

2.1.4 Preparing of Glass Filter Media

The sieving of glass has been arranged in specific layers as shown in Table 1. Glass particles (4.75mm-2.36mm) sizes were used at bottom of filter bed with 4-inch thickness. Glass particles (300µmm-150µmm) sizes were used at top of filter bed with 2-inch thickness. The glass particle sizes with (600µmm-300µmm), (1.18mm-600µmm) and (2.36mm-1.18mm) were used for the thickness 2, 2, and 3 inch respectively in the intermediate position of filter bed. Total depth of filter bed was 14 inches. All the filter materials for several layers were filled with normal compaction. Figure 2 shows the prepared filter and 3 shows the different components of Glass filter.

Table 1. Different layers and thickness of glass filter

Name of Layer	Grading of material	Thickness of Layer(inch)
1^{st}	Free board	2
2^{nd}	300µmm-150µmm	2
3^{rd}	600µmm-300µmm	2
4^{th}	1.18mm-600µmm	3
5^{th}	2.36mm-1.18mm	3
6^{th}	4.75mm-2.36mm	4

Figure 2. Prepared glass and sand filter media

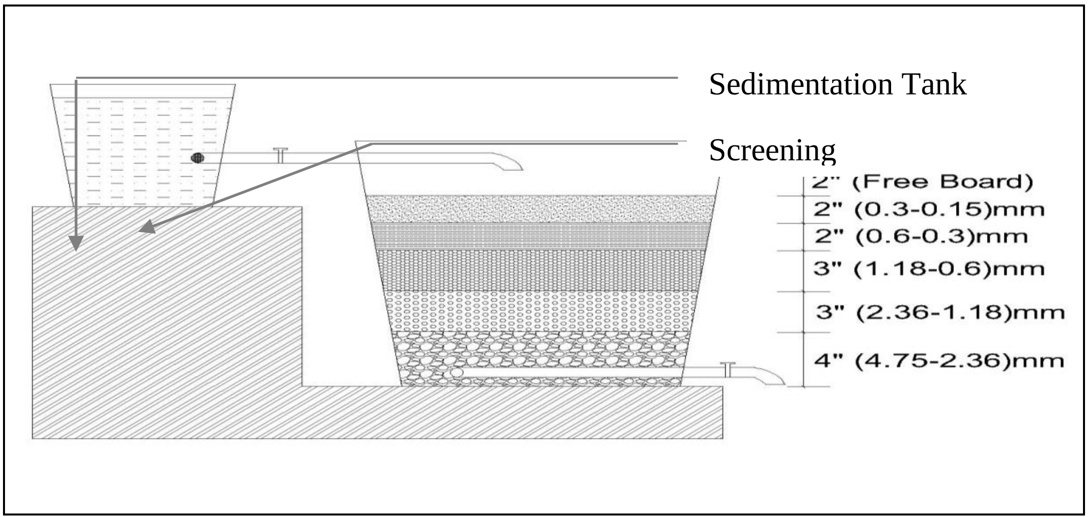


Figure 3. Showing various components of glass filter media

2.2 Preparation of Sand Filter Media

2.2.1 Sand Collection and Cleaning

Fine sand, Coarse sand and Gravel were collected from local rivers. The collected sand was cleaned properly by using ground water.

2.2.2 Sieve Analysis of Sand

The sand was sieved using 4.75 mm, 2.36mm, 1.18 mm, 600µmm, 300 µmm and, 150 µmm mesh sieves. Sand sizes from 4.75 mm to <150 µmm were separated for experimental use.

2.2.3 Preparation of Sand Filter

The sieving of glass has been arranged in specific layers as shown in Table 2. Sand filter was prepared as the similar process of Glass filter, which already described.

Table 2: Different grading layer and thickness of sand filter

Name of Layer	Grading of material	Thickness of Layer(inch)
1st	Free board	2
2nd	300µmm-150µmm	2
3rd	600µmm-300µmm	2
4th	1.18mm-600µmm	3
5th	2.36mm-1.18mm	3
6th	4.75mm-2.36mm	4

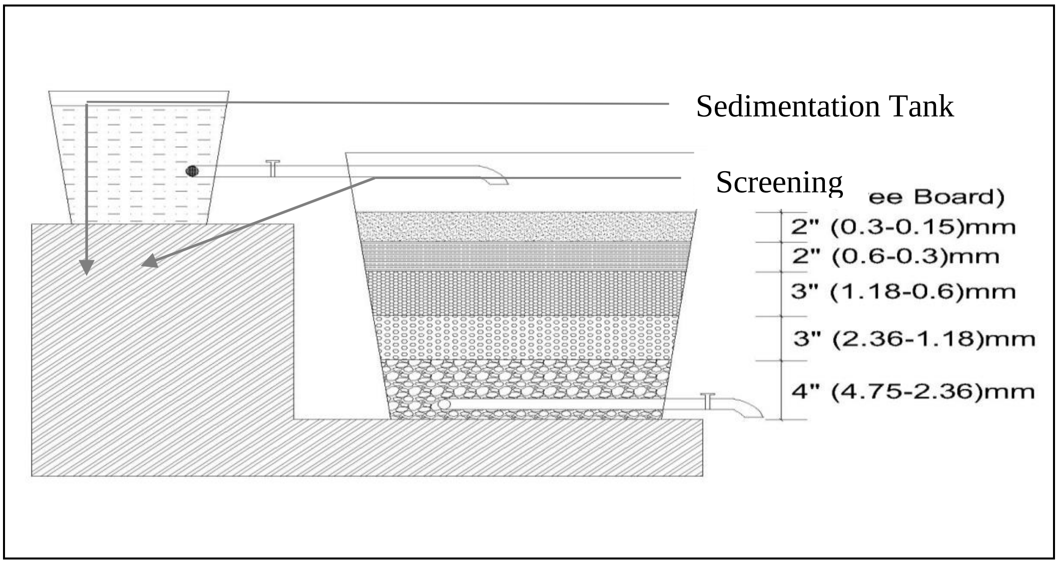


Figure 4. Graded sand filter media

2.3 Grey water collection, characterizations and filtration

2.3.1 Grey water Collection

Different types of grey water samples were collected from Teacher's Quarter (TQ) and Student Hall (SH) of Dhaka University of Engineering and Technology, Gazipur. The sample was collected in plastic bottle after cleaning with distilled water to avoid contamination. The samples were collected from outlet drain of building during normal operating hours.

2.3.2 Characterizations of Sample

After collection of grey water various types of test such as pH, turbidity, hardness, conductivity, total solids, suspended solids, dissolved solids, DO (dissolved oxygen) and BOD (biochemical oxygen demand), COD (chemical oxygen demand) were conducted in environment engineering lab of civil department of Dhaka university of Engineering and Technology (DUET), Gazipur. In all the measurement quality control assurance were marinated as per laboratory manual.

2.3.3 Filtration

In filtration, grey water was passed through filter (SLS, TG, Sand Filter media) in order to remove the particulate matter not previously removed by sedimentation. In filtration, the control flow rates were 0.17 liter/min, 0.20 litter/min and 0.33 liter /min for SLG, TG and Sand filters respectively. Filtered water was collected in plastic bottle immediately for laboratory test.

Finally, the filtered water quality was compared with the water quality parameter according to BD standard (ECR 1997) and WHO standard 2004. Furthermore, the impurities removal comparison among SLG, TG and Sand filters were also observed in order to recommend best filter media among them.

3. RESULTS AND DISCUSSION

The raw water and filtered water were tested in environmental laboratory of DUET for different water quality parameters (pH, color, DO, COD, BOD_5, TS, TDS, TSS, TC, FC, alkalinity chloride, nitrate phosphate and conductivity).

3.1 Comparison of pH

In pH test all the values have been taken at 25^0C temperature. It was observed that pH value was increased after filtering of all samples and details results were showed in figure 5.1 and 4.2. pH increasing in percentage was higher for SLS glass filter media in compared with TG and Sand filters. The pH of filtered water was increases by 20%, 22% and 19% for Student Hall (SH) and 0%, 10% and 1% for teacher's quarter (TQ) for SLG, TG and Sand filters respectively. The pH of all filtered water was obtained within the range of 7.94-8.44.

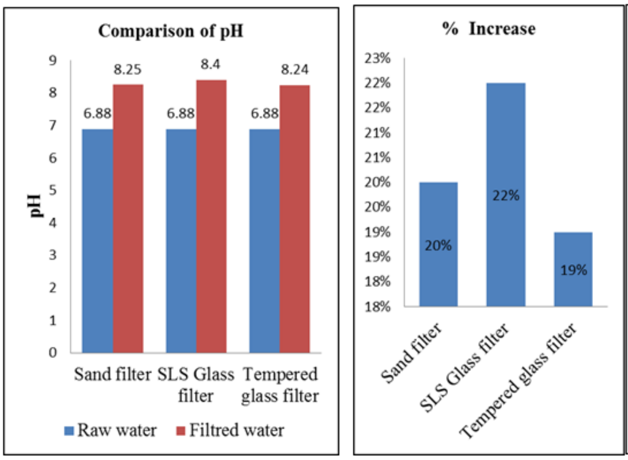


Figure 5.1 Comparison of pH (SH Sample)

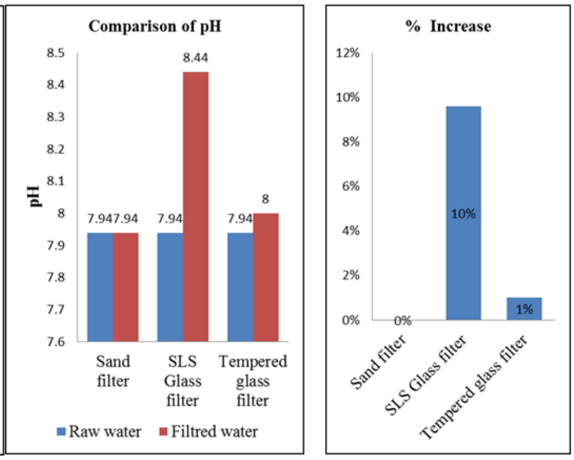


Figure 5.2 Comparison of pH (TQ Sample)

3.2 Comparison of DO

Dissolved oxygen is the most important element especially for drinkable water. The observed value of DO has been shown in figure 6.1 and 6.2. DO was also increased after filtration. The DO level of filtered water was increases by 54%, 60% and 64% for Hall and also 60%, 62% and 68% for teacher's quarter for SLG, TG and Sand filters respectively.

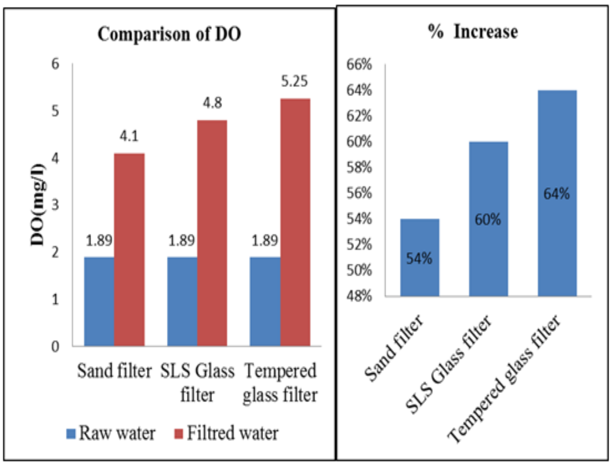


Figure 6.1 Comparison of DO (SH Sample)

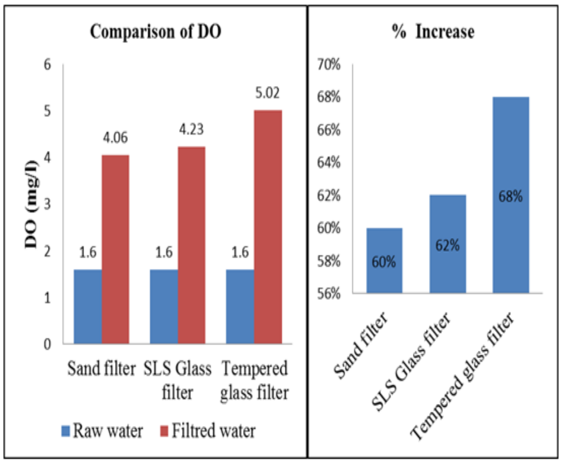
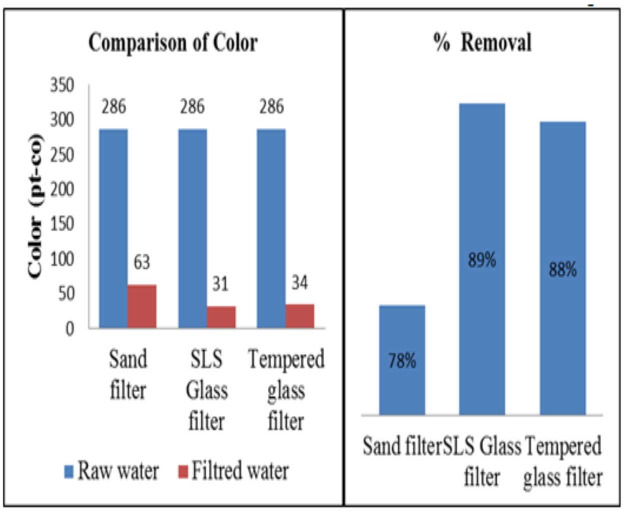


Figure 6.2 Comparison of DO (TQ Sample)

3.3 Comparison of Color Removal

The color removal efficiency for all filters media was sufficient. In comparative removal, SLS glass filter media was more effective than others. The tested results are shown in figure 7.1 and 7.2



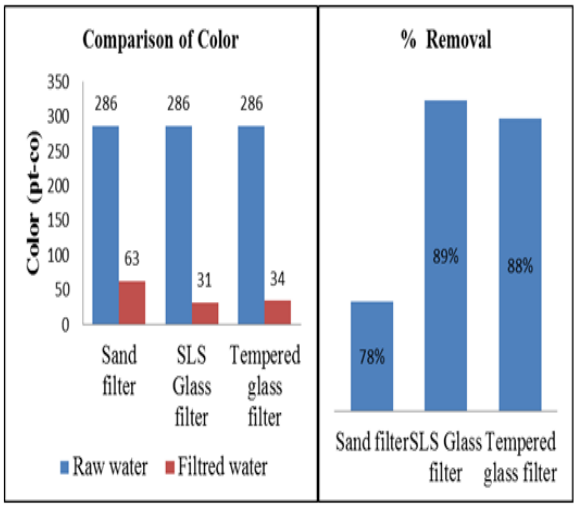
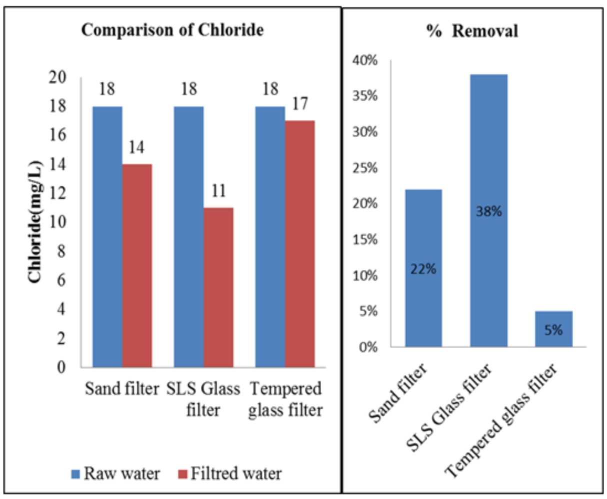


Figure 7.1 Comparison of color (SH Sample) **Figure 7.2 Comparison of color (TQ Sample)**

The removals of color in percentages were 78%, 89% and 88% for Hall and 94%, 95% and 97% for teacher's quarter for SLG, TG and Sand filters respectively.

3.4 Comparison of Chloride Removal

After filtered of grey water percentage of removal chloride was also high (shown in figure 8.1and 8.2). It was revealed that SLS glass more effective for removed of chloride.



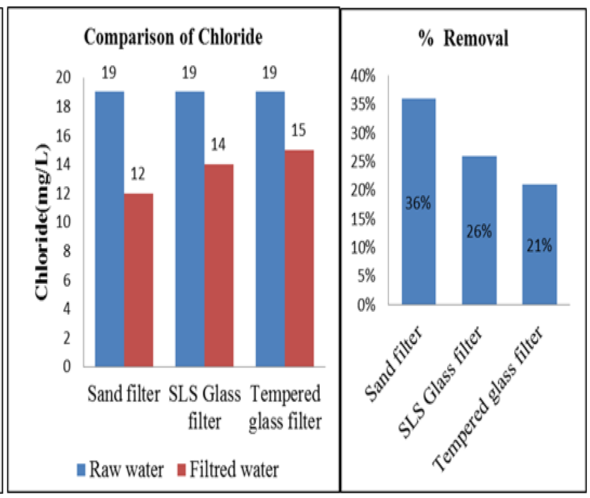
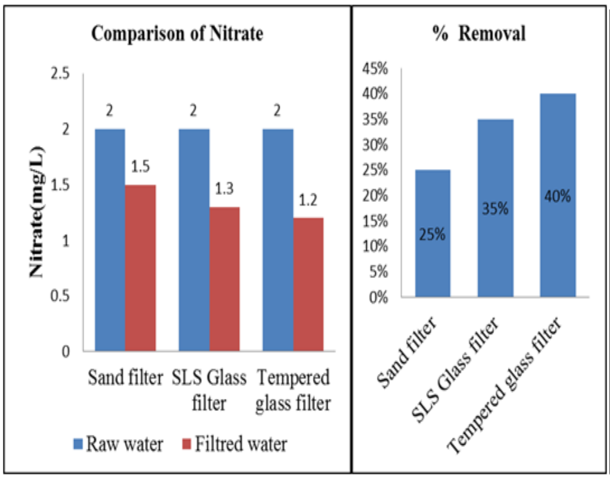


Figure 8.1 Comparison of chloride (SH Sample) Figure 8.2 Comparison of chloride (TQ Sample)

The removals of color in percentages were 22%, 38% and 5% for Hall and 36%, 26% and 21% for teacher's quarter for SLG, TG and Sand filters respectively.

3.5 Comparison of Nitrate Removal

Percentage of removal for TG filter has been computed as maximum. From figures (9.1 and 9.2) it was revealed that the removals of nitrate in percentages were 25%, 35% and 40% for Hall and 43%, 38% and 10% for teacher's quarter for SLG, TG and Sand filters respectively.



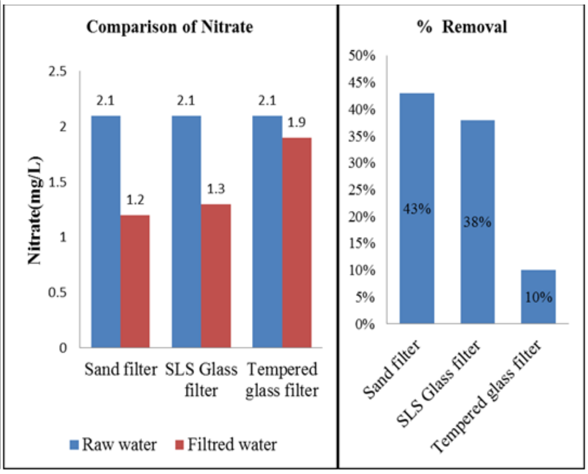
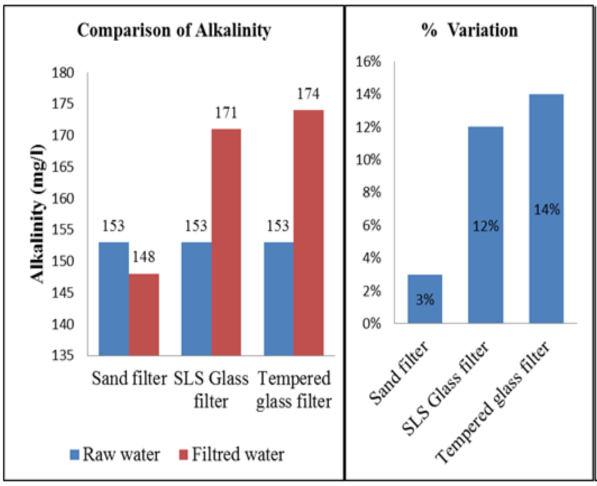


Figure 9.1 Comparison of nitrate (SH Sample) Figure 9.2 Comparison of nitrate (TQ Sample)

3.6 Comparison of Alkalinity Removal

TG glass filter media removed comparatively more alkalinity than other filter media. The details performances in removing Alkalinity of SLS, TG and Sand filters are shown in figures (10.1and 10.2).



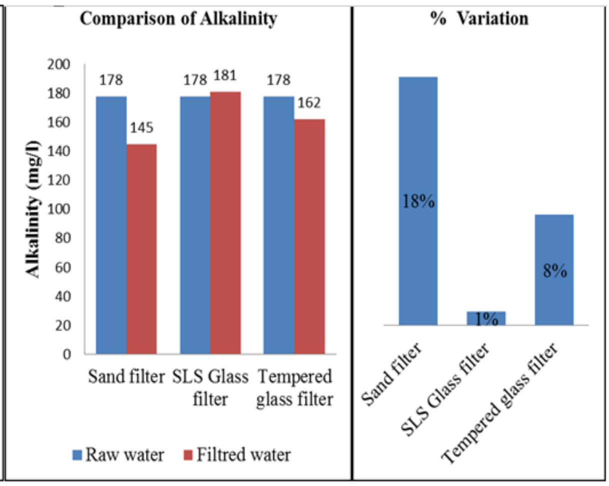
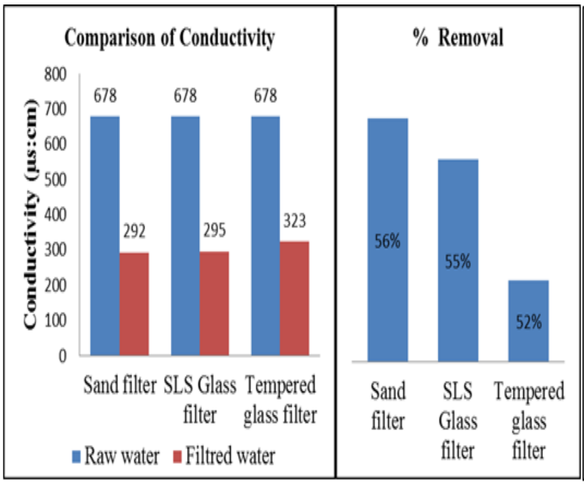


Figure 10.1 Comparison of alkalinity (SH Sample) Figure 10.2 Comparison of alkalinity (TQ Sample)

3.7 Comparison of Conductivity Removal

The order of conductivity removal was Sand> SLS> TG with the values 56%> 55% and 52% respectively. The removal efficiency was almost same for three filters.



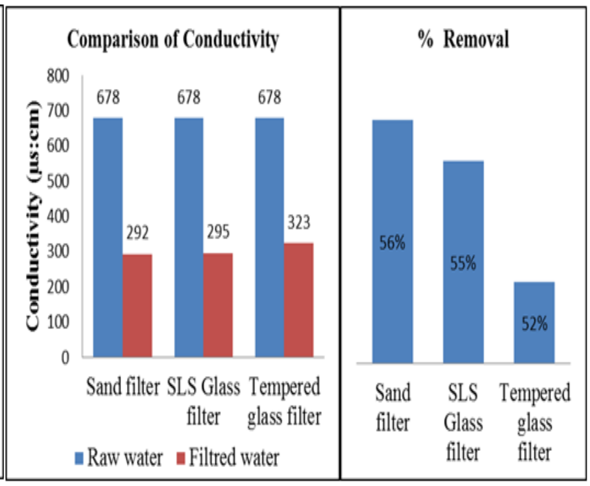
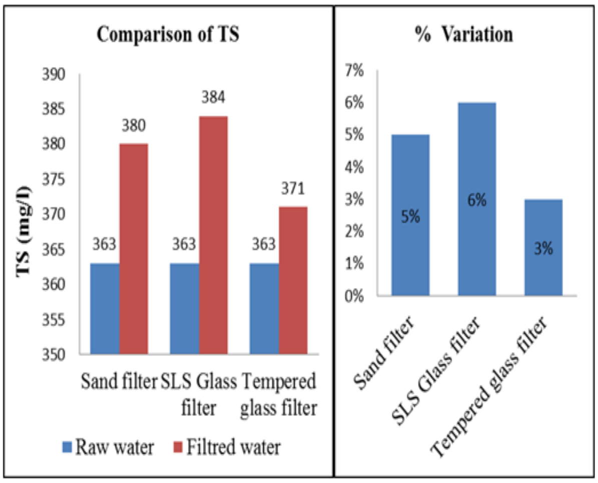


Figure11.1Comparison of Conductivity (SH Sample) Figure11.2Comparison of conductivity (TQ Sample)

3.8 Comparison of Total Solids Removal

From figure (12.1 and 12.2) it was disclosed that the removals of Total Solid in percentages were 5%, 6% and 3% for Hall and 41%, 29% and 11% for teacher's quarter for SLS, TG and Sand filters respectively.



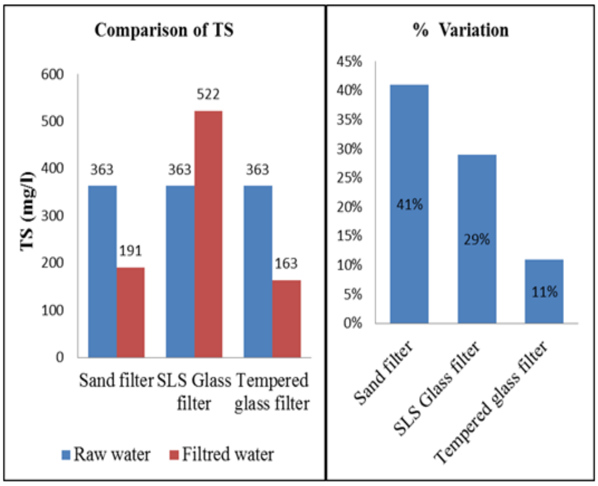
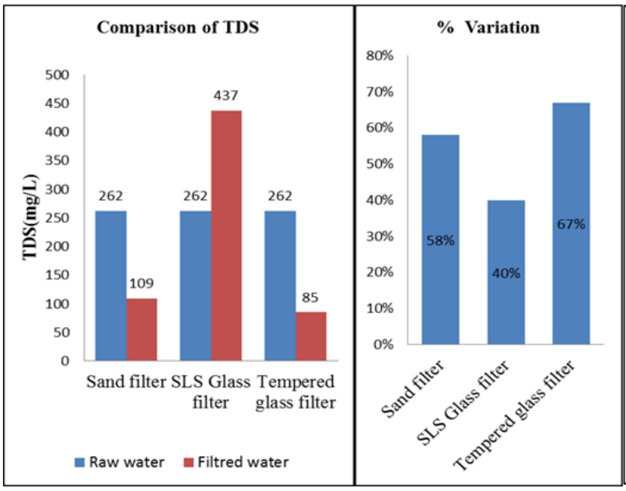


Figure 12.1 Comparison of TS (SH Sample) **Figure 12.2 Comparison of TS (TQ Sample)**

In this study, it has been shown that sand filter media and SLS filter media were more effective in removing Total Solids than TG glass filer media.

3.9 Comparison of Total Dissolved Solids (TDS) Removal

From figures (13.1 and 13.2) it was revealed that the removals of TDS in percentages were 58%, 40% and 67% for Hall and 10%, 11% and 11% for teacher's quarter for SLG, TG and Sand filters respectively.



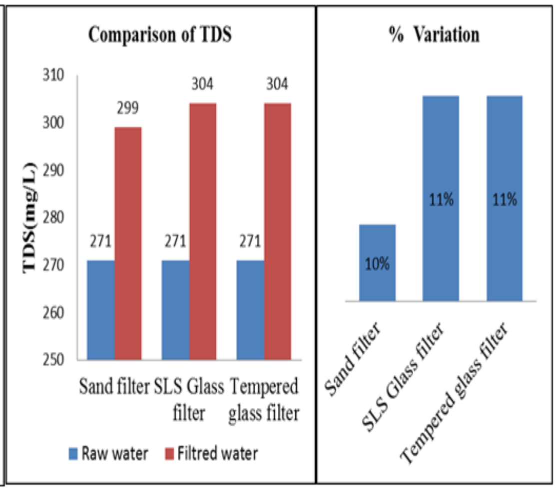
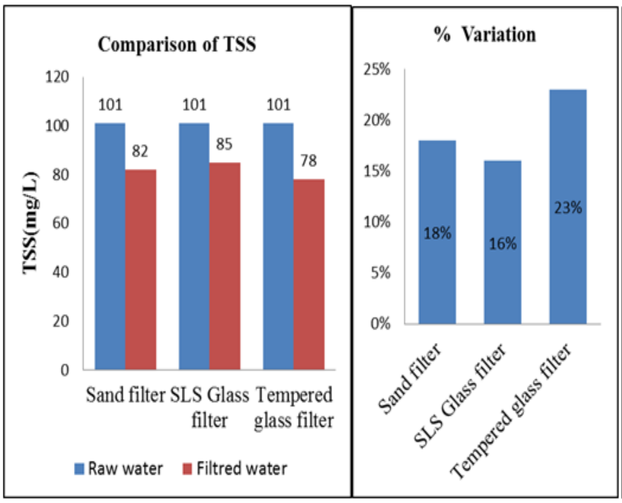


Figure 13.1 Comparison of TDS (Hall Sample) **Figure 13.2 Comparison of TDS (TQ Sample)**

3.10 Comparison of Total Suspended Solids (TSS) Removal

It was revealed that the removals of TSS in percentages were 18%, 16% and 23% for Hall and 22%, 9% and 14% for teacher's quarter for SLG, TG and Sand filters respectively.



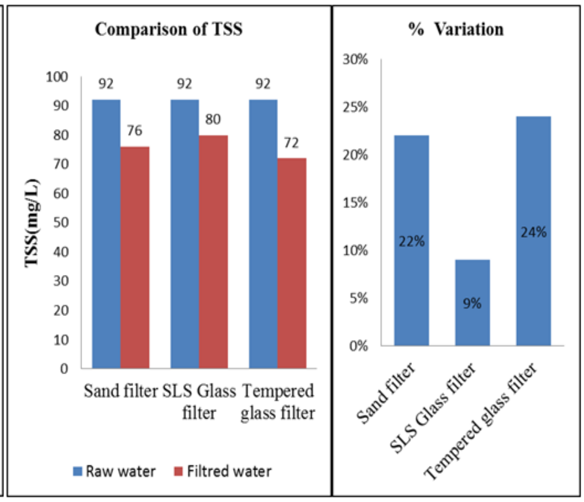
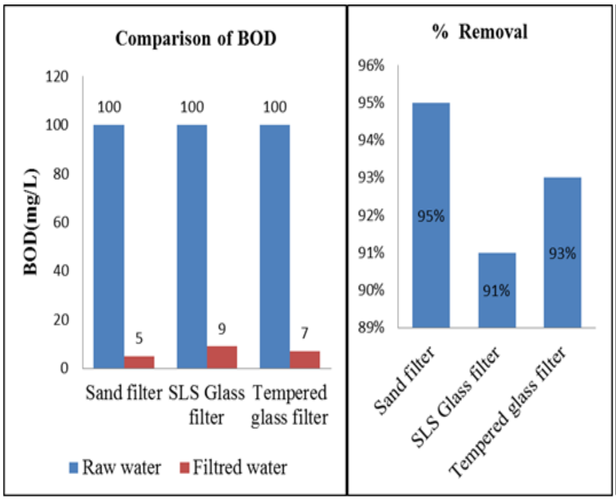


Figure 14.1 Comparison of TSS (SH Sample) **Figure 14.2 Comparison of TSS (TQ Sample)**

3.11 Comparison of Biological Oxygen Demand(BOD_5) Removal

From figures (15.1 and 15.2) it may be disclosed that the removals of BOD_5 in percentages were 95%, 91% and 93% for Hall and 92%, 93% and 88% for teacher's quarter for SLS, TG and Sand filters respectively.



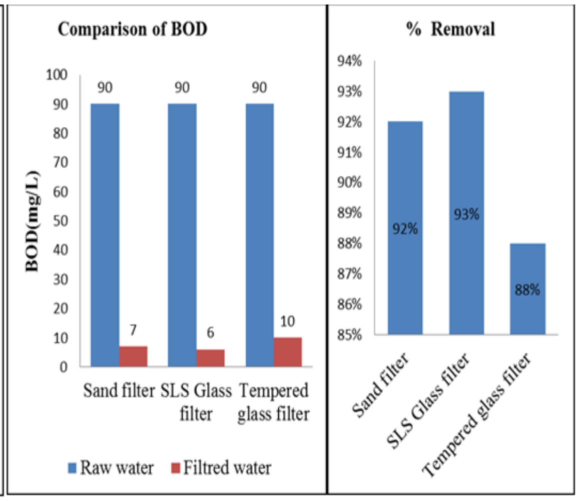
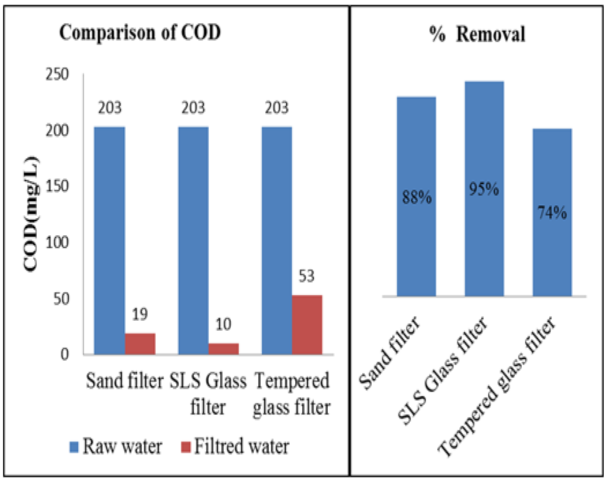


Figure 15.1 Comparison of BOD_5 (SH Sample) **Figure 15.2 Comparison of BOD_5 (TQ Sample)**

3.12 Comparison of Chemical Oxygen Demand (COD) Removal

In comparison of filter efficiency, it has been observed that SLS glass filter media reduce more COD than others media. The details results are in figures (16.1and 16.2).



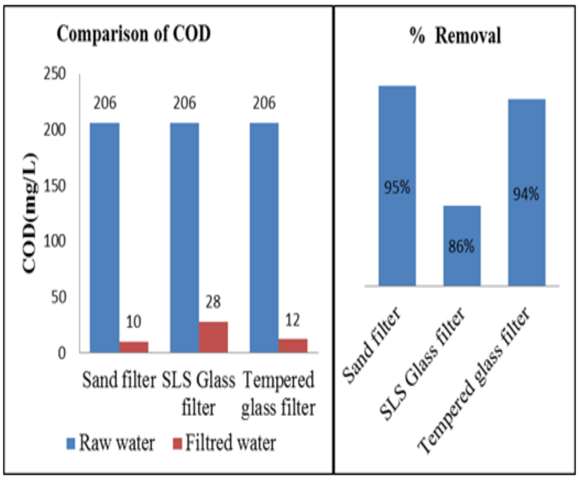


Figure 16.1 Comparison of COD (SH Sample) **Figure 16.2 Comparison of COD (TQ Sample)**

3.13 Comparison of Hardness Removal

In hardness, SLS and TG glass filter was more effective than sand filter media. The obtained results are in figures (17.1and 17.2).

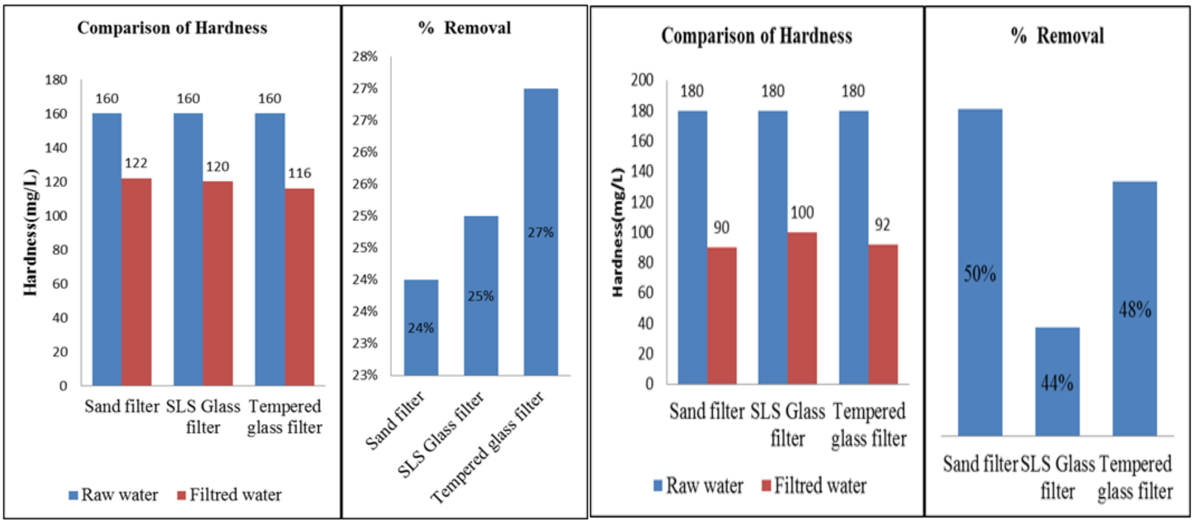


Figure 17.1 Comparison of Hardness (SH Sample) Figure 17.2Comparison of Hardness (TQ Sample)

3.14 Comparison of Phosphate Removal

In phosphate test, it was revealed that all kinds of filter media removed the Phosphate concentration. Whereas, TG and SLS were more effective than sand filter media

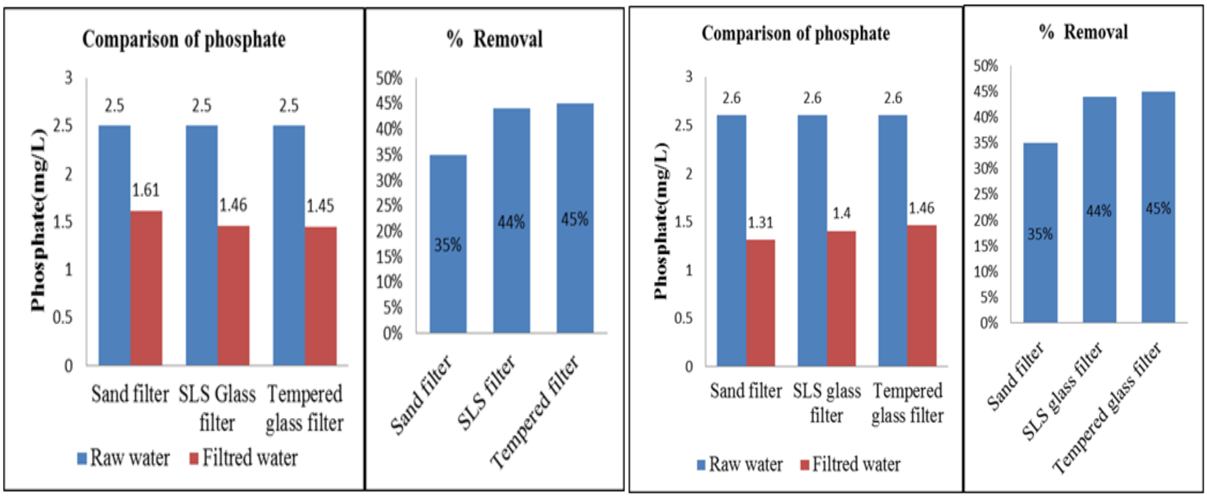
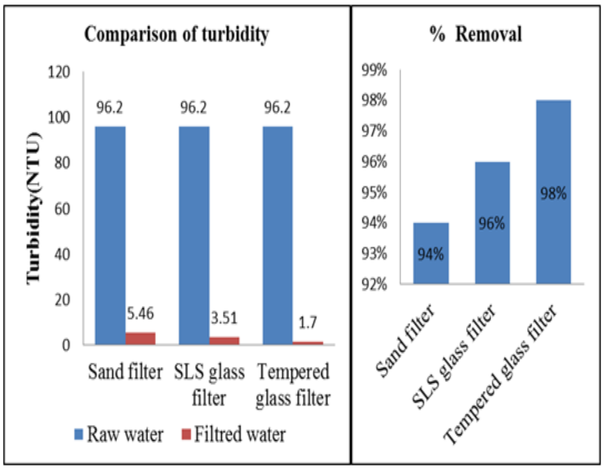


Figure 18.1 Comparison of phosphate (SH Sample) Figure 18.2 Comparison of phosphate (TQ Sample)

3.15 Comparison of Turbidity Removal

In turbidity test SLS and TG glass filter was more reduce than sand filter media. From figure 19.1 and 19.2, it may be disclosed that the removals of Turbidity in percentages were 94%, 96% and 98% for Hall and 85%, 93% and 92% for teacher's quarter for SLG, TG and Sand filters respectively.



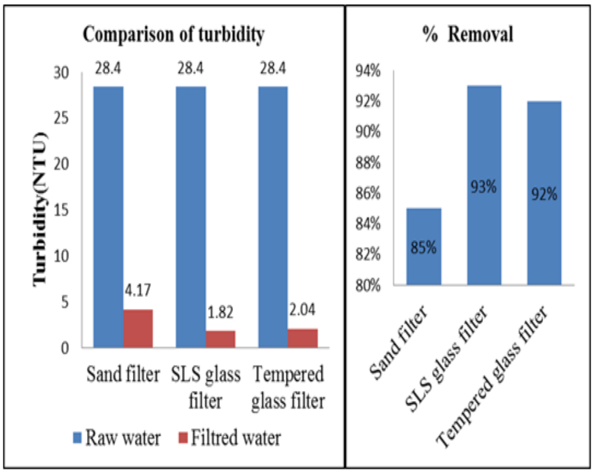


Figure 19.1 Comparison of turbidity (SH Sample) Figure 19.2 Comparison of turbidity (TQ Sample)

3.16 Total Coliform (TC) and Faecal Coliform (FC)

This study didn't get any TC and FC in raw water and after filtration the numbers TC and FC were also nil for all filter media.

3.17 Comparison with Various Standards

Table 2 and Table 3 showed the obtained results of various water quality parameters and comparison with BD standard (ECR 1997) and WHO standard.

Table 2. Suitability of filtered water for uses of SH sample

SL No	Parameter	Raw water	Filtered Water			Drinking water standards value		Remarks
			SLS Filter	TG Filter	Sand Filter	BD (ECR,97)	WHO	
01	pH	6.88	8.4	8.24	8.25	6.5-8.5	6.5-8.5	Within safe limit
02	Color(Pt-co)	286	31	34	63	15	15	Exceed safe limit
03	Odor	-	-	-	-	odorless	-	Within safe limit
04	COD(mg/l)	203	10	53	19	4	-	Exceed safe limit
05	BOD_5(mg/l)	90	6	10	7	0.2	-	Exceed safe limit
06	Chloride(mg/l)	18	11	17	14	150-600	250	Within safe limit
07	Nitrate(mg/l)	2	1.3	1.2	1.5	10	50	Within safe limit
08	Phosphate(mg/l)	2.5	1.46	1.45	1.61	6	-	Within safe limit
09	Alkalinity	153	171	174	148	-	-	Within safe limit
10	Hardness(mg/l)	160	120	116	122	200-500	500	Within safe limit
11	Conductivity (μs:cm)	678	295	323	292	-	-	
12	TS(mg/l)	363	384	371	380	-	-	
13	TDS(mg/l)	271	304	299	304	1000	1000	Within safe limit
14	TSS(mg/l)	92	80	72	76	10	-	Exceed safe limit
15	TC(nos/100ml)	Nil	Nil	Nil	Nil	0.00	0.00	Within safe limit
16	FC(nos/100ml)	Nil	Nil	Nil	Nil	0.00	0.00	Within safe limit
17	Turbidity(NTU)	96.2	5.46	3.51	1.7	10	5	Within safe limit

This study revealed that grey water treatment process using SLS glass filter could be more effective or removal color, BOD, COD, Turbidity, hardness than TG glass filter media. It has also been observed that treated parameters value with in safe limit except BOD, COD and TSS according to WHO guide line and Bangladesh Standards for drinking water parameter (Ahmed and Rahman 2005).

Table 3. Suitability of filtered water for uses of TQ sample

SL No	Parameter	Raw water	Filtered Water			Drinking water standards value		Remarks
			SLS Filter	TG Filter	Sand Filter	BD (ECR,97)	WHO (2004)	
01	pH	7.94	8.4	8.0	7.94	6.5-8.5	-	Within safe limit
02	Color(pt.-co)	698	40	18	41	15	15	Exceed safe limit
03	Odor	-	-	-	-	odorless	-	Within safe limit
04	COD(mg/l)	206	28	12	10	4	-	Exceed safe limit
05	BOD_5(mg/l)	100	9	7	5	0.2	-	Exceed safe limit
06	Chloride(mg/l)	19	14	15	12	150-600	250	Within safe limit
07	Nitrate(mg/l)	2.1	1.3	1.9	1.2	10	50	Within safe limit
08	Phosphate(mg/l)	2.6	1.40	1.46	1.31	6	-	Within safe limit
09	Alkalinity	178	181	162	145	-	-	Within safe limit
10	Hardness(mg/l)	180	100	92	90	200-500	500	Within safe limit
11	Conductivity (µs/cm)	297	216	323	363	-	-	Within safe limit
12	TS(mg/l)	363	522	163	191	-	-	Within safe limit
13	TDS(mg/l)	262	437	109	85	1000	1000	Within safe limit
14	TSS(mg/l)	101	85	78	82	10	-	Exceed safe limit
15	TC(Nos/100ml)	Nil	Nil	Nil	Nil	0.00	0.00	Within safe limit
16	FC(Nos/100ml)	Nil	Nil	Nil	Nil	0.00	0.00	Within safe limit
17	Turbidity(NTU)	28.4	1.82	2.04	4.17	10	5	Within safe limit

4. CONCLUSIONS

Major conclusions from this study may be summarized as follows:

- The maximum removal efficiencies of SLS glass filter media was obtained 94% for color, 94% for turbidity, 95% for COD, 91% for BOD, 89% for hardness, 21% for TSS, 39% for chloride and TG filter media was obtained 40% for nitrate, 43% for phosphate and sand filter media was obtained 57% for conductivity, 5% for alkalinity.
- SLS glass filter media was more effective in removing pollutants than TG filter and sand filter media. TG filter media was more effective in removing pollutants from grey water than sand filter.
- The effluents from all filter media were satisfied the requirements of both BD and WHO guide line of drinking standards except BOD, COD and TSS.
- Finally this study may be disclosed that treated water is not suitable for drinking purpose but it can be used for others purposes such as (gardening, washing cloth, toilet flushing, fish culture etc.).

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We are grateful to almighty Allah for giving the strength and courage that we have completed the thesis with successfully. We acknowledge with assistance received from any quarters in completing the project study. With would like to express our foremost intense appreciation to our supervisor Dr. Md. Akramul Alam, Professor, Department of Civil Engineering, Dhaka University of Engineering & Technology (DUET), Gazipur for his valuable, continuous guidance, helpful suggestions and constant encouragement to complete this study. The authors want to thank for considerable assistance during the laboratory investigation rendered by Shibu bonik (Technical officer) and Md. Firoz Alom (Lab Technician).

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Rainwater Harvesting System for Commercial Building in the Dhaka City: Reliability, Economic Benefit, Water and Energy Savings

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Abstract

Being one of the densely populated regions in Bangladesh, Dhaka city is facing the crisis for supplying clean water to its dwellers. The practice of rainwater harvesting (RWH) systems is getting attention at present. According to Bangladesh National Building Code (BNBC), Buildings of total floor area greater than or equal to 4000m^2 shall have its own RWH system. But there is no detailed study for the commercial buildings of Dhaka city based on this legislation. This paper presents a detailed analysis of potential rainwater savings and economic benefits of RWH systems under three distinct climatic condition (i.e. wet, dry and average year) in the multi-storied commercial buildings in Dhaka city to partially offset the daily non-potable water demand. A comprehensive software model was developed using MATLAB to analyze the reliability and economic benefits of RWH systems in the commercial buildings based on daily water balance model. The software uses input data like daily rainfall, tank size, run-off losses, catchment area and gives output data like reliability, overflow-ratio, water savings/year. It also analyses energy savings and B/C ratio for different project life. Historical 28-years daily rainfall data has been analyzed to choose the three distinct climatic condition. Typical commercial buildings of catchment area ranging from (120m^2-1242 m^2) and tank sizes (15m^3-60m^3) have been considered. The result indicates that 18-25% reliability can be achieved, and 200-2900 KL of water can be harvested yearly under the wet condition for catchment area varying from 120m^2 to 1242m^2. Energy savings and water savings have been considered and it has findings that the B/C ratio is greater than 1 in every aspect for different project life. The output results of this study have also been compared with earlier established model e-Tank and Rainwater Analysis tool.

Keywords: Rainwater Harvesting, Energy savings, Reliability, Commercial Buildings, Dhaka city.

1. INTRODUCTION

The water supply system in Dhaka city has been facing a major challenge for quite some time and is considered the worst due to rapid population growth and urbanization. Currently, Dhaka Water Supply and Sewerage Authority (DWASA) is the only responsible authority in the Dhaka city to supply consumable water to its dwellers. According to a study by Rahman et al (2014), DWASA meets only up to 75% of the total water demand, of which 87% of the water is collected from groundwater and the rest comes from two surface water treatment plants. At present, DWASA is trying to find alternative sources of water for not to depend on the conventional sources. To partially offset the constraints in water resource, some vigorous imperatives for adoption of conservative utilization of water such as recycle and reuse of water, rain water harvesting etc. have been trying to be undertaken. A study by Rahman et al (2014) assessed the sustainability of RWH system for Dhaka city and found that 11%

water can be saved annually in a building having a roof area of 170m^2 and this volume of rainwater can serve a building with 60 people for about 1.5 months in a year without traditional water supply. This study also showed that with a 170m^2 catchment area, about 262m^3 of water can be harvested over a year Imteaz, Rahman and Ahsan (2012), Imteaz, Matos and Shanableh (2014), Matos, Bentes, Santos, Imteaz and Pereira (2015), Imteaz, Ahsan, Naser and Rahman (2011) developed a tool named e-Tank using daily water balance modelling concept. According to Karim, Bashar and Imteaz (2015), The annual average rainfall in Dhaka is about 2200 mm, 75% of which occurs during the monsoon (June–October). This massive rainfall can be used as an alternative source of water supply for the Dhaka city if properly harvested. If RWH system is being adopted in Bangladesh, some portion of the increasing potable or non-potable demand (i.e. toilet flushing, gardening, floor cleaning etc.) of water can possibly be met. All of the previously mentioned studies have been conducted for the residential buildings considering water savings only; energy savings are not taken into considerations. However, there is no in detailed study of adopting RWH systems in the commercial buildings of Dhaka city. The objective of this paper is to investigate a detailed analysis of the potential savings of rainwater, energy and the economic advantages (water, energy, water+energy) of RWH systems in the multi-story commercial buildings in Dhaka, which have not been done yet. This study will help to convince the end users about expected monetary savings due to the potential water and energy savings. This study will also provide information to local authorities in adopting the RWH system for the commercial building through appropriate policies.

2. METHODOLOGY

For the calculation of reliability, a water balance model has been developed considering daily rainfall, contributing catchment (roof) area, losses due to leakage, spillage and evaporation, storage (tank) volume and water uses. Imteaz et al (2012) examined daily and month-to-month water balance model and exhibited predominance of daily water balance demonstrate over month-to-month water balance. The model analyses daily runoff volume considering the existing ground water tank of the building for storage. Every day demand is satisfied from the remaining storage and if the daily demand is not exactly the storage remaining, overabundance sum is gathered in the tank. In the model, spillage or overflow is calculated when the accumulated runoff volume exceeds the storage volume and if accumulated runoff cannot fulfil the demand, town water will be used to satisfy rest of the demand. Accumulated water storage equations,

$$A_t = S_t + A_{t-1} - D_w \quad (1)$$
$$A_t = 0, \text{ for } A_t < 0 \quad (2)$$
$$A_t = T, \text{ for } A_t > T \quad (3)$$

A_t is the accumulated rainwater (L) stored in the tank at the end of tth day, S_t is the stored rainwater volume (L) on the tth day, A_{t-1} is the Remaining rainwater volume (L) in the tank at the beginning of the tth day, D_w is the Daily water demand (L) on tth day, T is the Capacity of underground reservoir (L). If spilled water volume is W_S and town water volume is W_T,

$$W_S = S_t + A_{t-1} - D_w - T, \text{ for } S_t + A_{t-1} - D_w > T \quad (4)$$
$$W_T = D_w - S_t - A_{t-1}, \text{ for } S_t + A_{t-1} < D_w \quad (5)$$
$$\text{Overflow ratio} = \frac{\sum W_S}{\sum S_t} * 100 \quad (6)$$

Where $\sum W_S$ is the total water spilled during the evaluation period, $\sum S_t$ is the total stored rainwater volume during evaluation period. Time based reliability according to Imteaz et al (2011) is figured utilizing the equation given below:

$$\text{Time based Reliability, } R_T = \frac{T_D - U_D}{T_D} * 100 \quad (7)$$
$$\text{Volumetric Reliability, } R_V = \frac{\text{Total usable rainwater volume annually}}{\text{Total annual water demand}} * 100 \quad (8)$$

Where T_D is the total number of days in a particular year (365 or 366), U_D is the total number of days in a particular year unable to meet the demand by collected rainwater.
For economic analysis annual water, energy and (water + energy) savings is calculated and multiplied with unit price of the each to get annual monetary savings. *AWS* is the annual water savings (wet, dry, and average), P_W is the unit water price, *and PE* is the unit energy price, α is the average energy consumed per unit of water, E_S is the annual energy savings, equation for annual energy savings:

$E_S = AWS * \alpha$ (9)
Annual monetary water savings, $MAWS = AWS * P_W$ (10)
Annual monetary energy savings, $ME_S = E_S * P_E$ (11)
Annual monetary water + energy savings = $MAWS + ME_S$ (12)

As a standard strategy, all the benefits and expenses are changed over to Net Present Value (NPV), considering a yearly return rate. Benefit–cost ratio analysis related equations are given below:

$$\text{Benefit–cost ratio} = \frac{B}{C} \quad (13)$$
$$B = X * \frac{(1+r)^n - 1}{r\,(1+r)^n} \quad (14)$$
$$C = IC + OM * \frac{(1+r)^n - 1}{r\,(1+r)^n} \quad (15)$$

Where *B* represents the NPV of the benefits and C represents the NPV of the costs, *r* = rate of return (%/year), *n* = project life (years), *IC* is the installation cost and *OM* is the annual operation and maintenance cost, *X* = *MAWS* or ME_S or Annual monetary water + energy savings.

3. DATA

Daily precipitation information for Dhaka city territory was collected from the Bangladesh Meteorological Department for chronicled 28 years (1988-2015). The corresponding years with greatest and least yearly rainfall were considered to be wet year (2007, annual rainfall 2885mm) and dry year (1992, annual rainfall 1169mm). The year with annual precipitation near 28 years average annual precipitation was considered as an average year (1996, annual rainfall 2044mm). For this study, a survey was led and discovered that the catchment area of commercial buildings ranges from approximately 120m^2 to 1242m^2 with population sizes ranging from 150 to 1100, tank sizes range from 15m^3 to 60m^3. From the survey, three buildings have been chosen based on the maximum, minimum and average sized catchment areas i.e. 1242m^2 (max), 120m^2 (min), 600m^2 (avg). The tank sizes and population sizes of the specific buildings are obtained from the field survey which are 60m^3,15m^3, 30m^3, and 1100, 150, 600 respectively. To calculate daily water demand it is assumed that for commercial building in Dhaka city daily demand ranges from 30-45 liter per capita per day (lpcd) (BNBC 2017). To ascertain the runoff volume from the rooftop catchment territory of the commercial building, runoff coefficient is introduced as an input for the model can ranges from 0.8 to 0.9 was to contemplate for various losses from genuine precipitation sums on the rooftop because of spillage and spilling.

4. RESULTS AND DISCUSSIONS

Figure 1 outlines time-based reliability for wet season in larger catchment areas increment with the expansion of tank volume, yet in other cases nearly stay steady after a specific increment in tank volume. Like the time-based reliability also for this case, reliability will be higher in the wet season (Figure 2). Volumetric reliability remains relatively consistent with the extension of tank volume. Where the time-based reliability fluctuates from about 3% to 15% for different catchment sizes, volumetric reliability differs from about 8– 27% for a similar catchment estimate.

Figure 3 and Figure 4 outlines reliability-water demand relationship where reliability (time based or volumetric) significantly decreases with the increase in water demand ranges from 30 to 45 lpcd.

Overflow ratio decrease with the increase in water demand (varying from 30-45 lpcd) or tank volume (varying from 15-60 m^3) as shown in Figure 5 and Figure 6. The smaller area with larger tank sizes

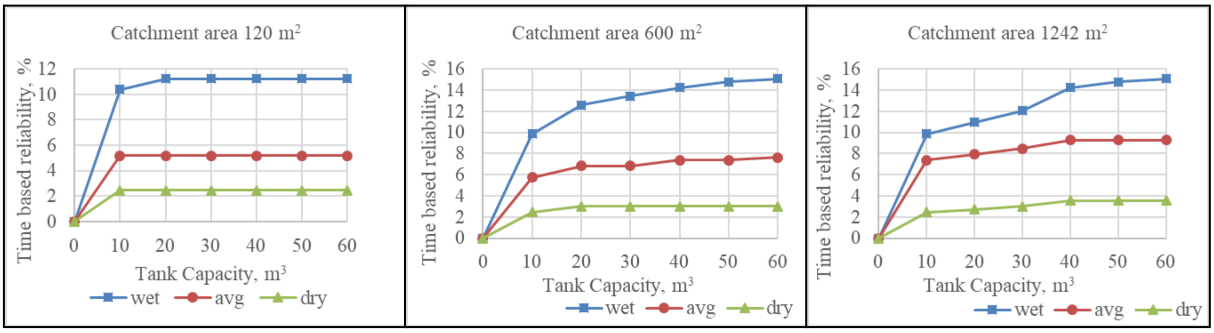

Figure 1. Time-based reliability vs Tank capacity

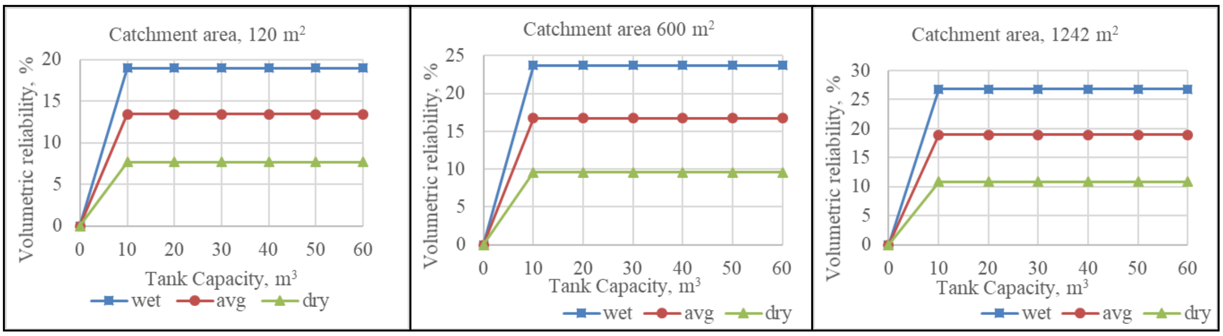

Figure 2. Volumetric reliability vs Tank capacity

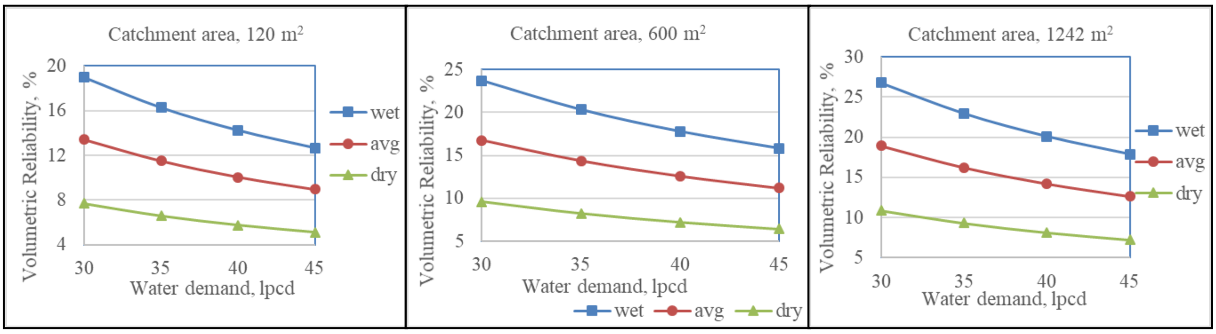

Figure 3. Volumetric reliability vs Water demand

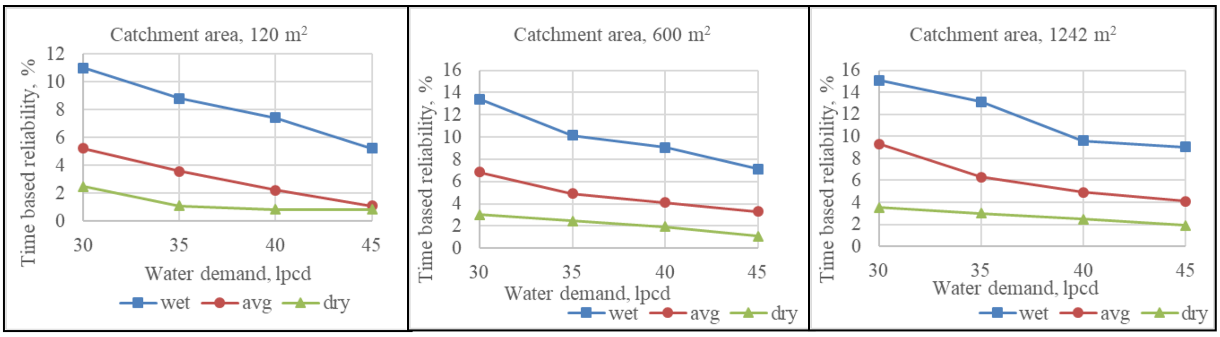

Figure 4. Time-based reliability vs Water demand

will have no spillage or overflow which illustrate that the existing underground tank will be adequate to counteract overflow. For large catchment area, the existing tank isn't sufficient to prevent overflow as the accumulated rainwater is greater in wet and average condition.

For economic analyses, unit water price has been considered as BDT 35.28 per kL of water (DWASA, 2018). Energy used for the production of unit water is considered 0.3 kWh/m^3 as suggested by Anwar et al (2010) and energy price is assumed BDT 4.12 per kWh as per DWASA (2010). Considering 30 lpcd water demand for each catchment area, monetary savings are given in Table 1. For catchment area having 120m^2, 600m^2 and 1242m^2, installation costs are assumed 10000, 20000, 30000 BDT and maintenance cost are 2000, 3000, 5000 BDT/year respectively. Using the benefits and costs, B/C ratios

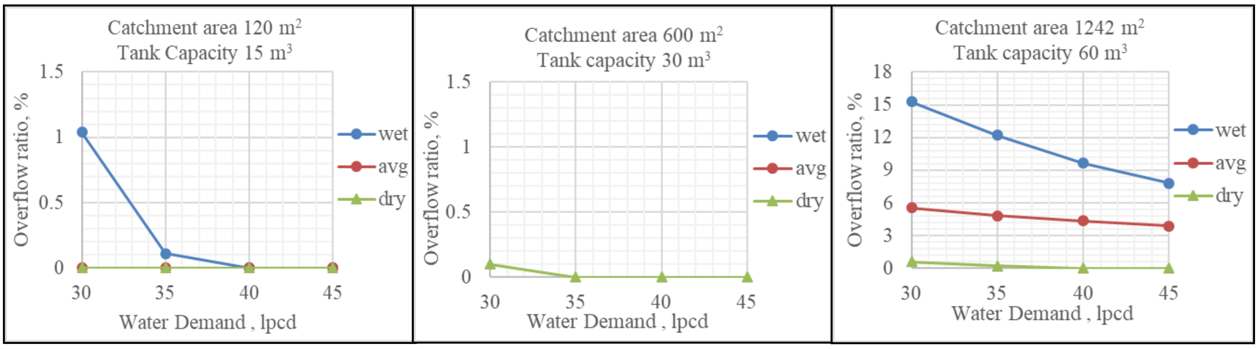

Figure 5. Overflow ratio vs Water demand

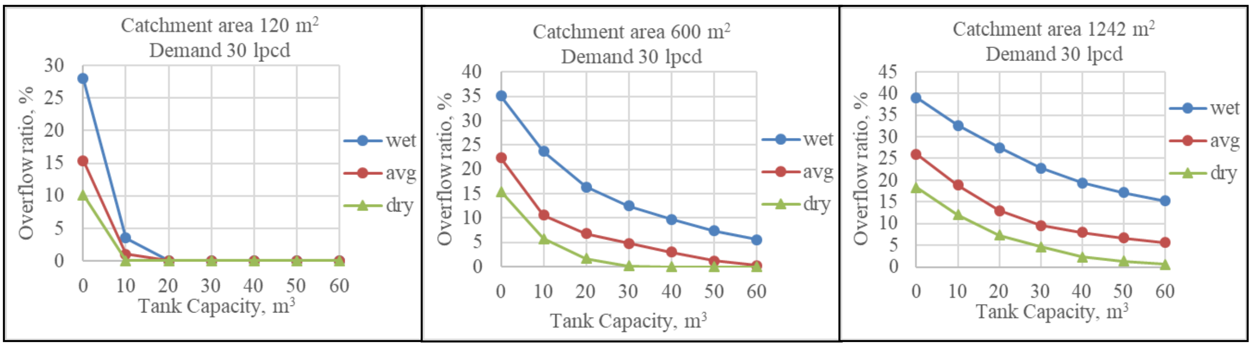

Figure 6. Overflow ratio vs Tank capacity

Table 1. Monetary savings Benefit-cost ratio analysis

Catchment area, m^2	Climatic conditions	Total demand, m^3	Monetary savings, BDT			Benefit-cost ratio		
			Water	Energy	Water + Energy	Water savings only	Energy savings only	Water + Energy savings
120	Wet	4.5	10878	381.0934	11259	2.8579	0.1001	2.9580
	Average		7788.1	272.8495	8061	2.0462	0.0717	2.1178
	Dry		4454.2	156.0475	4610.2	1.1702	0.0410	1.2112
600	Wet	18	48087	1684.7	49772	7.2723	0.2548	7.5270
	Average		37088	1299.4	38388	5.6089	0.1965	5.8054
	Dry		22250	779.4958	23029	3.3648	0.1179	3.4827
1242	Wet	33	96403	3377.4	99781	9.2530	0.3242	9.5771
	Average		76129	2667.1	78796	7.3070	0.2560	7.5630
	Dry		45832	1605.7	47438	4.3991	0.1541	4.5532

have been calculated for water, energy and water + energy savings and shown in Table 1 for 10 years of project life using 12.5% rate of return suggested by Karim et al (2015). From Table 1, it is clear that considering water and energy savings the project is beneficial in every climatic condition. If project life can be extended economic benefit will increase respectively. As the commercial water price in

Dhaka city is increasing in a regular interval expected amount of monetary savings can be achieved by introducing RWH in the commercial building. According to Karim et al (2015), the reliability and economic analysis of urban rainwater harvesting in Dhaka City for residential building and found that 15-25% reliability can be achieved under wet climatic conditions and BDT 2000 can be saved each year for roof catchment size of 140 m^2 with a tank size of 40 m^3. Whereas in this study for the commercial building, reliability and economic benefit are much higher because of the large catchment area and variation of water price. This study has also considered the energy savings which contributes to the overall monetary savings and B/C ratio to some extent as mentioned in Table 1. But for large catchment area, larger tank size is needed to avoid overflow. Further analysis should be done for the optimization of tank size in the commercial building. The data used in the study has been given as input in e-Tank and Rainwater Analysis tool which calculates reliability, overflow, monetary savings. For reliability, overflow and monetary savings, there are no significant differences in the output results given by this software.

5. CONCLUSIONS

Although there is a significant amount of rainfall in Dhaka city, DWASA is confronting difficulties to take care of up the expanding demand. In this case, rainwater harvesting can be an effective alternative source of water to meet up especially the non-potable water demand. Despite having legislation, no widespread implementation has been done on the RWH system. One of the main reasons behind this issue is the lack of validated scientific information on the feasibility and economic benefit of the RWH system. This study mainly focuses on the implementation of RWH system in the commercial building of Dhaka city finding out the reliability and economic benefits.

The volumetric reliability is 4-5% higher than that of time-based reliability of a specific building. With the varying tank capacity, there is overflow in the wet and average year except for dry year. This indicates the potentiality of rainwater harvesting and a significant amount of water will be lost if tank capacity is not increased. Also, with increasing demand, overflow is decreased indicating the viability of this system.

Economic analysis showed that yearly 200-2900 KL of water can be harvested and around 7000-100000 BDT can be saved roughly per year in different climatic condition. Due to the high price of water, this project is beneficial in every condition although according to (Md. R. Karim et al 2015) it is non-beneficial for residential building in Dhaka city in dry years. Moreover, 35-630 KWh energy can be saved per year if the RWH system is implemented.

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Wetland Delineation of Dry Season Using Landsat-Derived NDVI Index: A Case Study in Kishoreganj District of Bangladesh

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Abstract

Wetlands are a valuable natural resource for ground water recharge, flood control, and water quality improvement. They are considered to be the richest of the biomass, cradles of biological diversity that support unique flora and fauna and very productive environments. The loss and destruction of wetlands are common problems that result from increased human activities. Globally more than half of its wetlands has been lost in the past 100 years. The degradation and shrinkage of wetlands seriously threaten the security of the ecological environment and the conservation of biodiversity. The main objective of the study is to explore the availability of wetlands in dry season using Satellite Imagery by applying remote sensing technique. Kishoreganj, one of the major wetlands bearing districts of Bangladesh is selected as our study area. Normalized Difference Vegetation Index (NDVI) derived from LANDSAT 8 image of January 2018 has been analysed. NDVI is a non-linear function which ranges between -1 to +1. For extraction of the wetland in the study area, values between -0.10 to 0.10 were selected from the NDVI image since wetlands were found in these ranges. Total land area of study area is approximately 2557.26 km ^{2} in which wetland in day season is only approximately 39.8 km ^{2}. Only 1.56 % wetland exists in this area in dry season and this amount has been decreasing gradually. This decreasing trend has adverse impact on social, environmental, agricultural, economic and other sectors of this area.

Keywords: Wetland, NDVI, LANDSAT 8, Remote Sensing.

1. INTRODUCTION

Wetlands are invaluable natural productive ecosystem in the world. The area of wetlands is about 6.8 million sq. km of the earth's land surface and they are considered to be one of the most threatened natural ecosystems (Matthew et al (1987)). The Ramsar Convention (1971) has defined wetlands as *'areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.'* More than two thirds of Bangladesh can be considered as wetland according to the Ramsar convention definition, since 6.7 percent of the land surface is always under water, 21 percent is deeply flooded and 35 percent experiences shallow inundation (FAO 1988).

Bangladesh floodplains are one of the world's most significant wetlands which serve as a habitat to hundreds of species of fish, plants and other wildlife. These wetlands not only act as shelter for a great number of globally endangered animal species, migrating birds, plant and vertebrate species, but also provides numerous beneficial services to people in the form of water supply, the maintenance of fisheries and wildlife resources, flood storage, carbon sequestration, groundwater recharge and water purification (Rahman 2005; BirdLife International 2004; RAMSAR 2007). Despite recognition of their ecological significance and environmental services to humankind, natural wetlands continue to be converted to non-wetlands. Wetlands habitat of Bangladesh is under constant stress due to rapid growth of population; over-exploitation of both ground and surface water; expansion of agriculture and subsequent conversion of wetlands through drainage into rice fields; ill-planed flood control and irrigation infrastructures for augmentation of agricultural productivity (Nishat 1993). As consequences, wetlands-based ecosystem may end with a loss of flora, fauna and the living conditions of local people are deteriorating as livelihoods, socio-economic institutions and cultural values are affected.

Remote sensing is one of the most considerable sources available for wetland identification and delineation. The usage of space-borne multispectral and multitemporal images can be useful to evaluate waterlogged areas of wetland ecosystems (Dwivedi and Sreenivas 2002). Due to simplicity, water indices are extensively used for identification of water bodies. The primary objective of this study was to assess the extent of wetlands in dry period using reflectance bands from LANDSAT 8 OLI-TIRS combined satellite imagery. Since water demands are especially high in the dry period, NDVI based wetland delineation is mainly focused on dry season of Bangladesh.

2. STUDY AREA

Kishoreganj is the most wetland bearing district of North Eastern part of Bangladesh which is bordered by Mymensingh, Netrakona and a part of Sunamganj District to the north, Narsingdi district to the south, Brahmanbaria and Habiganj districts to the east, Gazipur and Mymensingh districts to the west (Figure 1). It has an area of 2557.26 km^2 and a population of 3,029,000 (Census 2011). The rivers Old Brahmaputra, Meghna, Kalni, Dhanu, Ghorautra, Baurii, Narasundar and Piyain run through the district. Most of the rivers flowed towards Bhairab upazila. Khunkhuni, Mithamain, Boro Haor are some of the major Haors of Kishoreganj district. Seasonal flooding starts early mid-May and continues up to December. As a result, most of the northern part of Kishoreganj district remain inundated during monsoon and post monsoon period. But in dry season (January to April) when flood water recedes, the wetland gets isolated and remain as distinct water bodies till the next rainy season comes. This observation suggests that acquisition of imagery during the dry season may be best for identifying tropical wetlands where they experience a pronounced drawdown of the water table.

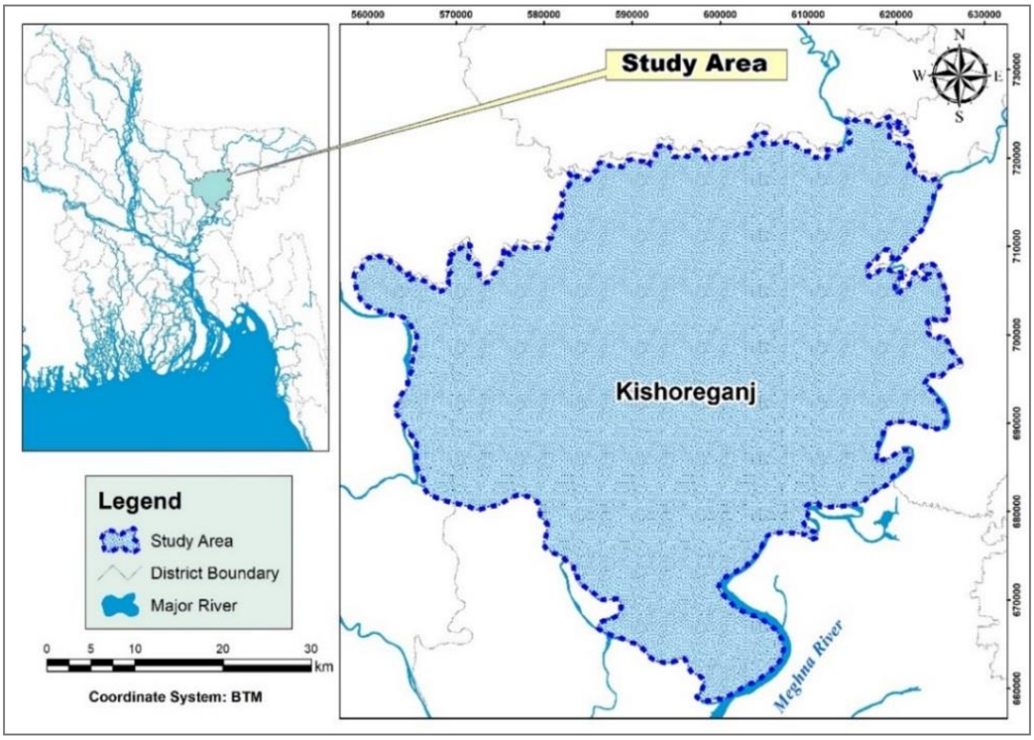


Figure 1. Study Area

3. SUPPORTING DATA

Satellite image: The Level 1 Terrain-Corrected data acquired by the Landsat 8 OLI sensor on 20 January 2018 were collected from the United States Geological Survey (USGS) using Global Visualization Viewer (GLOVIS) portal. With the launch of Landsat 8 on 11 February 2013, the improved Operational Land Imager (OLI) sensor and Thermal Infrared Sensor (TIRS) were introduced. In order to carry out the NDVI based water delineation, one multispectral Landsat 8 C1 Level1 image were selected (LANDSAT_SCENE_ID = "LC81370432018020LGN00", WRS_PATH = 137, Starting Row = 043, Reference Datum = ‘‘WGS84”, Projection = UTM, Zone Number = 46) to coincide with winter of hydrologic year 2018. LANDSAT 8 OLI-TIRS image consist of nine spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9, 15 meter for Band 8 (panchromatic) and 100 meter for thermal bands 10 and 11 (Table 1). The obtained multiband images of red, near-infrared (NIR) bands were converted to top-of-atmosphere reflectance using metadata with the help of ArcGIS. The spatial resolution of used images was 30 meters. Figure 2 represents the used satellite image for this study.

Table 1. Landsat 8 Bands (Barsi et al 2014)

Bands	Resolution (meters)	Wavelength (μm)
Band 1 - Coastal /Aerosol	30	0.435 - 0.451
Band 2 - Blue	30	0.452 - 0.512
Band 3 - Green	30	0.533 - 0.590
Band 4 - Red	30	0.636 - 0.673
Band 5 - Near Infrared (NIR)	30	0.851 - 0.879
Band 6 - Shortwave Infrared (SWIR)-1	30	1.566 - 1.651
Band 7 - Shortwave Infrared (SWIR)-2	30	2.107 - 2.294
Band 8 - Panchromatic	15	0.503 - 0.676
Band 9 - Cirrus	30	1.363 - 1.384
Band 10 - Thermal Infrared (TIRS) 1	100	10.60 - 11.19
Band 11 - Thermal Infrared (TIRS) 2	100	11.50 - 12.51

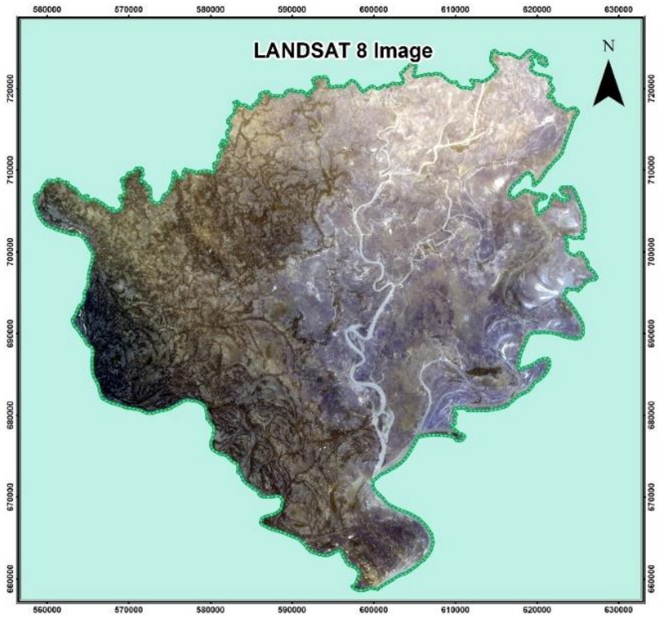


Figure 2. LANDSAT 8 OLI-TIRS combined image of the study area

4. METHODOLOGY

After obtaining the data, it was pre-processed and sampled for validation. To obtain the objective of the study determination of NDVI was then performed. Figure 3 shows the overall method adopted for identification of water bodies using LANDSAT 8 OLI-TIRS combined imagery.

4.1. Image Pre-processing

The first step involved specifying the sub-areas to be studied and the geometric correction of the images are applied. The DN values of the Landsat 8 (2018) of USGS EROS Centre, converted to TOA spectral radiance using the radiance rescaling factors provided in the Landsat header MTL metadata file (Eq. 4.1). This type of correction is a pre-requisite in many remote sensing applications such as classification and change detection procedures (Song et al. 2001). The conversion formula is

$$L_\lambda = M_L * Q_{cal} + A_L \qquad (4.1)$$

where, L_λ =Spectral radiance (W/(m2 * sr * µm)); M_L = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata); A_L = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata); Q_{cal} = L1 pixel value in DN

4.2. Normalized difference vegetation index (NDVI)

Tucker (1979) developed the Normalised Difference Vegetation Index (NDVI) using the two bands of light: red and near-infrared. The normalized difference vegetation index (NDVI) (Eq. 4.2) is the ratio of the difference between the near-infrared band (NIR) and the red band (R) and the sum of these two bands (Figure 4) (Rouse Jr et al 1974):

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4.2}$$

NDVI combines these reflectance characteristics in a ratio, so it is an index related to photosynthetic capacity. It is used to measure the vegetation cover and also water bodies over the earth surface (Tucker and Choudhury (1987), Jackson and Huete (1991)). Tucker (1979) found that the NDVI value ranges from -1 to +1. Here, +1 describes the dense vegetation. Water typically has an NDVI value of less than zero. Here, -1 signifies the presence of extensive deep water bodies.

Figure 3. Overall flowchart adopted in this study

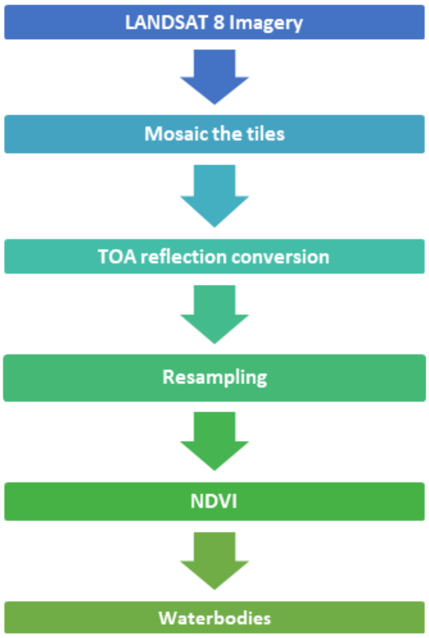
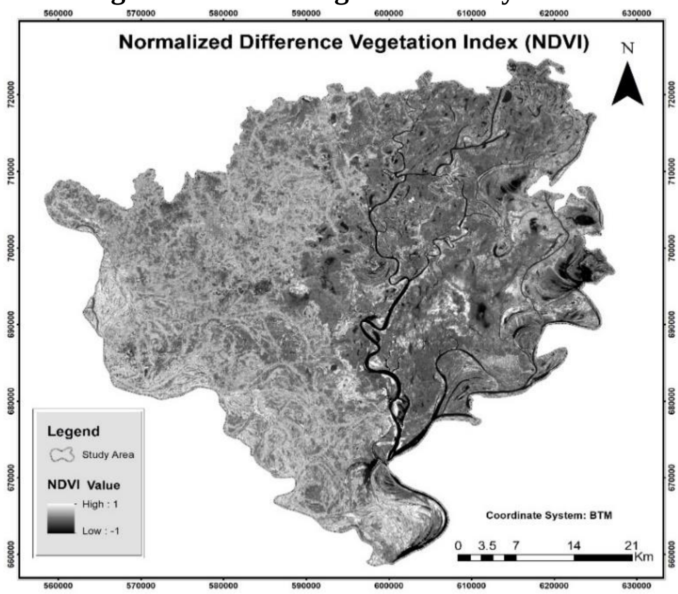


Figure 4. NDVI image of the study area



5. RESULTS AND DISCUSSION

Wetland delineation is the process by which the investigator identifies and locate wetlands, then qualitatively or quantitatively assesses the extent of wetlands on the site. The NDVI based identification of the Landsat 8 OLI-TIRS imagery (2018) reveals that the amount of waterbodies is about 39.8 km^2 within the study area. The spatial resolution plays a significant role in pixel-based classification of satellite imagery. In general, high spatial resolution data are helpful for fine-scale assessments. Since selected imagery has the resolution of 30m*30m, some small extent of wetlands and narrow wetlands were failed to be extracted in this study. Water bodies has pixel larger than 30 m*30 m were successfully identified. In addition, constrained field access to inundation areas adds challenges to comprehensive assessment of wetlands. However, off-site wetland identification can be used as a substitute for on-site wetland delineation when the purpose is to get the general idea of an objective. Figure 5 shows delineated waterbodies for Kishoreganj district for the month of January 2018.

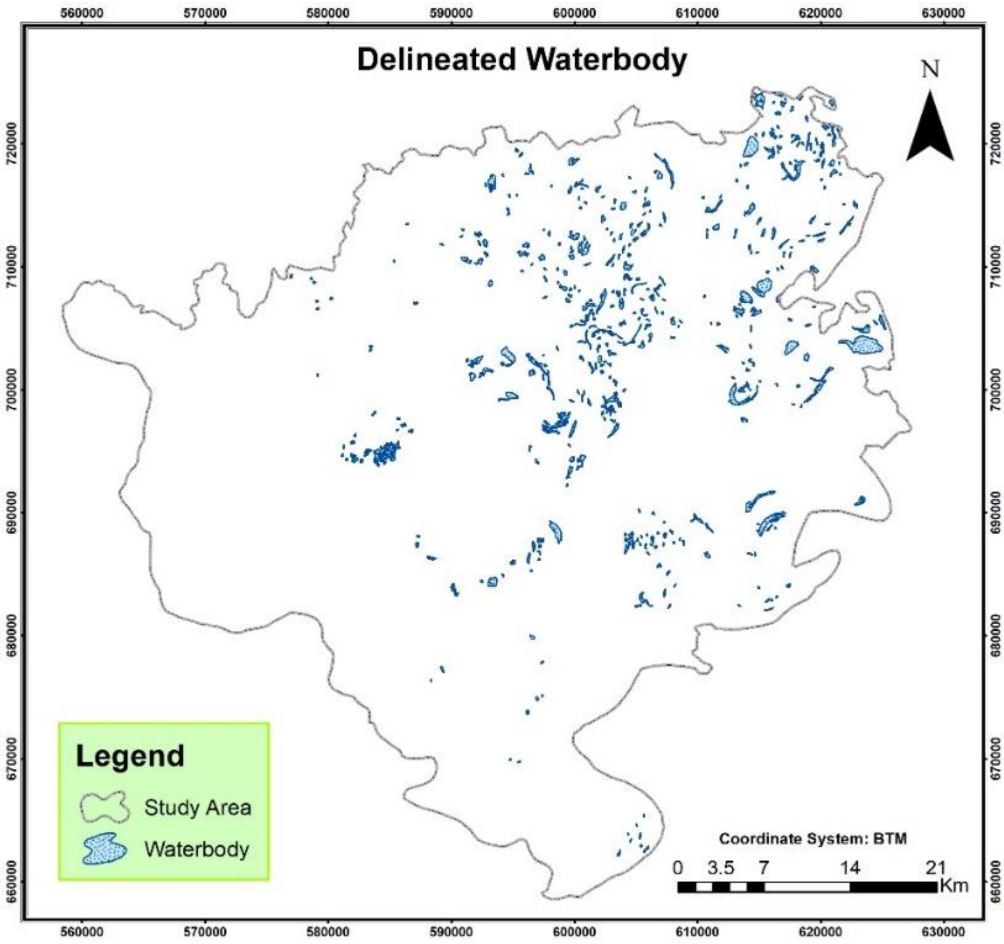


Figure 5. Delineated waterbody in dry season

6. CONCLUSION

Wetlands function as natural sponges that trap and slowly release surface water. Trees, root mats and other wetland vegetation also slow the speed of flood waters and distribute them more slowly over the floodplain. This combined water storage a braking action lowers flood height and reduces erosion. In order to effectively manage any environmental resource, its distribution and extent must be known along with its diversity. Although the study area falls in a wetland bearing district of North Eastern part of Bangladesh, the percentage of wetlands (1.56%) in dry month (January) is very low. This percentage falls successively up to April. The degradation of those areas has been causing several problems like, the extinction and reduction of wildlife as well as many endemic varieties of rice and aquatic plants, herbs, shrubs and weeds, loss of natural nutrients and natural water reserves. So, a scientific endeavor to develop sustainable pathway to conserve the wetland resources could help protect them and promote the country's economy to a greater extent.

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Identification of Potential Zones for Natural Groundwater Recharge in Dhaka City of Bangladesh

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Abstract

Dhaka is one of the world's largest groundwater-dependent cities relies on groundwater from Plio-Pleistocene fluvio-deltaic sands of the Dupi Tila formation is facing severe declination of groundwater table in spite of receiving around 2000mm/year annual rainfall. Unplanned urban development due to rapid population growth has been the cause of encroachment on retention and natural drainage areas. This study attempts to identify the potential zones for natural groundwater recharge within the study area through GIS analysis. Satellite image analysis and GIS mapping reveal that about 27.81% of the city area allows natural recharge at present conditions (2018) which is much lower compared to the heavy abstractions for municipal and industrial supplies. Based on the topography, slope, soil, land use, drainage density and thickness of clay layer, potential zones for natural groundwater recharge have been identified. These remaining potential zones for natural groundwater recharge should be protected for the existence of the mega city.

Keywords: Dupi Tila Formation, GIS, Potential Zones.

1. INTRODUCTION

The availability of groundwater is reducing gradually due to over exploitation (Morris et al 2003; Hoque et al 2007), and the lack of groundwater management (Khondaker 2006; Kaliraj 2014). As groundwater is the largest available source of fresh water lying beneath the ground and constitutes an important source for various purposes like domestic needs, supply for industries and for agriculture etc. (Raviraj 2017), therefore it has now become crucial to target recharge zones for the protection of these zones in order to protect this vital resource for the future. Dhaka city, having a population of more than sixteen million, exclusively depends on groundwater as a source of quality drinking water (Rahman 2015). But this megacity is facing severe groundwater depletion. Over exploitation due to high demands and lack of recharge due to shrinkage of waterbodies and open spaces are the main causes of this depletion. Rapid urbanization has been triggering this problem (Islam 2018). Demand is increasing day by day with the gradual reduction of natural recharge zones. An attempt has been made in this study to identify existing potential zones for natural groundwater recharge within Dhaka city corporation. Study findings will be helpful for the planners and decision makers for taking necessary steps to protect these potential zones of groundwater recharge as a safe guard for the Dhaka City Corporation.

2. STUDY AREA

Dhaka is the capital and largest city of Bangladesh. It is also one of the most densely populated city in the world. Dhaka is the economic, political and cultural center of Bangladesh. It is situated between latitudes 23°42' and 23°54'N and longitudes 90°20' and 90°28'E. The area of the study is 306.4 square km. The city is bounded by the rivers Buriganga to the south, Turag to the west, Balu to the east and Tongi Khal to the north. Dhaka experiences about 2,000 mm rain annually, of which about 80% falls during the monsoon. Since the dwellers of this city is greatly dependent on groundwater resources, therefore, identification of potential recharge zones is necessary to improve the groundwater condition of the study area. The location map of the study area is shown in Figure 1.

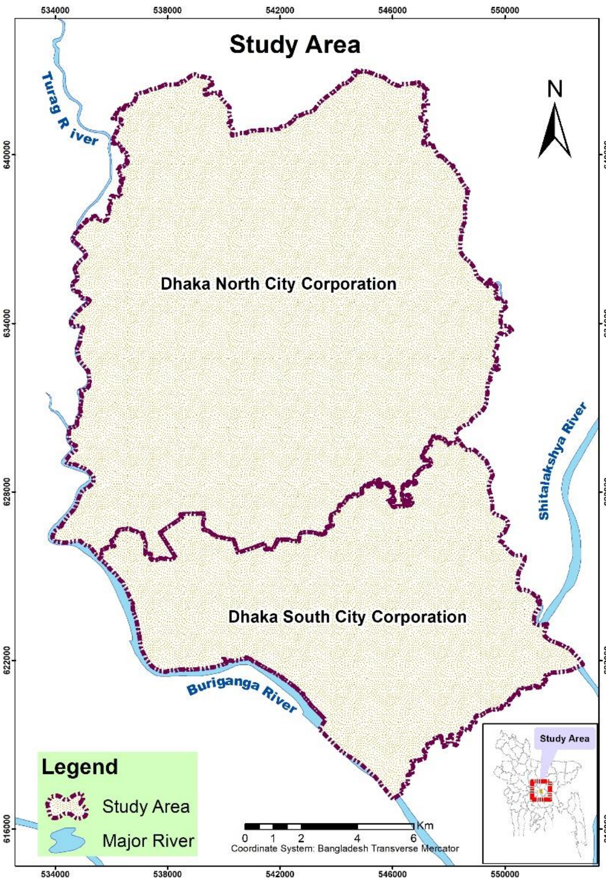

Figure 1. Study area

3. METHODOLOGY

The tasks can basically be divided in to the following categories:

- Collection and processing of data of the study area
- Thematic layer preparation
- Assigning weightage
- Identification of potential recharge zones using weighted overlay technique in ArcGIS

3.1 Data Collection and Processing

This study involves mapping of different features that influence groundwater recharge in different degrees. Hence the required data to produce thematic maps of Topography, Slope, Soil, Land use, Thickness of Clay Layer and Drainage Density of the study area were obtained from various sources for analyzing and integrating to get the final result.

Soil Map was collected from SRDI, Lithological data were collected from DWASA, Land use Map was collected from RAJUK, Drainage network was collected from IWM, Topography data was collected from USGS Earth Explorer and Slope was generated from topographic data.

These data were used to produce thematic map of the study area using Arc GIS 10.4.

3.2 Thematic Layer Preparation

Topography

Dhaka city falls in a flat terrain, where elevation of land surface varies from 0.8 to 14.1 m PWD. High elevated area is not suitable for groundwater recharge, but depressed area is good for groundwater recharge. Northeast and Southeast parts are more suitable for groundwater recharge in Dhaka city based on topography. Based on topography, the study area was divided in five categories is shown in Figure 2 (A).

Slope

The slope of an area is an important parameter which determines the groundwater recharge capability. The slope of Dhaka city ranges from 0 to 2.19 (degree). The majority of the study area is under low degree of slope, this plain to gentle slope area characterized by very good category for groundwater recharge due to nearly flat terrain, and slow surface runoff allowing more time for rain water to percolate. The area with a steep slope is considered as poor groundwater recharge areas due to higher slope, higher runoff, and low infiltration. Based on slope, the study area was divided in five categories is shown in Figure 2 (B).

Thickness of Clay Layer

Thickness of clay layer plays an important role in groundwater recharging. Less thickness of clay layer is suitable for groundwater recharge because it allows water to percolate and boost underneath aquifer. High thickness of clay layer acts as aquitard which impedes groundwater recharge. The value of clay thickness ranges from 3.05 to 41.14 m within this study area. Most of the study area has less thickness of clay layer ranges from 3.05 to 7.08 m which is good for groundwater recharge. Based on clay thickness, the study area was divided in five categories is shown in Figure 2 (C).

Land use

The study area mostly consists of built-up area, mixed area, water bodies, agricultural land and open spaces. In this study there are some areas where combination of different land use types exists in a small area, they were categorized as mixed area in this study. From the land use point of view, agricultural lands are an excellent site for groundwater potential. Meanwhile built up land is given a low score due to the affected recharge of the groundwater regime by inhibiting precipitation through the aquifers. Because of being the most densely populated city in the world, most of the city falls under built-up area and there are very few open spaces left at present. Based on land use, the study area was divided in five categories is shown in Figure 2 (D).

Soils

The predominant soil types found in this study area are Urban land, Calcareous dark grey and calcareous brown floodplain soil (grey clay), Grey floodplain soil (Silt, Loam, clay) and Non-calcareous dark grey floodplain soil (dark grey and brown soils). These types of soils are not good for groundwater recharge, because of dominating urban land and floodplain clay. Based of soil type, the study area was divided in four categories is shown in Figure 2 (E).

Drainage density

Drainage density is an expression of the closeness of spacing channels, thus providing a quantitative measure of length of stream with a square grid of the area in terms of km/km^2. Drainage density has less influence in Dhaka city because of thick clay layer beneath the land surface which impedes groundwater recharge. The value of drainage density ranges from 0 to 11.22 km/km^2. Based of drainage density, the study area was divided in five categories is shown in Figure 2 (F).

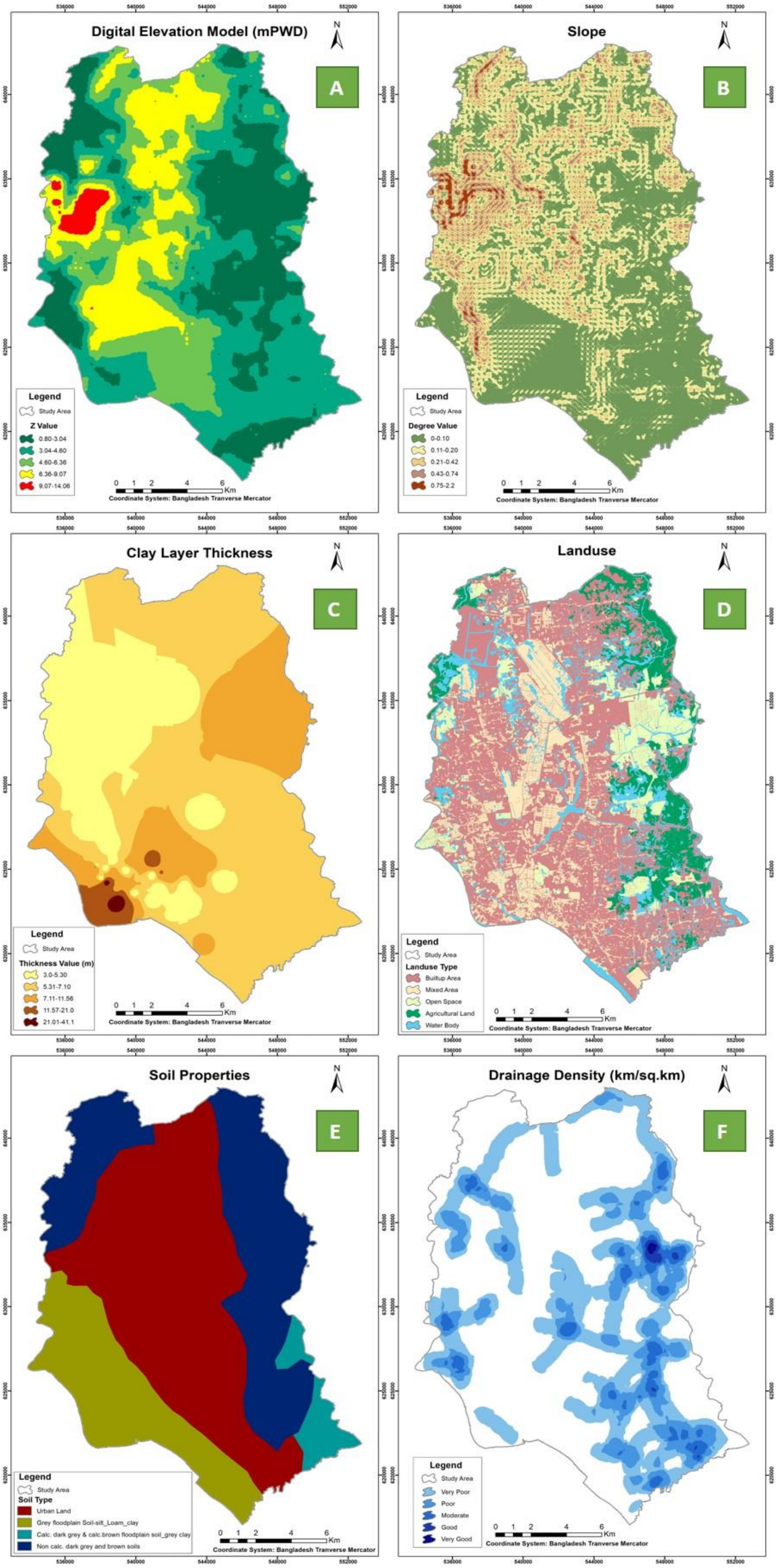

Figure 2. Thematic Layers

3.3 Assigning Weightage

Each of the thematic maps has been reclassified and assigned suitable weightage according to multi influencing factor. Groundwater potential recharge zones were identified by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 10.4.

The multiple parameter analysis for delineating groundwater recharge sites in the study area has been done by Multiple Influencing Factor (MIF) technique. In this study, six spatial parameters such as slope, land use, soil, drainage density, topography and thickness of clay layer are analyzed by MIF approach.

Weight of each factor has been assigned based on their influence in groundwater recharge in the study area. Class which is most suitable for groundwater recharge has been given maximum rank and class which is not suitable for groundwater recharge has been given minimum rank.

Classes of each influencing factors were then assigned ranks with respect to its groundwater recharge potential as shown in Table 1.

Table 1: Weighted factors influencing the recharge zones

SL. No.	Factors	Classes	Ranking (In no.)	Weightage (%)
1	Land use classes	Built-up Area	1	25
		Mixed Area	2	
		Open Space	3	
		Agricultural Land	4	
		Waterbody	5	
2	Topography	0.80-3.04	5	15
		3.04-4.60	4	
		4.60-6.36	3	
		6.36-9.07	2	
		9.07-14.06	1	
3	Thickness of Clay Layer	3.0-5.30	5	15
		5.30-7.10	4	
		7.10-11.56	3	
		11.56-21.0	2	
		21.0-41.1	1	
4	Slope classes (Degree)	0-0.10	5	15
		0.10-0.23	4	
		0.23-0.42	3	
		0.42-0.74	2	
		0.74-2.19	1	
5	Drainage density Classes (km/km2)	0-0.75	1	15
		0.75-2.03	2	
		2.03-3.39	3	
		3.39-5.06	4	
		5.06-11.23	5	
6	Soil classes	Urban land	1	15
		Grey floodplain soil (Silt, Loam, clay)	2	
		Calcareous dark grey and calcareous brown floodplain soil (grey clay)	3	
		Non-calcareous dark grey floodplain soil (dark grey and brown soils).	4	

4. Results and Discussion

4.1 Identification of potential recharge zones using weighted overlay technique in ArcGIS

Finally, after successful integration of all the thematic maps, an output raster map was obtained which indicates the potential groundwater recharge zones (Figure 3). Earlier, ranks from 1 to 5 were assigned for individual classes of topography, slope, land use, drainage density and ranks from 1 to 4 were assigned for individual classes of soil type. Based on the influence on water recharge hence the final output raster was generated with 4 classes. Value 1 indicates 'POOR' recharge, 2 indicates 'MODERATE' recharge, 3 indicates 'GOOD' recharge and 4 indicates 'VERY GOOD' recharge areas.

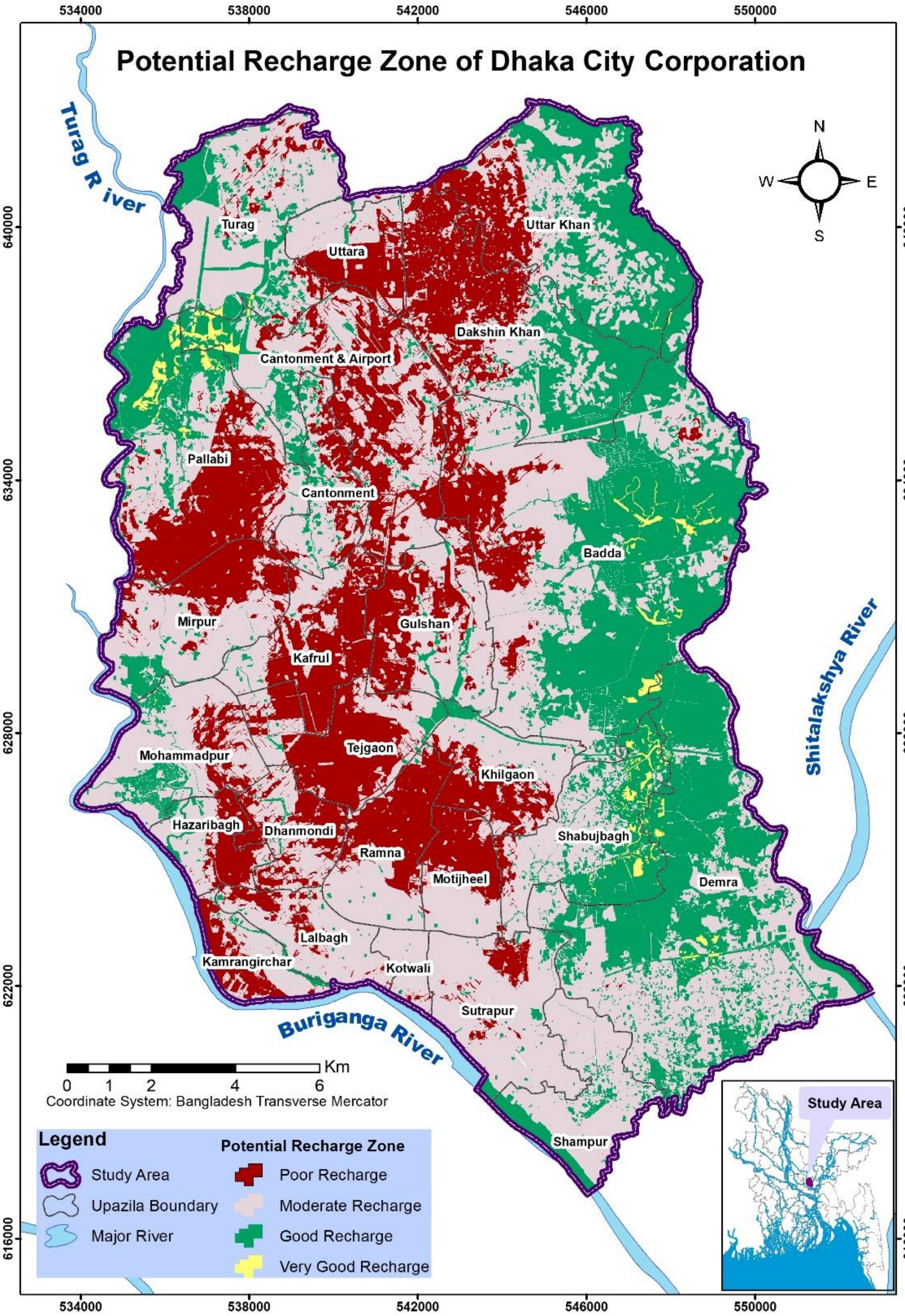

Figure 3. Potential Zones for Natural Groundwater Recharge

5. CONCLUSION

From our study, GOOD (26.87%) and VERY GOOD (0.94%) classes were considered potential zones for natural groundwater recharge in Dhaka city of Bangladesh. Around 27.81% area within the study area is suitable for natural groundwater recharge among which Badda (27.90%), Uttar Khan (23.94%), Pallabi (7.17%), Dakshin Khan (6.35%), Turag (4.20%), Cantonment and Airport (3.28%), Mohammadpur (1.96%), Mirpur (1.21%) Upazilas of Dhaka North City Corporation and Demra (23.94%) and Sobujbagh (6.98%) Upazilas of Dhaka South City Corporation are the major contributing areas. This percentage is very small and alarming too. Potential zones for natural groundwater recharge have been declining day by day. Since this city is greatly dependent on its groundwater resources, therefore protection of these potential zones should be ensured for the protection of the future of this mega city.

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Assessment of Suitability of GSMaP Satellite Estimated Precipitation Data in Estimating Runoff of Dharla River Basin

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Abstract

*Bangladesh has been formed as the greatest deltaic plain at the confluence of the Ganges, Brahmaputra and Meghna and is highly vulnerable to climate changes. For this reason, study on hydrologic model is very important for Bangladesh. To set up a hydrological model and to assess the reliability of Satellite Estimated precipitation data for determining discharge of the outlet of Dharla river basin are the main objectives of this study. In this study, hydrologic model of Dharla river basin with drainage area of 6120 sq.km is developed using HEC-HMS. Flash flood, Monsoon flood and bank erosion are some common issues with this river basin. A lumped hydrological model is developed using HEC-HMS to simulate precipitation-runoff process. SRTM 90m resolution DEM is used for delineation of basin which is downloaded from CGIAR-CSI. River network is digitized by Google Earth. Arc map 10.1 is used for watershed delineation. In place of gauge rainfall, satellite estimated rainfall data is used. The Japan Aerospace Exploration Agency (JAXA) provide hourly data of precipitation in 0.1*0.1-degree resolution observed by satellite. The simulation result is checked after real time data provided by BWDB at Kurigram station. The value of correlation coefficient (R^2) for calibration period (2009-2012) and validation period (2013-2014) are 0.71 and 0.81 respectively. From six-year model simulation, it is found that the model gives satisfactory result at dry period. At the time of high discharge, model result shows more deviation from observed data. So, GSMaP is more suitable at dry season.*

Keywords: Hydrologic model; HEC-HMS; GSMaP; Satellite Estimated Precipitation; JAXA; SRTM DEM.

1. INTRODUCTION

Bangladesh is a riverine country. Due to its location in the low-lying deltaic floodplains at the convergence of three Himalayan Rivers, heavy monsoon rainfall concomitant with poor drainage often results in annual flooding. The river systems drain a catchment area of about 1.72 million sq. km. The floodplains of the rivers are home to a large population, most of which is rural and poor, whose life is linked to the flooding regime. It is very important to study on every river basin of Bangladesh. By this study, we can acquire knowledge about types, time and duration of flood around this region. Flood is a common phenomenon in the south Asian part of the world. It has effects on food security, ecology, biodiversity, river flows, water security, human and animal health etc.

2. STUDY AREA

Dharala river basin is at north-west region of Bangladesh. It is a trans-boundary river, which originates from the Himalayas where it is known as the Jaldhaka River. Then it flows through the Jalpaiguri and Cooch Behar districts of West Bengal, India. The river enters Bangladesh through the Lalmonirhat District and flows as the Dharla River until it joins with the Brahmaputra River near the Kurigram District. The river basin has about 6000 sq.km area from which about 70% is at India. So, it is hard to get observed data from India. In this study, satellite generated precipitation data is used to avoid this difficulty. The study area is shown in Figure 1.

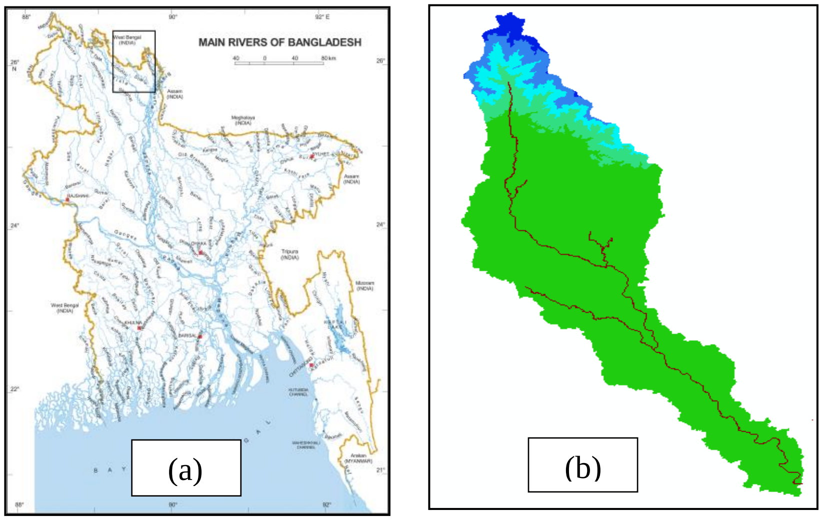

Figure 1. (a) Location of study area at map of Bangladesh. (490km*645km)
(b) Clipped DEM with river network and sub-basin shape file.

3. METHODOLOGY

3.1 DATA COLLECTION

3.1.1 Digital Elevation Model

To delineate watershed for Dharala river basin, digital elevation model (DEM) is downloaded from CGIAR-CSI Geoportal. The CGIAR-CSI GeoPortal is able to provide SRTM 90m Digital Elevation Data for the entire world. After downloading the SRTM digital elevation data, watershed delineation is done by ArcMap 10.1. After delineation shape file of stream network and sub-basin is found. Projection system of these shape file is Bangladesh Traverse Mercator. The clipped DEM and river network are shown in Figure 2.

3.1.2 GSMaP Rainfall

GSMaP stands for Global Satellite Mapping of Precipitation. The GSMaP project was promoted for the study "Production of a high-precision, high-resolution global precipitation map using satellite data", sponsored by Core Research for Evolutional Science and Technology (CREST) of the Japan Science and Technology Agency (JST) during 2002-2007. Since 2007, GSMaP project activities are promoted by the JAXA Precipitation Measuring Mission (PMM) Science Team. Description of GSMaP data is shown in Table 1.

Table 1. Description of GSMaP data

Variable	Rainfall rate (mm/hr)
Domain	Global (60N - 60S)
Grid resolution	0.1 degree latitude/longitude
Temporal resolution	1 hour

3.1.3 Evapotranspiration

Evapotranspiration data of Kurigram and Thakurgaon station been collected from IWM.

3.1.4 Water level and discharge

Water level and discharge data are collected from Bangladesh Water Development Board (BWDB). At the outlet of Dharala river basin, Kurigram station is situated which is numbered as station no.77.

3.2 GSMaP PRECIPITATION DATA ANALYSIS

GSMaP data is processed to obtain daily rainfall data. The downloaded data is compressed file in grid format. First, compressed zip file is expanded. Then, required data for specific catchment is picked from gridded file by using C++ program provided by JAXA. In the downloaded file, the precipitation data is in millimeter per hour unit. But, for use in the model data is converted into inch per day unit. Values of all grid point within a catchment are added to get gauge reading with unit gauge weight. From previous study, it can be seen that GSMaP rainfall are under simulated for every catchment of north-west region of Bangladesh (Sultana 2015).

3.3 MODEL DESCRIPTION

HEC-HMS (Hydrologic Engineering Centre and Hydrologic Modeling System) model was developed by the US Army Corps of Engineers (Feldman 2000) that could be used for many hydrological simulations. The HEC-HMS model can be applied to analyse urban flooding, flood frequency, flood warning system planning, reservoir spillway capacity, stream restoration, etc. (U.S. Army Corps of Engineers 2008). The proliferation of personal computers and the development of the HEC-1 model of the U.S. Army Corps of Engineers in 1998 to a GUI (graphical user interface) based user-friendly HEC-HMS model is available in the public domain, have come as another useful tool to the field hydrologists. Unfortunately, the HEC-HMS model, or any of the many watershed models for that matter, has not found many takers due to the uncertainty involved in the estimation of parameters of the models. But, parameter estimation on a regional scale at least may be possible to switch over to watershed models like the HEC-HMS and take advantage of the high-speed computer programs than spread sheet exercises (Kalita 2008). The HEC-HMS contains four main components.

1. An analytical model to calculate overland flow runoff as well as channel routing,
2. An advanced graphical user interface illustrating hydrologic system components with interactive features,
3. A system for storing and managing data, specifically large, time variable data sets, and
4. A means for displaying and reporting model outputs (Bajwa and Tim 2002). This model is not calibrated and validated for the Krishna basin and need reliable data inputs to check the suitability of the model for the study location and purpose. Calibration of rainfall-runoff models with respect to local observational data is

used to improve model predictability. When model results match observed values from stream-flow measurement, users have greater confidence in the reliability of the model (Muthukrishnan et al. 2006).

3.4 MODEL RUN

Each run is composed of one basin model, one meteorological model and one control specification. After provision of all required parameters it is needed to manage and execute runs. By selecting compute in run manager menu option simulation run is created. The model is run for a year with output time interval of one day.

4. CALIBRATION OF MODEL

Before the application of any model, it is necessary to calibrate it with the observed data. Model Calibration is a process of comparing the model to actual system behavior until model accuracy is judged to be acceptable. Method used in this study are Simple Canopy, Simple Surface, Soil Moisture Accounting Loss, Clark Unit Transform and Linear Reservoir Base Flow. Each method in HEC-HMS has parameters. Some of the parameters may be estimated by observation and measurements of stream and basin characteristics, but some of them cannot be estimated. When the required parameters cannot be estimated accurately, the model parameters are calibrated by creating optimization trial. The model is calibrated using the observed discharge data of Kurigram station from January 2009 to January 2012 is shown in Figure 3. After optimizing the parameter, the value of Correlation Co-efficient (R^2) is 0.71.

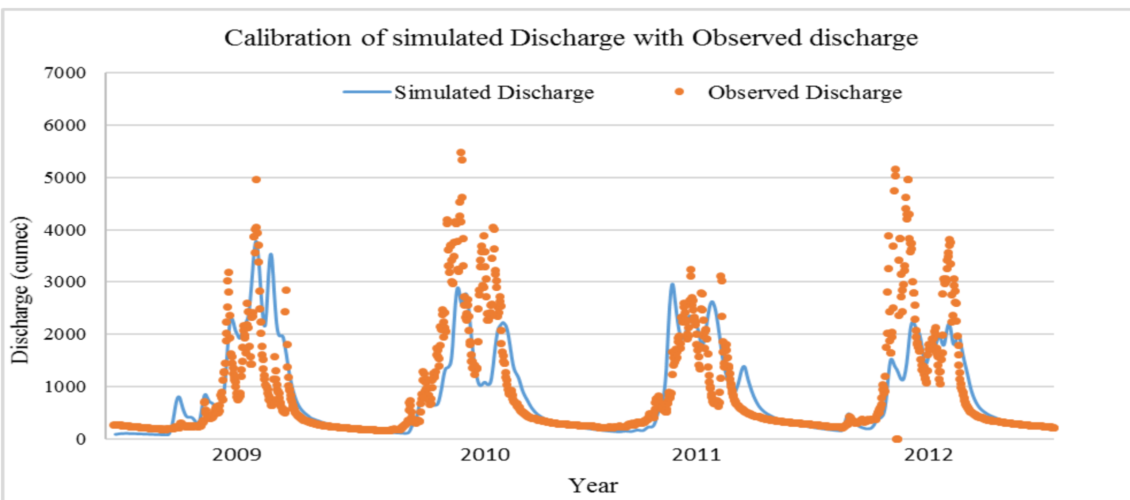

Figure 3. Observed and Simulated discharge at the outlet of the Dharala basin.

5. VALIDATION OF MODEL

Model validation demonstrates the capability of the model to produce accurate predictions for periods outside the calibration period. Model validation for this study was used to determine the effectiveness of the calibrated parameters in predicting the flow discharges at Kurigram station of Dharala River for the period 2013-2014 is shown in Figure 4.

From calibration and validation graph, it can be realized that validation graph shows more variation than calibration graph. With time, this variation increases. For example, in year 2013 peak flow occur at 23 July (2987 cumec) in simulated result where observed data shows that peak occurs at 11 July (4962 cumec).

Again in year 2014, peak flow occurs at 8 August (4361 cumec) in simulation where observed data shows that peak flow occurs at 28 August (5920 cumec). It shows more variation in both time and discharge.

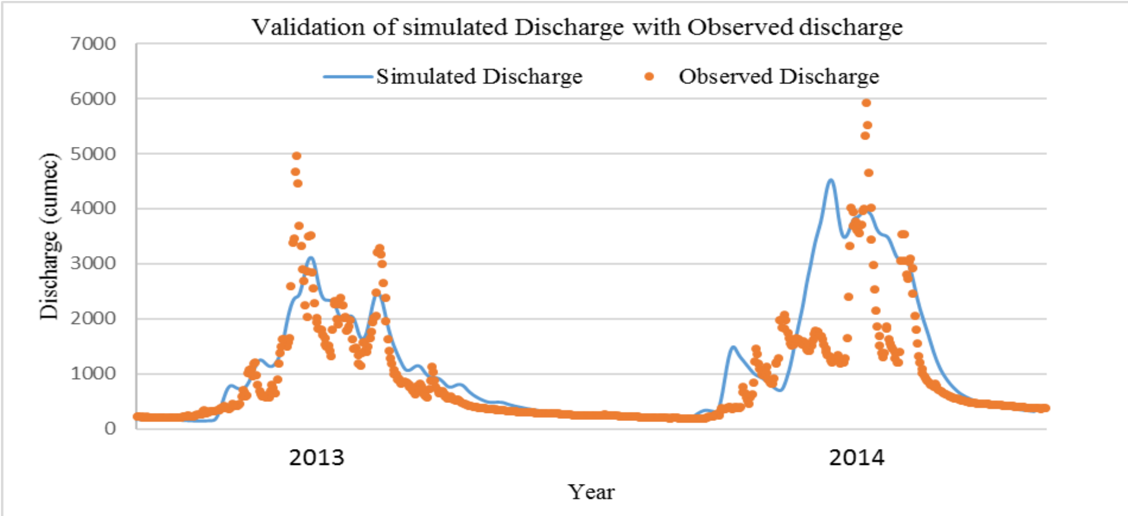

Figure 4. Observed and Simulated discharge at the outlet of the Brahmaputra basin for validation period.

6. RESULTS

The value of correlation coefficient (R^2) for calibration period (2009-2012) and validation period (2013-2014) are 0.71 and 0.81 respectively. After simulation, it is seen that observed outflow is generally greater than simulated outflow. So, GSMaP gives underestimated precipitation value compered to observed value. This observation also proved in previous study relating GSMaP. From calibration and validation graph we can see that the model gives satisfactory result at dry period. At the time of high discharge, model result shows more deviation from observed data. So, GSMaP is more reliable at dry season. From six-year model simulation, it is found that peak discharge occurred at 2 August, 2014. The value of peak flow is 4515.4 cumec. At the time of peak flow, volume passes through outlet is 38928 million m^3.

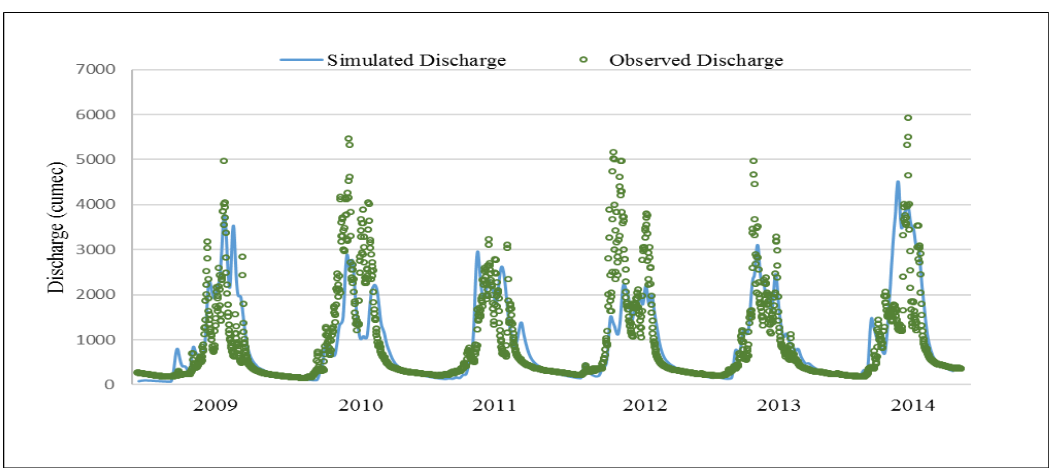

Figure 5. Comparison of simulated discharge vs. observed discharge for year 2009-2014

7. CONCLUSION

Basin parameters are adjusted by several trials considering the effect of one component on others. Calibration can be more effective and give much better result if each parameter is adjusted corresponding to each sub basin. This process may be time-consuming and requires in depth knowledge of each parameters and their correlations in basin hydrology. Observed discharge data were very much insufficient for developing a rating curve of Kurigram Station. This was very crucial for calibration and validation of model. So, a better rating curve equation shall obviously increase the performance of the model. River system designed in basin model of HEC-HMS is straight line. But rivers are not close to straight. It will be more realistic if river can be drawn with its natural bend. Working with satellite data is very complex and time consuming. On the other hand, real time data of transboundary river is very difficult to get and is not continuous. So, we should find more reliable way to relate satellite data with observed data. The model is simulated for six years. But longer time period may be used for further analysis on the availability of data. Several studies can be made using this model in future. These includes, but not limited to, effects of land use on flow, effects of any upstream development such as construction of dam, urbanization etc.

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Reuse and Recycle of Septic Tank Effluent through Bio-adsorption Process

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Abstract

Rapid population explosion is promoting ever-increasing wastewater production worldwide with severe lack of proper discharge area, especially in the developing and under-developed countries. Septic tank system, being an acceptable means of domestic wastewater disposal in rural and many urban areas without sewer system, requires further effluent treatment before disposal to protect public health and avoid environmental risks. This research focused on physical and biological treatment as a viable alternative to conventional chemical processes in improving effluent's bacteriological quality because of its simpler chemical-free design and low investment in terms of both initial cost and space required. The effectiveness of effluent treatment through bio-adsorption process by using attached microorganisms on varying locally available filter materials (e.g. gravel, broken burnt clay brick chips and plastic modules) was explored in laboratory-scale to suggest an effective way of domestic effluent treatment while monitoring two significant water quality parameters e.g. Chemical Oxygen Demand (COD) and Turbidity. Achieved results show that after multiple recycles through filter media gravel, brick-chips and plastic-modules removed 89.34%, 88.03%, 94.64% of COD and 96.58%, 95.83%, 97.15% of turbidity respectively under the condition of particle sizes between 10-15 mm. Geometric configuration of the filter materials and hydraulic retention time were monitored throughout the experiment. The final treated effluent met quality criteria for reusing in subsurface irrigation, groundwater recharge, evapotranspiration, car wash, toilet flushing etc.

Keywords: Wastewater Reuse, Septic Tank Effluent, Biological Reactor, Microbial Removal, Bio-adsorption.

1. INTRODUCTION

Increasing global population and urbanization growth result in producing huge amount of wastewater and ever-growing water stress which can be identified as the most challenging environmental safety and economy related problem faced by today's world civilization. Due to the lack of proper dumping areas and the continuous increase of water demand, reuse and recycle of domestic wastewater has become a critical issue. Adequately treated wastewater meeting strict quality criteria, can be planned for reuse for many non-potable purposes which can lead to reduction in water consumption from other sources (Vigneswaran 2009). Septic tank system has generally been recognized as an acceptable means of disposal of domestic wastewater in many under-developed and developing countries like Bangladesh. It removes most settle-able and floatable materials and functions as an anaerobic bioreactor that promotes partial digestion of retained organic matter (Subramani and Akela 2014). But primary and secondary treatment does not remove as much of the organic pollution in wastewater as may be assumed whereas tertiary treatment is simply advanced treatment of wastewater beyond secondary treatment (Jurleit 2013). The purpose of this advanced treatment is to provide a raise to the effluent quality to the desired level. This cutting-edge treatment can be accomplished by a variety of methods. Among the possible techniques, the bio-adsorption process shows potential as one of the most efficient methods which basically utilizes attached micro-organisms to the filter medium to remove organic matter from wastewater. This process is widely applied for separation and purification of wastewater because of high reliability, energy efficiency, design flexibility, technical maturity and the ability to regenerate the exhausted adsorbent (Kandasamy et al 2009). In other words, bio-adsorption has advantages over other methods because of its simpler chemical-free design and low investment in terms of both initial cost and space required. Accordingly, in this study effectiveness of effluent treatment through bio-adsorption process on various filter materials has been explored in order to suggest a cost-effective way of wastewater treatment, recycle and reuse.

2. METHODOLOGY

Filter media selection is the most crucial parameter to achieve required effluent quality in case of biological reactors, where microbes are responsible for pollutant removals via attached growth process. In addition to this, performance of filtration also depends on sampling procedure, influent solids concentration, laboratory setup and experimental condition, bed depth and filtration rate.

2.1. Variation of Filter Media

The experiment was conducted with three different materials considering their durability, insolubility, resistance to spalling and local availability- (i) Gravel, (ii) Broken burnt clay brick chips and (iii) Plastic Modules. Small filter media, which are extremely porous, boast incredible surface areas to accommodate a lot of bacteria in a small space. So, in case of gravel and brick chips materials, the filter compartment was filled with the grain size of around 10-15 mm. In case of plastic modules, cylindrical shaped hollow particles were used.

2.2. Experimental Setup

The experiment was conducted by recycling the wastewater multiple times through a PVC pipe with 2-inch diameter and 5 ft length. The setup was divided into three parts: (i) Inlet structure (0.5-inch diameter pipe), (ii) Filter structure and (iii) Outlet Structure (0.25 inch diameter pipe). For aeration purpose and to avoid anaerobic condition small vertical pipes were installed on the filter structure at certain gaps. The setup was kept away from direct sunlight to prevent algal growth. Flow-control devices were installed to the inlet and outlet structures to maintain a certain water level and flow throughout the filter length. Continuous flow was maintained as intermittent flow operation can greatly reduce the particle removal efficiency due to the possibility of bio-film's drying up and subsequently losing its biological properties (Galvis et al 2006). Slope was provided for gravity flow and it was maintained to be about 1 in 13 for all cases.

2.3. Sampling Procedure

The samples were collected from the septic tank of Bangladesh University of Engineering and Technology area. Before placing the filter materials, they were properly washed in tap water. For full growth of biological slime layer wastewater was passed through the filter bed for 20-25 days prior to taking samples. In this period, it was ensured that the bed materials would not dry out by controlling outlet and inlet.

2.4. Test Procedure

Aeration for 4 hours was performed as a method of acquiring secondary treated effluent which was then passed through the inlet feeding structure for further treatment by the filter material already coated with a biological slime layer. As the liquid trickled over the filter material, oxygen and the dissolved organic matter diffused into the film to be metabolized by the microorganisms in the slime layer. The effluent was recycled multiple times through the filter media to achieve the desired results for turbidity and COD removal. Effluent sample size of 15 Litre and flow rate of 0.65 L/hr were maintained throughout the experiment as good removal is best achieved at lower rates (Boller 1993).

3. RESULTS AND DISCUSSION

Effluent was passed through the filter materials after aeration and collected at the outlet structure. Afterwards, it was again recycled through the inlet feeding structure due to length limitation in laboratory scale and tested for different water quality parameters.

3.1. Secondary Effluent Quality Parameters for Different Coarse Media

After 4 hours aeration the parameters of obtained secondary effluent quality were observed. The test results are listed below in Table 1.

Table 1. Secondary Effluent Quality Parameters for Different Coarse Media

	Gravel		**Brick Chips**		**Plastic Modules**	
Parameters	Septic Tank Effluent	Secondary Effluent	Septic Tank Effluent	Secondary Effluent	Septic Tank Effluent	Secondary Effluent
Turbidity (NTU)	207	187	134	116	210	186
COD (mg/L)	721	122	646	117	712	168
pH	7.50	7.40	8.11	7.67	7.62	7.49
EC (μS/cm)	1102	1409	1803	2080	1320	1576

The secondary treated effluent was then passed through the filter media for further treatment.

3.2. Bio-adsorption Process Effect on Gravel as a Coarse Media

The secondary treated effluent was recycled five times through the gravel to achieve the desired results for turbidity and COD removal. Hydraulic retention time (HRT) was measured to be 6:21 minutes. It was evident from the obtained results that turbidity value dropped from 187 NTU to 6.4 NTU after only 3rd recycle when gravel was used as a filter media. It took almost three days to achieve the standard (10 NTU) result. Continuing the process till 5th recycle, almost 99.36% turbidity removal could be achieved. On the contrary, COD value of the effluent reduced from 122 mg/L to 13 mg/L after 5th recycle by using gravel. It can be stated that the COD value will reach down to less than 4 mg/L (ECR standard) after further dilution with water source while discharging.

3.3. Bio-adsorption Process Effect on Brick Chips as a Coarse Media

The secondary treated effluent was recycled six times through the brick chips to achieve the desired results for turbidity and COD removal. Hydraulic retention time (HRT) was measured to be 6:09 minutes. A decrease in turbidity value from 116 NTU to 4.84 NTU could be noticed up to 3rd recycle by using brick chips as a filter media. It took almost three days to achieve the standard (10 NTU) result. Continuing the process till 6th recycle, almost 97.98% turbidity could be removed. However, in case of brick chips, a slight fluctuation in the values of turbidity was observed. Instead of decreasing gradually, an increased value of turbidity was observed than the one measured after immediate previous recycle. This might be due to the fact that degradation and scouring of brick chips surface might have taken place with flow. Furthermore, it took 6 recycles for COD value to decrease from 117 mg/L to 14 mg/L while using brick chips as a filter media. This value will reach down to less than 4 mg/L (ECR standard) after further dilution with water source at the time of disposal.

3.4. Bio-adsorption Process Effect on Plastic Modules as a Coarse Media

The secondary treated effluent was recycled three times through the plastic modules to achieve the desired results for turbidity and COD removal. Hydraulic retention time (HRT) was measured to be 4:51 minutes. Turbidity value could be detected to decline from 186 NTU to 5.3 NTU after 3^{rd} recycle by using plastic modules as a filter media. It took almost three days to achieve the standard (10 NTU) result. But in case of plastic modules, the turbidity value remained almost same with further recycles. This might have happened because of its hollow structure due to which it couldn't hold as much solid particles compared to the other materials. On the other hand, COD value was recorded to drop from 186 mg/L to 9mg/L only after 3^{rd} recycle by using plastic modules as a filter media, thus diminishing the need for further recycles. The drastic removal of COD might have been possible due to the larger rough surface area of plastic modules. It can be implied that the COD value will reach down to less than 4 mg/L (ECR standard) after further dilution with water source while discharging.

3.5. Comparison between Bio-adsorption Process Effect on Turbidity and COD Removal Efficiency of Different Materials

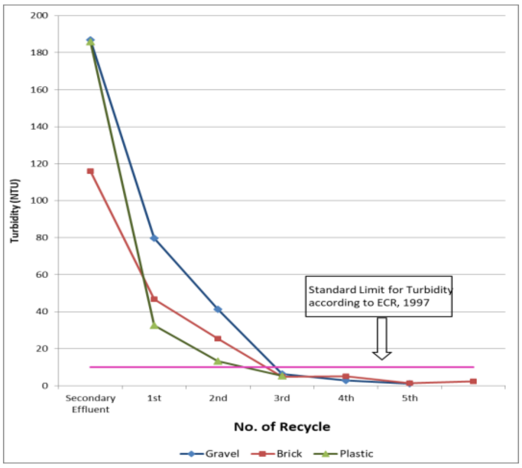

Figure 1. Turbidity Removal Efficiency in Correlation to Different Materials

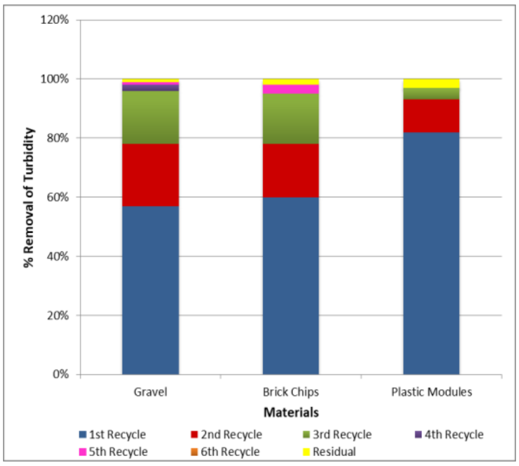

Figure 2. Turbidity Removal Efficiency of Different Materials with no. of Recycle

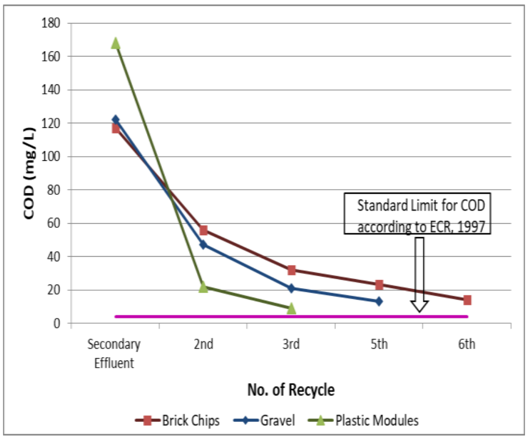

Figure 3. COD Removal Efficiency in Correlation to Different Materials

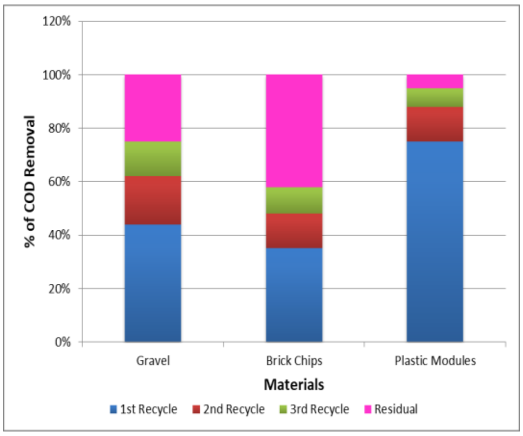

Figure 4. COD Removal Efficiency of Different Materials with no. of Recycle

A comparison between bio-adsorption process effects on turbidity removal of different materials has been shown graphically in Figure 1. Removal efficiency has been found to be 96.58% for gravel, 95.83% for brick chips and 97.15% for plastic modules, considering recycling up to 3rd time in all cases. The desired turbidity value could be obtained after three recycles for all the considered filter materials. But plastic can remove the maximum percentage of turbidity faster compared to the other materials to a certain extent because of its geometric structure which is capable of retaining larger particles. However, after a certain period, the percentage of removal remains the same for plastic modules whereas gravel continues removing turbidity with subsequent recycles and brick shows fluctuation with each recycle. It can be also inferred from Figure 2 that highest residual is observed in case of plastic modules because of their mesh-like structure which cannot retain smaller particles.
Figure 3 represents a comparison between bio-adsorption process effects on COD removal efficiency of different materials. Removal efficiency has been noted to be 89.34%, 88.03% and 94.64% for gravel, brick chips and plastic modules respectively, all up to 3rd recycle. The desired removal could be obtained after 5 recycles for gravel, 6 recycles for brick and 3 recycles for plastic. So, it can be concluded that plastic has better efficiency in removal of COD compared to other materials, as shown in Figure 4, whereas the residual was highest when brick chips were used as filter media. In all cases, COD/BOD ratio was observed in the range 2.4~2.9.

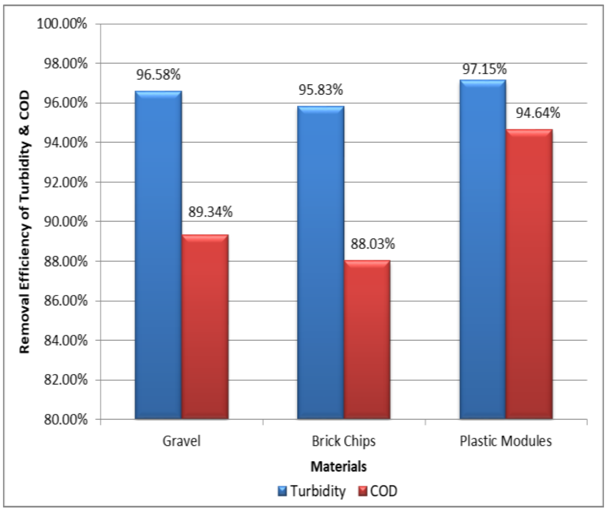

Figure 5. Comparison between Removal Efficiency of Turbidity & COD of Different Materials up to 3rd Recycle

From the above findings, as shown in Figure 5, it can be concluded that plastic module is the most effective filter material for septic tank effluent treatment through bio-adsorption process for reuse purpose. But plastic modules not being economic and readily available make them unsuitable for using in large scale projects. In contrast, gravel is easily available and economic, and the results obtained using gravel do not show much variation with plastic modules. Hence, as filter media, gravel can be suggested as the best alternative for septic tank effluent treatment if economy is the main concern.

4. RECOMMENDATION

This study was targeted towards the dwellers of Dhaka city having lower medium income status. It is only a small step in forming a wastewater management system. The final effluent that was achieved after completion of treatment procedure met quality criteria for reusing in different purposes e.g. subsurface irrigation, groundwater recharge, evapotranspiration, car wash, toilet flushing etc. A broad study based on factors affecting effluent treatment system like technical feasibility, public health, social acceptability and sustainability can be conducted. These factors can further be contextualized into an environmental framework and can be discussed under social, political and environmental characteristics.

To ensure complete disinfection and to achieve desired limits, minor/ low scale granular sand filtration is recommended. Further low dose chlorination followed by dechlorination might also be required.

5. CONCLUSION

Wastewater reuse and recycle has a big potential to bring about worldwide environmental and socio-economic benefits. It has been proven to be a sustainable approach and can be cost-effective in the long term while not compromising public health. By providing an additional source of water, wastewater recycling can help us find ways to decrease the diversion of water from sensitive ecosystems. As the growth of water demands and environmental needs is in upward direction with time, wastewater recycling will play a greater role in our overall water supply. If the aforementioned laboratory-scale experiment can be engaged in practical life, in addition to acquiring final effluent meeting quality criteria, the horizontal setup of filter bed can also prevent clogging-problem faced while using the vertical pits. To conclude, by working together to overcome obstacles, wastewater reuse and recycle along with conservation can help us to conserve and sustainably manage our vital water resources.

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Optimization of a Sewer Pipe Network using Online Resources

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Abstract

In our present time designing an efficient sewer pipe network is crucial. As the wastewater quantity is increasing drastically than before so, it's tough to tackle this problem with our former methods. In the near past, we used more in-situ techniques to optimize a sewer pipe network. Which was not only time consuming but also waste of our valuable resources. So, we should comprehend more available online resources and current optimization tool to optimize sewer pipe network more effortlessly. This will not only help us to optimize the sewer pipe network efficiently but also reduce the overall projected cost. In this paper, different online resources and google maps were extensively used to optimize the sewer pipe network for Dhanmondi, Dhaka, Bangladesh. However, there are some main hurdles in this project need to overcome, such as, excavation cost, optimum pipe diameter, pipe lengths, number of manholes and lack of online resources. To get rid of this, several iterations were performed to get the final optimization result on Microsoft Excel. Lastly, this simple method can be adopted by anyone and also can able to optimize sewer pipe network spontaneously.

Keywords: Sewer Pipe Network, Dhanmondi, Cost Analysis, Google Maps.

1. INTRODUCTION

Dhanmondi is known as one of the primacy areas of Dhaka City. The area is mostly famous for its residential purpose, apart from that there are several playgrounds, hospitals and educational institutions situated in Dhanmondi. The total area of Dhanmondi is around 4.34 km^2 Ahmed et al (2012). However, the present condition of Dhanmondi is vulnerable due to the unplanned sewer network system. Different parts of the Dhanmondi areas are often water logged during the rainy season and it cost unbearable pain to the inhabitant of Dhanmondi. In this study, one of the prime objective is to solve this problem within the minimum cost and provide a better sewer pipe network facility for Dhanmondi area. Nevertheless, as the area of Dhanmondi is enormous, so it is tough to optimize whole area through a single optimization set. As a result, we divided the Dhanmondi area into several blocks and optimize one particular block area only. Later, this optimization process technique can be used as a model to calculate the overall Dhanmondi's sewer pipe network.

However, not only Dhanmondi, many cities and industries are also facing the same kind of water logging problems due to the unplanned sewage collection system. The result of this poor planning leads not only the unnecessary cost during the construction of sewer pipe network but also it augments the duration of the construction process. Day by day the high construction cost and limited capital cost have motivated many researchers to find out an optimum solution for designing of the sewer pipe network Rajendra and Pravin (2016). Our present study is one of the payoffs of this outcome.

The purpose of the sewer pipe network is to collect the sewage from different adjoining areas and finally deliver it to the sewage treatment plant (STP). To design a sewer pipe network, the designer should consider two criterias, the sewer flow as a partial and the flow of sewer should take place under the gravitational condition. In addition to that manholes are an important parameter of pipe network

designing, which are generally used for the cleaning, maintenances and repair purposes Nagoshe et al (2014).
Earlier researchers more focused upon the conventional system to optimize the sewer pipe network, for instance initially they investigated the overall projected area in situ, then they plan for the optimization of the network. This involves heavy cumbersome due to the enormous trial and error, also a waste of valuable resources. Furthermore, the traditional process also requires extensive time for the optimization process Vijayan et al (1997). To overcome these obstacles, here we try to find out a better and convenient solution for optimization of sewer pipe network. Our present method requires not only less time but also fewer resources, as mostly we depend upon online resources, Microsoft excel and google maps. However, to make the project more viable, we selected a feasible area like Dhanmondi, Dhaka as our projected location. And our predicted result elucidates that it can be durable for the Dhanmondi.

2. METHODOLOGY

2.1 General Procedure

At first, the required data was collected from different online resources. Then the intended projected area was selected through Google Maps. The area of the projected location marked as the red circle is shown in the Figure 1. In addition to that, the length of different sewer pipes also measured using the Google Maps distance tool, and the water elevation was calculated roughly through the (http://en-au.topographic-map.com). Subsequently we assumed several feasible sewer pipe diameters and optimized the best one. As we don't know, which diameter of sewer pipe would have minimum cost. Apart from that, the sewer pipe diameter has chosen such a way that, sewer can flow on gravity condition. The cost of excavation, manhole cost and terrain conditions data were calculated based on the cost function equations, which briefly discussed in the cost function chapter. However, to optimize the minimum cost of each link, we also used the trial and iteration method using Microsoft Excel. Initially, we calculated both main sewer pipes and branched sewer pipes cost, then the final optimum cost of all network links was measured. Here manning's and continuity equations were used to determine the head loss and sewer discharge and sewer flow was partially considered in our analysis.

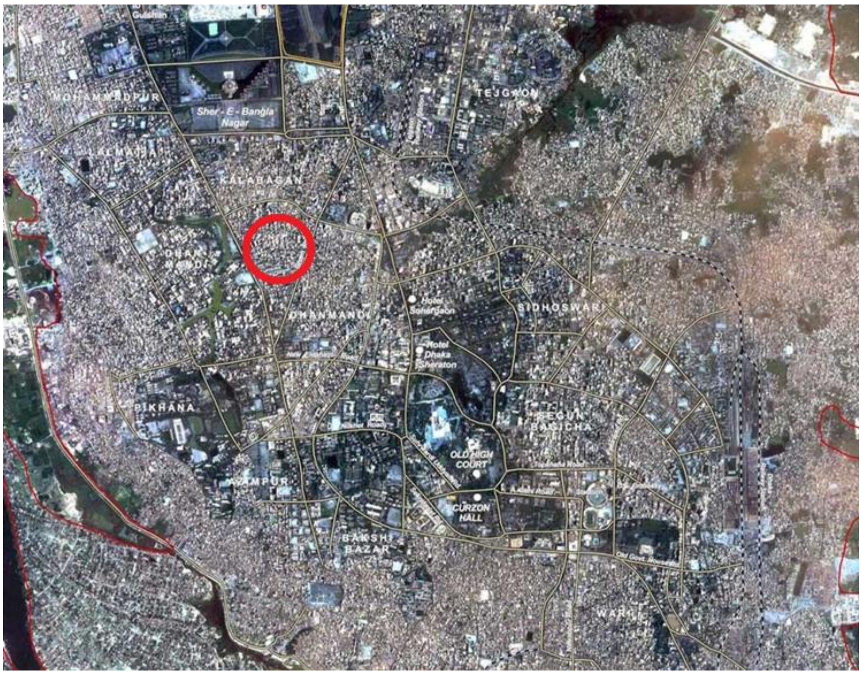

Figure 1. Projected Area Dhanmondi, Dhaka.

2.1. Cost Function

The cost function is an important parameter to determine the optimum sewer pipe network. The cost function equations were taken from the Nagoshe et al (2014). Here, the total cost of sewer pipe network is equivalent to the cost of sewer pipes, excavation of sewer trenches cost and manholes cost. The network is divided by several links. The link of a sewerage network has inverted d_1 and d_2, a trench width W, sewer diameter D, and sewer length L.
The cost of a sewer pipe C_m can be expressed as,

$C_m = k_m \times L \times D^m$, Where k_m and m are the pipe cost parameters.

The cost of excavation is the primacy for any network system. It depends on the cost of earthwork, sheeting and shoring.

Here, Cost of excavation assumed as, $C_e = K_e L\ (d_1 + d_2)$.
Where K_e is the earthwork cost coefficient. Which can be measured by,

$$K_e = \frac{1}{2} W C_e + \frac{1}{6} W \left(\frac{d_1^2 + d_1 d_2 + d_2^2}{d_1 + d_2} \right) C_r + C_s + \frac{1}{3} \left(\frac{d_1^2 + d_1 d_2 + d_2^2}{d_1 + d_2} \right) C_{rs}$$

Where, C_e =unit excavation cost at ground level, C_r=increase in unit excavation cost per unit depth, C_s= unit cost of sheeting and shoring per unit area, C_{rs}= increase in unit cost of sheeting and shoring per unit depth, *Tk/m*^{2}./m (Manual, 1993)

The cost of manhole can be written as, $C_h = k_h d_h$, Where k_h= manhole cost co efficient and d_h= depth of each manhole.

2.2. Design Constraints

To design the sewer pipe network efficiently, there are lots of design constraints which have to overcome in the project. Otherwise, the design will be fragile and some failures on the design can lead waste of valuable resources, it will also kill the valuable time. To design the network potentially, here we assumed several design constraints during our optimization process:

i. The self-cleaning velocity means the sewage itself has some inherit velocity that can reduce the clogging at the bottom of the sewer pipe. (Table 1) The minimum self-cleaning was adopted from the Swamee et al (1987).

Table 1. Self Cleaning velocity.

Sewer diameter, m	Self-cleaning Velocity m/s
0.15 - 0.25	1.00
0.30 - 0.60	0.75
>0.60	0.60

ii. The minimum manhole spacing was considered as 80 m in our design.
iii. The minimum diameter of the sewer should be 100 to 200 mm (Manual, 1993).
iv. The maximum sewer depth is generally considered between 6.0 to 10.0 m; Swamee (2001).

3. RESULTS AND DISCUSSIONS

The road was separated such a way that it has one major link and several branched links. Branched links collected sewer from the different adjoining area then it delivers to the main sewer link. The starting point of the major link is 1-1 and the last point of the major link is 1-6. Overall, 1-1, 1-2,1-3,1-4,1-5,1-6 are main sewer pipe links and 2-1, 2-2, 2-3, 3-1, 3-2, 4-1, 5-1, 5-2, 6-1,6-2,6-3,6-4,6-5, 7-1, 8-1,8-2,8-3, 9-1, 10-1,10-2 are the branched sewer pipe links. In the Figure 3, all apprehended links were showed in detail. After that, we assumed different feasible diameters for each of the link (Table 2), as here we don't know which diameter of sewer pipe would have minimum cost. Later we used trial and iteration for each links sewer pipe feasible diameter. However, the elevation of the link was measured through online. To select the feasible diameter, we considered the aforementioned design constraints 2.3.

Table 2. Feasible Diameter for each link

Links	Elevation (m)	Feasible Diameter (mm)			Links	Elevation (m)	Feasible Diameter (mm)		
1-1	18.74	350	300	250	5-2	18.83	250	200	150
1-2	18.44	450	400	350	6-1	19.53	150	125	100
1-3	18.15	500	450	400	6-2	19.41	200	175	150
1-4	17.83	600	550	500	6-3	19.13	250	200	150
1-5	17.69	700	650	600	6-4	18.94	150	125	100
1-6	17.43	750	700	650	6-5	18.81	350	300	250
2-1	19.21	200	175	150	7-1	19.14	200	175	150
2-2	19.13	225	200	150	8-1	18.94	200	175	150
2-3	18.93	250	200	150	8-2	18.91	250	200	150
3-1	18.96	200	175	150	8-3	18.83	300	250	200
3-2	18.81	250	200	150	9-1	18.95	200	175	150
4-1	19.75	200	175	150	10-1	19.02	200	175	150
5-1	19.12	200	175	150	10-2	18.88	250	200	150

Therefore, the cost of every option from each link has been calculated. In the link 1-1, the flow was taken 2.1 m^3/s by the Manning's equation. Here, the flow was assumed to be flown 75% for the partial flow condition, as when sewer flow through the pipe, it always not full into the sewer pipe, some portions of pipe are always empty. To overcome this, aforementioned condition was apprehended. In addition, the length of the link 1-1 was measured 81 m through the Google distance tool. After that the sewer pipe cost, cost of excavation and each manhole cost was calculated for each (1-1-1,1-1-2,1-1-3) options. In our present study, the cost of sewer pipe per unit length is 2197 BDT/m, cost of excavation is 300 BDT/ m and manhole cost is 12440 BDT/per assumed from Nagoshe et al (2014). Subsequently the optimum sewer pipe cost was calculated. In link 1-1 the optimum branched link was 1-1-3 and the minimum cost was taken 191980 BDT (Table 3), other options were costlier. In the same way all the other links optimum costs have been calculated. Apart from that, the sewer diameter and elevation was measured such a way that sewer would follow in the gravity condition.

Table 3. Link 1-1 cost analysis.

Link	Q, m^3/s	Options	Dia, m	Length m	The cost of sewer pipe (C_m) BDT	The cost of Excavation (C_e) BDT	The cost of Manholes (C_h) BDT	Total cost BDT
1-1	2.1	1-1-1	0.35	81	62284	116640	30851	209776
		1-1-2	0.30	81	53387	116640	30851	200878
		1-1-3	0.25	81	44489.	116640	30851	191980

Later on, in a similar way all the links optimum options have been calculated. The total cost of all links is 37,74908 BDT. Which is feasible to implement in the in-situ. Here, trial and iteration process was used to calculate the excavation cost, sewer pipe cost and manhole cost in the Excel. From the (Table-4), it was found that the highest expensive link is 1-4 and the longest sewer pipe length is linked 6-5. Here, we assumed two manholes in link 2-3, 4-1,6-5 and 8-1. Apart from that, we used manholes in every junction of the link, where roads are turned over.

Table 4. Total cost analysis for the overall sewer network system.

Links	Q m^3/s	Options	Dia. m	Length m	The cost of sewer pipes (BDT)	The cost of Excavation (BDT)	The cost of Manholes (BDT)
1-1	2.10	1-1-3	0.25	81	44489	116640	30851
1-2	4.10	1-2-3	0.35	44	33833	66660	31970
1-3	5.44	1-3-3	0.4	46	40424	72312	33214
1-4	8.84	1-4-3	0.5	90	98865	149040	35454
1-5	13.3	1-5-3	0.6	38	50091	65778	36324
1-6	16	1-6-3	0.65	40	57122	71040	37320
2-1	0.29	2-1-3	0.15	27	8897	27054	21645
2-2	0.40	2-2-3	0.15	22	7250	23694	23014
2-3	0.54	2-3-3	0.15	126	41523	163674	30851
3-1	0.29	3-1-3	0.15	38	12522	46398	26497
3-2	0.54	3-2-3	0.15	83	27352	116283	31597
4-1	0.29	4-1-3	0.15	102	33614	139842	31970
5-1	0.29	5-1-3	0.15	43	14170	54567	27741
5-2	0.54	5-2-3	0.15	80	26364	116640	32717
6-1	0.13	6-1-3	0.1	18	3954	16686	19779
6-2	0.29	6-2-3	0.15	12	3954	11664	20526
6-3	0.54	6-3-3	0.15	41	13511	43050	23014
6-4	0.13	6-4-3	0.1	30	6591	34650	24880
6-5	1.32	6-5-3	0.25	133	73050	186333	33214.8
7-1	0.29	7-1-3	0.15	90	29659	135810	34085.6
8-1	0.29	8-1-3	0.15	118	38886	153990	30726.8
8-2	0.54	8-2-3	0.15	36	11863	55296	32966
8-3	0.88	8-3-3	0.2	41	18015	67650	35454
9-1	0.29	9-1-3	0.15	71	23398	116511	36324.8
10-1	0.29	10-1-3	0.15	56	18454	85176	33214.8
10-2	0.54	10-2-3	0.15	54	17795	90882	36573.6

Finally, the optimum sewer pipe diameter of all links was shown in the AutoCAD drawing. Furthermore, the optimum total cost of all links is also shown in a line graph format (Figure 2). The (figure 3) showed that the initial point of main sewer link diameter is 350 mm and the end point diameter is 750 mm. On the other hand, branched sewer pipes diameter is between 100 mm to 300 mm. The sewer pipe diameter arranged such a way that the sewage can flow under gravity condition.

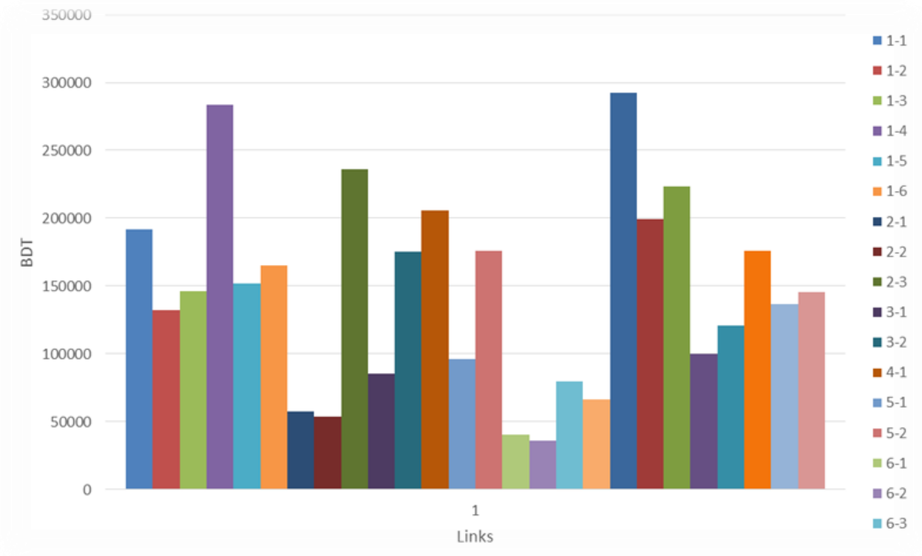

Figure 2. The total cost of all links.

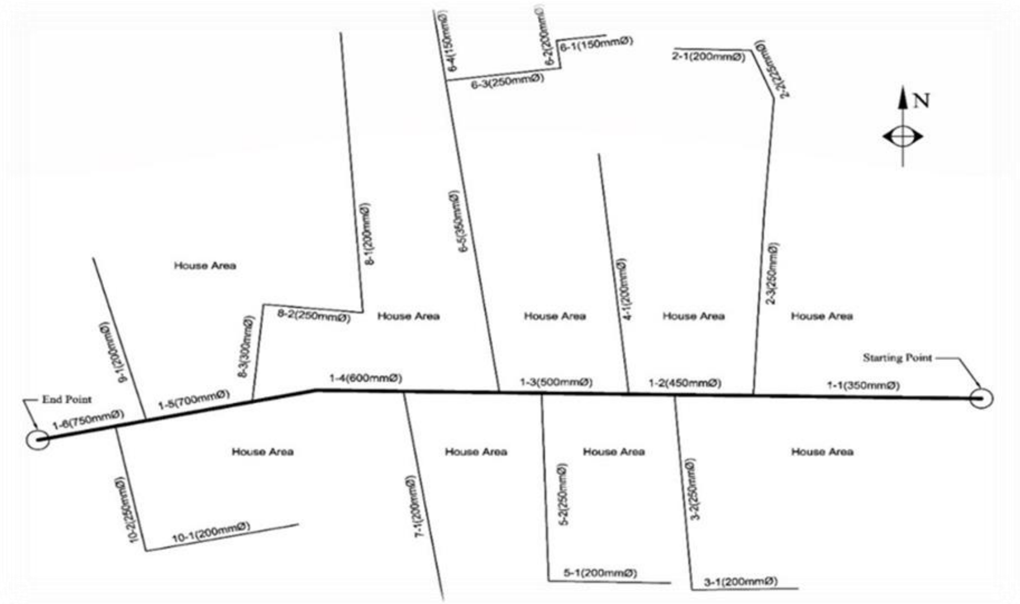

Figure 3. The overall sewer pipe diameter for all links.

4. CONCLUSION

In this paper, the projected area of Dhanmondi's sewer pipe network was efficiently measured by a simple method. As in this method, no in-situ tools were used, so the cost of the project optimization would be minimal. Although several difficulties were faced during the project work, for instance, lack of accurate online elevation and excavation cost data etc. To make the project more accurate, I have done some questionnaire to correlate our data for the feasible purpose. However, this method has some drawbacks to measure the large scale area due to the heavy iteration. But it can be solved by generate the whole area into several blocks. Subsequently, the overall optimization can be done by merge all the several blocks data. In our project, the total cost of the network is calculated 37,74908 BDT. To make the optimization more efficient, we need to do some future works, such as software works for optimization (like, SewerGem) or some in-situ measurements.

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Using Turbidity to Determine Total Suspended Solids in an Urban Stream: A Case Study

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Abstract

A high concentration of total solids will make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water. Levels of total solids that are too high or too low can also reduce the efficiency of water treatment plants, as well as the operation of industrial processes that use raw water. The estimation of Total Suspended Solids (TSS) is very much important in relation to selection of proper treatment process. The direct measurement of TSS is relatively costlier and time consuming than turbidity measurement. Though universal correlation doesn't exist, there are many investigations showing that turbidity is in relation with suspended sediments. For example, Model developed for Turbidity & TSS for the Sitnica river, Kosovo, shows the coefficient of determination R^2= 0.8687, for fourteen rivers around Singapore R^2= 0.80 & for urbanizing streams at Puget, Canada, R^2=0.96. The aim of this work is to establish a regression model that would enable the measurement of TSS in the Sitalakhya river at Dhaka through the measurements of turbidity. TSS & Turbidity concentration was measured daily throughout the year 2017 and regression model was developed to surrogate turbidity for TSS. It is found that for the year 2017 as a whole the R^2= 0.48, for the dry and wet season they were 0.51 & 0.59 respectively, which are not excellent but fairly good correlation. When calculating the regression equation for every month we found that R^2 varies from 0.04 to 0.79, and half of the twelve values fall below 0.2. Thus, for this particular site, the use of turbidity as a surrogate to TSS for individual monthly measurement is not effective throughout, however, to get an instantaneous idea of pollution during dry and wet season as a whole, the model can be used.

Keywords: Correlation, surface water, turbidity, total suspended solids.

1. INTRODUCTION

All streams carry some SS under natural conditions. However, if concentrations are enhanced through, for example, anthropogenic perturbations, this can lead to alterations to the physical, chemical and biological properties of the water body. Physical alterations caused by SS include reduced penetration of light, temperature changes, and infilling of channels and reservoirs when solids are deposited. These physical alterations are associated with undesirable aesthetic effects, higher costs of water treatment, reduced navigability of channels and decreased the longevity of dams and reservoirs as pointed out by Bilotta and Brazier (2008). Dawson and Macklin (1998) and Haygarth et al (2006) mentioned that chemical alterations caused by SS include the release of contaminants, such as heavy metals and pesticides and nutrients such as phosphorus into the water body from adsorption sites on the sediment. Furthermore, where the SS have a high organic content, their in-situ decomposition can deplete levels of dissolved oxygen in the water, producing a critical oxygen shortage which can lead to fish kills during low-flow conditions, pointed out also by Bilotta and Brazier (2008).

Turbidity can be caused by the presence of suspended solids, such as clay, silt, sand, from inorganic materials and organic matter such as algae and/or plankton. The presence of dissolved organic matter fluorescent dissolved organic matter, and other dyes will also contribute towards the turbidity of water. As the turbidity is a function of particle shape, size, and composition it follows that if two waters have the same turbidity, they may not necessarily contain the same concentration of suspended solids. Figure 1 is a photograph of two waters with differing turbidity. The water on the left is visually cloudier (higher turbidity) than the water on the right. The cloudy water on the left contains very small particles that have a strong ability to reflect and scatter light. The sample on the right has a smaller number of larger particles giving the water a lower turbidity. However, these two waters contain the same mass of suspended solids that is they contain the same concentration of total suspended solids. The difference between these two samples is particle size. In the left sample there are a large number of small (low mass) particles and in the right, we have a much smaller number of large (higher mass) particles. For each sample, if we multiplied the number of particles by the mass of the particles, we would get the same answer. This was explained in Watery News (2016).

For most waters containing suspended particles, there will typically be a defined relationship between Turbidity (Measured in NTU) and Total Suspended Solids (mg/l).

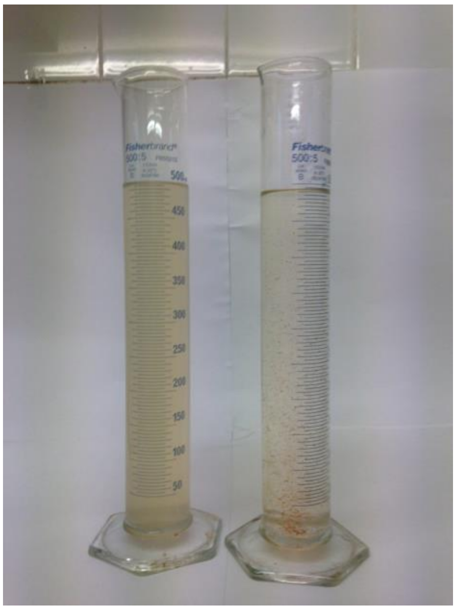

Figure 1. Waters with differing levels of turbidity (Watery News 2016)

The universal correlation between turbidity and TSS doesn't exist, as reminded by Carlson (2005), however there are some investigations showing that turbidity is in relation with suspended sediments. It is known that the eventual relationship between TSS and turbidity is affected by density, size, and shape of particles and water colour. But, if a good correlation between TSS and turbidity is developed then turbidity may serve as a proxy for suspended solids and pollutant concentrations within a chosen basin. This was observed by Nasrabadi et al (2016) and Holliday et al (2003).

Many researches have been conducted in this field. The relationship between suspended sediment and turbidity along the Elbe River was investigated by The German Federal Institute of Hydrology. This study took place from June 1996 until February 2001 and involved 1405 measurements of turbidity, suspended matter and flow rates. The study showed that large streambed particles and water colour adversely affected the measurements and the measurement error was found to increase with increasing flow rate. A linear relationship between TSS and turbidity was found for naturally suspended sediments in rivers in South Germany. Another investigation was conducted in Kansas River and Little Arkansas River. About twenty samples were collected at eight stream-gauging stations between 1998 and 2001 in order to document the effectiveness of turbidity as a surrogate. Results from this study, showed a coefficient of determination of 0.987 between the turbidity and suspended sediments. This was due to the favourable condition of turbidity measurement, noticed by Kusari (2017), that the particle size for the test sites was 95 percent fines.

The Shitalakhya river is the lifeline of Dhaka city. At least three million city dwellers are directly dependent on the drinking water produced and supplied by treating water from this river at the largest treatment plant in Bangladesh. Raw water quality of this river is very vital to the sustainable development of the city as well as the sustainable supply of drinking water to the citizens. In general, around fifteen thousand samples are tested annually for quality assessment including TSS and turbidity in relation to operation of the treatment plant which involves considerable time and cost. No such study correlating different quality parameters have been conducted recently with Shitalakhya water. The correlation study between turbidity and TSS may help to ascertain TSS from turbidity information, thus saving time and money.

With this background the aim of this study is to establish, if feasible, a regression model that would enable the measurement of TSS in the Sitalakhya river at Dhaka through the measurements of turbidity.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Dhaka the capital city of Bangladesh which has a distinct monsoonal season, with an annual average temperature of 26°C and monthly means varying between 19°C in January and 29°C in May, sometimes reaching to 40°C. Approximately 87% of the annual average rainfall of 2,123 millimeters occurs between May and October. Dhaka is located at 23° 42′ N 90° 22′ E, on the banks of the Buriganga river and surrounded by other peripheral rivers. The largest water treatment plant of the country is situated near the river Sitalakhya in the eastern periphery of Dhaka city at Latitude N 23° 43' 11.25" and Longitude E 90° 26' 14.25" as was stated by Serajuddin et al (2018).

2.2 Sample collection and analysis

Raw Water samples were collected from the treatment plant intake from a depth of 0.6 d of the channel. Samples were collected in clean plastic cans of 2 litres capacities for physicochemical analysis. The collected samples were transferred to the laboratory of the plant, by following the precautions laid by standard methods as in APHA (1995). Turbidity (Nephelometric Method), DO, temperature, were determined within the field of collection, the other parameters including TSS (Gravimetric Method) were analyzed in the laboratory within the stipulated period.

3. RESULTS AND DISCUSSIONS

The concentration of two important physical water quality parameters is tested taking the raw water of the Sitalakya river extracted at the intake of the largest water treatment plant in Dhaka. The study covers a period of one full year in 2017 and the concentrations of both the parameters were recorded on daily basis throughout the year and are analyzed. All the test result values are utilized in this study. The global number of the sample tested in this study period is around 730 comprising almost equally in each month covering all seasons. The results of the analysis for the average, minimum and maximum concentration values for all the parameters used as test data during the study period are presented in Table 1.

The regression analysis has been carried out to relate Turbidity with TSS. The regression is carried out first for the whole year taking all the daily measurements. Secondly the regression is done for the dry season and wet season separately comprising respectively the months of November to April and May to October. Lastly it is carried out for each month of the year in order to get a comprehensive picture of the whole year across the months. The investigation of and relationships between the parameters in the form of scatter graph are shown in Figures 2 to 4. Their mathematical expression & the coefficient of determination are also shown in Figures 2 to 4, which present apparently linear correlation between the variables.

As it can be noticed from Figure 2 and Table 2, the correlation between turbidity and total suspended solids for the study period for the year as whole gives a positive relationship and it is as follows: TSS (mg/l) = 0.2711 * Turbidity (NTU) + 5.3798 (p <0.01), but the Coefficient of determination is only 0.48, which we cannot call excellent.

Table 1. Average & maximum monthly concentration of Turbidity and Total suspended solids

Months	Total suspended Solids (mg/L)			Turbidity (NTU)		
	Max.	Average	Min.	Max.	Average	Min.
January	23.7	14.0	8.2	58.9	29.5	6.2
February	22.0	18.4	9.8	72.4	48.2	30.6
March	38.0	20.5	15.5	96.0	57.4	38.2
April	25.3	10.3	1.8	69.3	19.5	6.1
May	13.3	7.5	4.4	16.8	13.9	9.4
June	13.0	7.3	2.4	22.4	18.3	11.3
July	35.0	15.6	6.6	53.9	25.8	14.7
August	29.6	14.3	7.0	47.4	20.7	10.8
September	32.6	12.0	3.6	31.7	16.6	7.9
October	23.6	12.9	4.8	52.3	23.2	11.8
November	9.2	4.0	1.0	19.0	7.0	3.4
December	14.6	5.4	2.8	18.6	7.6	3.6

Similarly from the depicted graph of wet and dry season (Figure 3 and Figure 4) we can notice that their relationship is positive and it follows the regression equation TSS (mg/l) = 0.2089 * Turbidity (NTU) + 8.009 (p <0.01) and TSS (mg/l) = 0.5307 * Turbidity (NTU) + 1.1151 (p <0.01) respectively and the coefficient of determination is 0.51 and 0.59 respectively, which also we cannot say excellent.

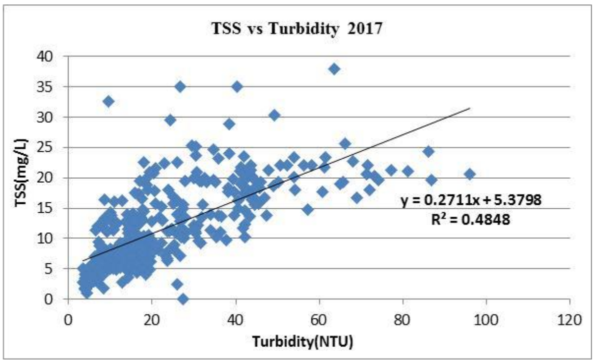

Figure 2. Regression analysis of turbidity and TSS for 2017

Lastly the calculated regression equations and their respective coefficient of determinations for each month are shown in Table 2. We notice that there is a wide range of variations in the R^2 values, ranging from 0.04 to 0.79. Half of the R^2 values lie below 0.20 and even the lowest value stands to 0.04. The highest R^2 is found in July with a value of 0.79.

An explanatory variable, such as turbidity in this relationship, cannot be used confidently throughout the year to compute the response variable Total Suspended Solids. Since the predictive ability of the relationship can be assessed based on the coefficient of determination (R^2), then for the selected location there is not strong correlation between turbidity and TSS throughout. As it is evident from the graphs and table, we can conclude that prediction of TSS based on turbidity readings, for this given site in any part of the year is not reasonable and thus it would be wise not to use such correlations in lieu of measuring the parameter conventionally for this site and for this river water throughout the year.

Never the less the outcome of the present study is not abnormal. Because though Turbidity has the advantage that it can be measured at higher solution time-steps, however, there are limitations when using turbidity as a surrogate measure of SS. First, turbidity is a measure of only one of the many effects of SS (discussed in this paper). Second, turbidity responds to factors other than just SS concentrations. Turbidity readings are influenced by the particle size and shape of SS, the presence of phytoplankton, the presence of dissolved humic substances and the presence of dissolved mineral substances. Consequently, a high turbidity reading can be recorded without necessarily involving a high SS concentration. Therefore, if relying solely on turbidimeter data, it is not straightforward to know exactly what is causing the turbidity. Whilst time-series of turbidity may do well at describing the reduction in light penetration and aesthetic issues surrounding SS, it is likely that their use will lead to underestimation of the broader effects of SS in the aquatic environments.

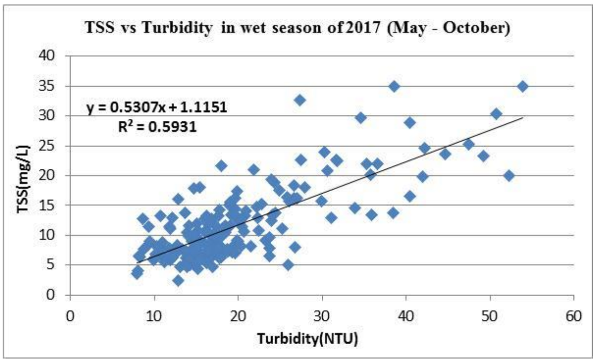

Figure 3. Regression analysis of turbidity and TSS for the wet season in 2017

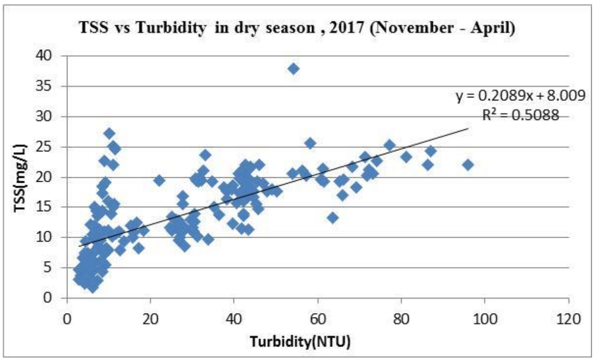

Figure 4. Regression analysis of turbidity and TSS for the dry season in 2017

Table 2. Correlation equations between Turbidity and TSS in each month in 2017

Months	Correlation Equation	Coefficient of Determination (R^2)	*p* value
January	TSS (mg/l) = 0.165 * Turbidity (NTU) + 9.1828	0.0684	>0.05
February	TSS (mg/l) = 0.0791 * Turbidity (NTU) + 14.751	0.0957	>0.05
March	TSS (mg/l) = 0.173 * Turbidity (NTU) + 14.34	0.1794	>0.01
April	TSS (mg/l) = 0.1857 * Turbidity (NTU) + 6.6561	0.5261	< 0.01
May	TSS (mg/l) = 0.1754 * Turbidity (NTU) + 4.942	0.0456	>0.05
June	TSS (mg/l) = 0.1981 * Turbidity (NTU) + 3.675	0.1589	>0.05
July	TSS (mg/l) = 0.6348 * Turbidity (NTU) - 0.7308	0.7945	< 0.01
August	TSS (mg/l) = 0.426 * Turbidity (NTU) + 5.5006	0.4919	< 0.01
September	TSS (mg/l) = 0.7042 * Turbidity (NTU) + 0.3302	0.6409	< 0.01
October	TSS (mg/l) = 0.3905 * Turbidity (NTU) + 3.8692	0.6363	< 0.01
November	TSS (mg/l) = 0.3747 * Turbidity (NTU) + 1.3598	0.6961	< 0.01
December	TSS (mg/l) = 0.3313 * Turbidity (NTU) + 2.9035	0.1696	>0.01

4. CONCLUSIONS

With a continuous daily data over the year of 2017 of turbidity and TSS an effort was made to correlate them with an intention if turbidity can be used as a surrogate to TSS as is done in many rivers in other countries.

From the result of the study, it is evident that the developed regression model for the analyzed river water does not indicate an excellent linear correlation between TSS concentrations and turbidity levels throughout the year at this sampling point, since the correlation coefficient of R^2 is mostly lower than expected. However, in many studies in other countries the correlations between turbidity with TSS were found excellent, like study done in Sitnika river (R^2 = 0.87) by Kushari and Ahmedi (2013), study done in Singapore rivers (R^2 = 0.80) by Daphne et al (2011). Another higher correlation coefficient (of R^2 = 0.979), was developed by a log-linear model while using the turbidity to determine Total Suspended Solids in storm water runoff from green roofs by Yaseri et al (2013). Also, a study focusing on using turbidity to determine Total Suspended Solids in urbanizing streams in the Puget Lowlands, Canada, derived a correlation coefficient as high as of R^2= 0.96 by Packman et al (1999), in a study in Kelantan river, Malaysia, the coefficient of determination was found 0.96 by Khan et al (2014).

In this reach of Sitalakhya river, it would be better not to use the turbidity values to determine the TSS throughout the year consistently. However, to have an instantaneous rough idea of TSS the relation developed may be used by the plant operator in dry and wet season as a whole and separate experiment may be conducted on other reaches of the river to determine the relation with extensive sample analysis.

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Application of Quasi-2D Hydraulic Model for the Local Level Flood and Drainage Management in a Growing Industrial Area near the Foot Hills

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Abstract

Flood and Drainage Congestion is one of the most recurrent water borne disaster in Bangladesh. There are four different types of flood in the country where flash flood creates enormous loss and damage in urban, industrial and agricultural area. This research focuses on identification of causes of drainage congestion and providing remedial measures in a growing industrial area Mirsharai near the foothill of Sitakunda low hill ranges. Detail quasy-2D hydraulic model has been developed using MIKE11 software for the study area to investigate the cause of inundation such as due to land use change, blockage or insufficiency of conveyance capacity in the downstream reaches of drainage route, and inadequate opening of the existing cross-drainage structures, etc. The model has been calibrated using the water level and discharge data collected from the field measurement. To improve the drainage situation of the area, several options have been tested/simulated like removal of the structures having inadequate opening, excavation and widening of khals, increase in the storage capacity in the study area, etc. Finally, a set of interventions have been suggested for improving the drainage situation of the area. In particular, it is observed that flood bypass, space for flood retention and widening of flood passage structure have been suggested to maintain the study area flood free from the 100-year return period flood. The results also suggested that existing cross-drainage structures in the Dhaka-Chittagong railway/ highway needs to be reviewed under changed land use condition and also continuous monitoring & maintenance of the drainage networks is important to remove sedimentation and blockage by human interventions.

Keywords: Hydrological model, quasi-2D hydraulic model, drainage congestion, Options simulation, Mirsharai.

1. INTRODUCTION

Hydrodynamic models are useful tools for the simulation and prediction of flows and water levels during the flood events. For the assessment of the flood risk, several researchers work on parametric and physically based 1-Dimensional, quasi 2-Dimensional and 2-Dimensional mathematical model as helping tools (Balica et al 2013; Castellarin et al 2011). 2-D model requires high resolution topographic data and spatial variation of input rainfall data which is scarce in data poor regions in the world. However, the quasi-2D model is very useful tool in relatively less data to address and to solve flood risk globally (Castellarin et al 2011).

Flood is a recurring phenomenon in Bangladesh and frequent floods have adverse consequences for the development of our country (Ahmad and Ahmed, 2003). Floods in Bangladesh have been classified into four types such as flash flood, monsoon river flood, local rain fed flood and cyclone & storm surge flood (WMO/ GWP 2003). Among them, flash flood and urban flood by local rainfall creates enormous loss and damage in urban, industrial and agricultural areas; thus, protection of urban especially industrial areas from flood is an important issue (Ahammed and Hewa, 2012; Schmitt et al 2004). Several influential factors such as environmental changes (e.g., land-use change, climate variability and improper river management) may be responsible for deteriorating river conveyance capacity subsequently increasing the chance of flooding at the local scale (Castellarin et al 2011, Wheater and Evans 2009; Brath et al 2003). North-east and eastern hilly areas of Bangladesh face flash flood from incessant rainfall, especially coastal area experiences tropical cyclones and associated tidal bores frequently (Choudhury et al 2004).

The study area located in the foothills of the low hill ranges which is moderate flash flood zone which normally prevailed maximum 3 to 4 hours earlier. Recently, a major catastrophic flash flood occurred in the study area on 01 June 2017 with 352mm rainfall due to cyclone ‘Mora’ (IWM 2018). The study area faces problem of water logging due to heavy rainfall which creates economical loss of the industry and movement of local people. The surrounding area was inundated for 6 to 7 hours as reported by local stakeholders. From the historical land use, it was revealed that the study area was functioned as water retention before development. Even some cross-drainage structure under the Dhaka-Chittagong railway and roadway are obstructed due to encroachment. And narrow down of the Barmai Chhara in between Dhaka-Chittagong new and old highway reduced the conveyance capacity of the channel. Thus, this study focuses such unexplored moderate flash flood prone foothill area which is recently developed as industrial zone.

The main objective of the study is the flood and drainage assessment which includes identification of causes of drainage congestion in the study area; development of flood and drainage model applying “a quasi-2D model approach” using MIKE 11 software; and finally, preparation of drainage management plan based on several remedial measures through different options simulations with the application of developed model.

2. STUDY AREA

The study area is located in the eastern-hilly region of Bangladesh as shown in Figure 1. The study area includes Karerhat, Zowararganj, Hingulia, Dhum, Osmanpur unions of Mirsharai Upazila under Chittagong district. The study area is situated on the eastern side of the Dhaka-Chittagong railway line near the foot hill of Sitakunda low hill ranges which is moderate flash flood zone. The land level in the study area varies from 9 to 15 mPWD inside the project area. The overall hydrology of the study area is similar of the South-East region where pre-monsoon prevails from April to Mid-May, monsoon from mid-May to October, post-monsoon from November to December and dry season from January to March (IWM 2006). Thus, most of the rainfall occurs from April to October.

The runoff generated from the upstream sub-catchment of Barmai Chhara reaches to the study area within a short period. Finally, the flood flow passes to the Feni river through the Barmai Chhara-Ichamoti Khal-Ajompur Khal System as shown in Figure 1. There is another drainage route namely Mara Chhara located approximately 300m north of the Barmai Chhara which drains the flow to the Feni River also. There is a 40-vent regulator on the Feni river constructed by BWDB under the “Muhuri Irrigation Project”. Purpose of the regulator is to provide sufficient head to the Feni, Muhuri and Selonia rivers to feed irrigation canal along with the prevention of the saline water intrusion during low tide.

3. DATA AND METHODS

3.1. Methodology

The overall approach and methodology of the study comprises review of relevant past studies, primary & secondary data collection, analysis of hydro-meteorological data, development of quasi-2D flood & drainage model, analysis of model output in terms of study requirement such as flood & drainage management plan, etc. To understand the effect of short duration and high intensity rainfall in the drainage study, design rainfall has been estimated along with hourly distribution of the storm following the guideline of the study JICA (1987).

3.2. Data Collection & Analysis

Data collection campaign covers both primary and secondary source data collection in the study area. Primary data includes gathered information through field visits, cross-sections of river/ khal survey, water level observations and discharge measurements, etc. Secondary source data includes historical hydro-meteorological data, structure inventory, geo-spatial data, topographic land level data, etc. Different types data used to conduct the study and their source are presented in the Table 1.

Figure 1. Location of the study area and delineated sub-catchment

Table 1. Types of data used and their sources

Data Type	Source	Temporal Resolution
Cross section	IWM	-
Structure Inventory	IWM	-
Hydrological Data (Water Level, Discharge)	IWM, BWDB	Daily
Hydro meteorological (Rainfall, Evaporation, Temperature)	BWDB, BMD, IWM	Daily
Geo-Spatial	IWM, BWDB, SoB, Google Earth	-
Digital elevation model (DEM)	SRTM, FINMAP	-

Collected rainfall data has been checked through double mass curve which is the way of consistency checking of the rain gauge data compared to the other surrounding stations data. Figure 2 shows the consistency checking plot for Mirsharai station which is the nearest station from the project area and it is observed that the rainfall data is consistent and reliable in comparison to peripheral other stations.

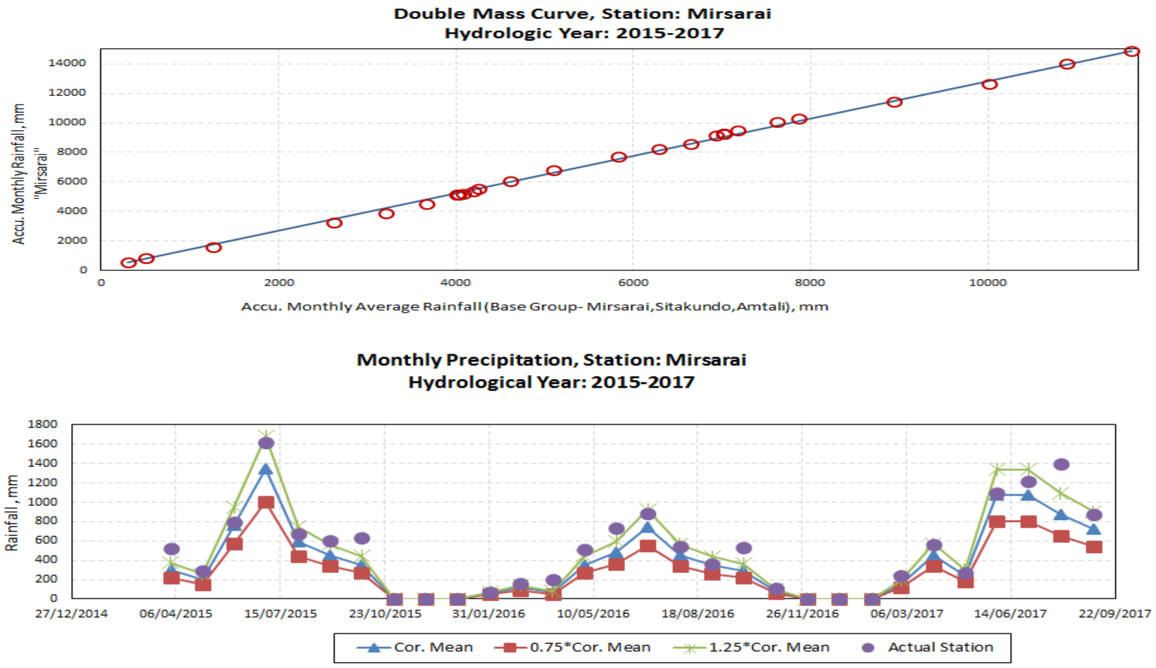

Figure 2. Double mass plot of Mirsharai vs base group accumulated rainfall (top) and Check of Mirsharai monthly rainfall against base group (bottom)

3.3. Development of the Model

Development of model for the study area includes several steps: (i) delineation of sub-catchments (Figure 1), (ii) computation of mean rainfall and evaporation for each sub-catchment, (iii) setup hydrological/rainfall runoff model, (iv) schematization of the river system, (v) set up of hydraulic model and (vi) simulation as well as calibration of the model.

A hydrological (rainfall runoff) model has been developed using NAM module of MIKE11 software package by DHI. The NAM (NedborAfstromnings Model) is the module for runoff computation from the watershed or catchments considering different hydrological variables and parameters that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base flow (DHI 2017). A detailed hydraulic model has been developed for the study area coupling with the rainfall-runoff module. The detail update of project information such as in and around khal network and hydraulic structures has been incorporated in the hydraulic model.

4. RESULTS AND DISCUSSIONS

4.1. Performance of the Developed Model

Performance of the hydrological and hydraulic model has been assessed through calibration with observed set of data at specific measured locations. Developed model has been calibrated with the observed discharge near the outlet of Barmai Chhara U/S sub-catchment which is shown in Figure 3.

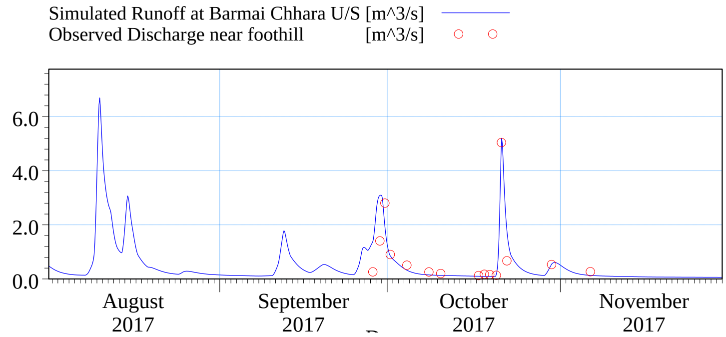

Figure 3. Comparison of simulated runoff with observed discharge (Q) at the outlet of the Barmai Chhara U/S Sub-Catchment

The hydrodynamic model in the study area has been simulated for the hydrological year of 2017. Simulated base model has been calibrated with the observed water level at location Q01 and WL01 and shows fair match with observed data. Comparison plot of the simulated and observed water level at location Q01 and WL01 are shown in Figure 4 and Figure 5 respectively.

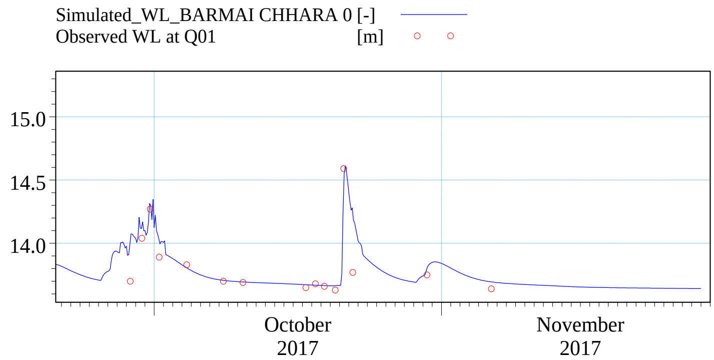

Figure 4. Comparison plot of water level at location Q01 on Barmai Chhara

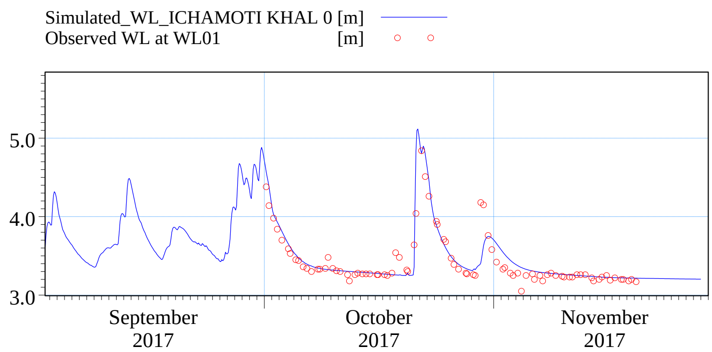

Figure 5. Comparison plot of water level at location WL01 on Ichamoti khal

4.2. Existing Drainage Situation

Developed model has been simulated for the event of 1st June 2017. Figure 7 shows the simulated water level (longitudinal profile) in Barmai Chhara. It shows that maximum flood level near inside the project area is approximately 13.83 mMSL and water level near upstream of Railway Bridge is 11.34 mMSL. From the longitudinal profile of the water level through Barmai Chhara, it has been observed that the flood accumulates before the existing steel bridge and pipe culvert at location 1360m and 1735m respectively due to insufficient opening to pass the flow. Again, the water level near U/S of the railway culvert is also above the railway track (10.77 mMSL) and creates over flow. Which is also due to the insufficiency of the opening of Dhaka-Chittagong railway and highway culverts.

4.3. Development of Options for Drainage Improvement

For the solution of the flooding problem in and around the study area several options have been developed and simulated which includes removal of structures having insufficient openings, widening and deepening of khals through excavation, increasing storage area, establishing connections between existing major khals etc. The descriptions of different options are listed in the Table 2 and the plan view of the options are shown in Figure 6.

In Option 1, Option 2 and Option 3 the preliminary design cross-section of Barmai Chhara has been considered. In Option4 more widened cross-section for the realigned Barmai Chhara has been considered for increasing storage capacity of this Chhara. In all options existing steel bridge (S3) and pipe culvert (S4) located near BSRM area at 1360m and 1735m chainage respectively have been removed which created impediment of flow through Barmai Chhara. South Periphery khal has been proposed to re-excavate which connects Barmai Chhara to the Borrowpit01. This khal ensures the connectivity of the Barmai Chhara with Khilmurari khal through Borrowpit01 and Borrowpit02 which facilitates the flood flow through several culverts under Dhaka-Chittagong highway and railway. In Option 3 additional storage has been considered with South Periphery khal. And in Option 4, storage has been considered by widening of realigned Barmai Chhara. In Option 5 ensure connection (Borrowpit03) between Barmai Chhara and Mara Chhara with Option 4. And in Option 6 increase opening of the existing bridge (S5) and culvert (S6) under Dhaka-Chittagong railway and highway respectively with Option 4.

Table 2. description of different options

Options	Description
Base	With existing all structure and existing cross-sections
Option 1	Preliminary design section of Barmai Chhara removing steel bridge (S3) & pipe-culvert (S4), excavation of Borrowpit01 and Borrowpit02
Option 2	Op1 + Improvement of Sonapahar khal and removing off-take structure (S1-1)
Option 3	Op 2 + additional storage along South Periphery khal
Option 4	Op 2 + widening and realignment of Barmai Chhara
Option 5	Op 4 + establish connection between Barmai Chhara and Mora Chhara (Borrowpit03)
Option 6	Op 4 + Increase opening of Dhaka-Chittagong railway bridge (S5) and highway culvert (S6)

Longitudinal profile of water level through study area for several options are shown in Figure 8, Figure 9 and Figure 10 for Option 4, Option 5 and Option 6 respectively. From the figures, it is clear that for in Option 4 due to widening of the Barmai Chhara (increasing the storage facility), the flood level has been improved inside BSRM area but still water logged near Dhaka-Chittagong railway. This situation has been improved in Option 5 and Option 6. In Option 5, the improvement achieved due to the establishing connection between Barmai Chhara and Mara Chhara through Borrow pit. And in Option 6, the situation has been improved for the increasing opening of existing structures under Dhaka-Chittagong railway and highway.

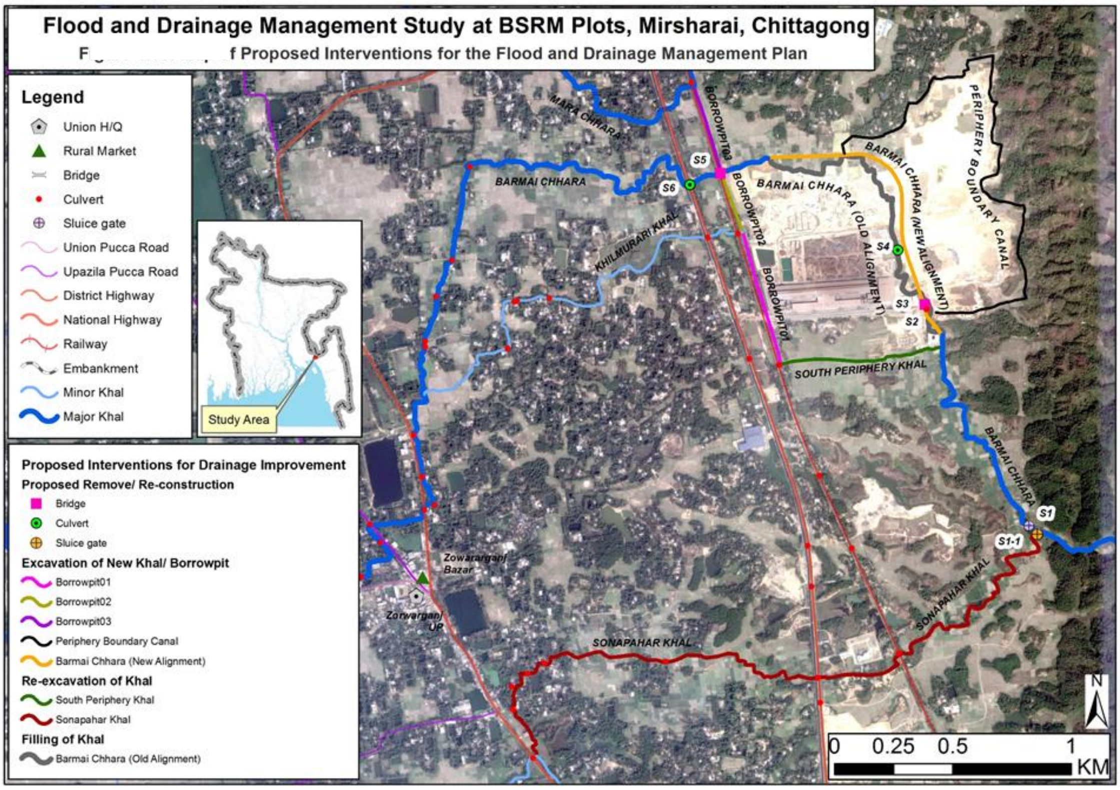

Figure 6. Map of proposed interventions for the flood and drainage management plan

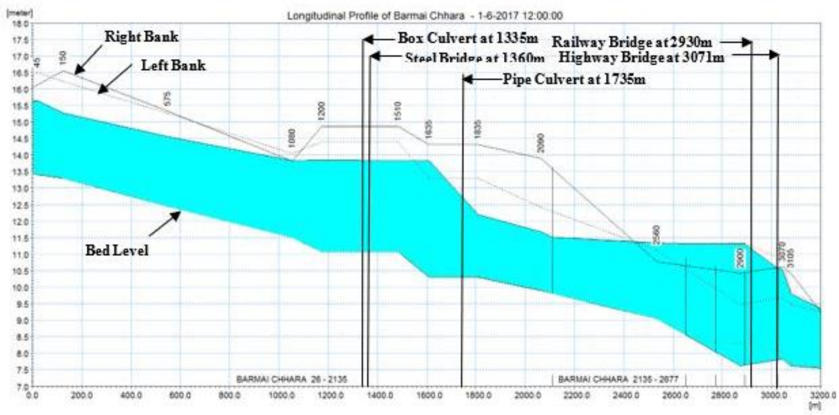

Figure 7. Longitudinal profile of Barmai Chhara at base condition (existing situation)

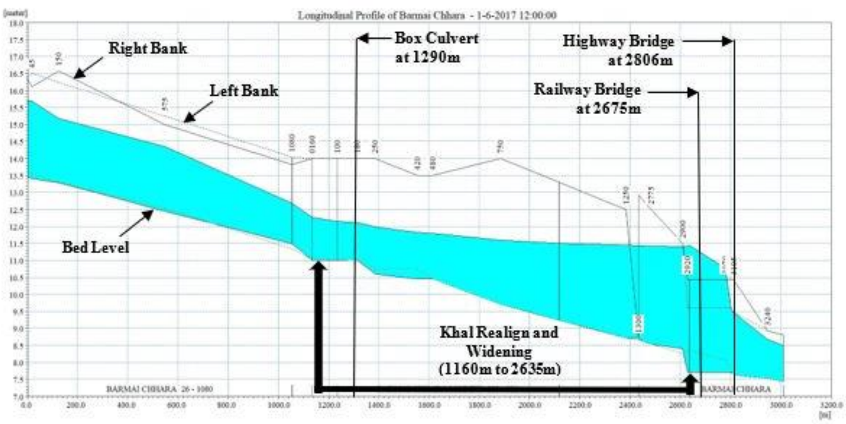

Figure 8. Longitudinal profile of Barmai Chhara for Option 4

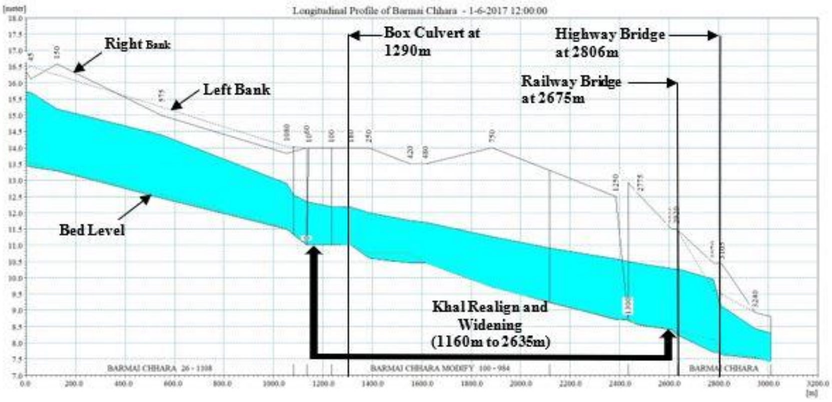

Figure 9. Longitudinal profile of Barmai Chhara for Option 5

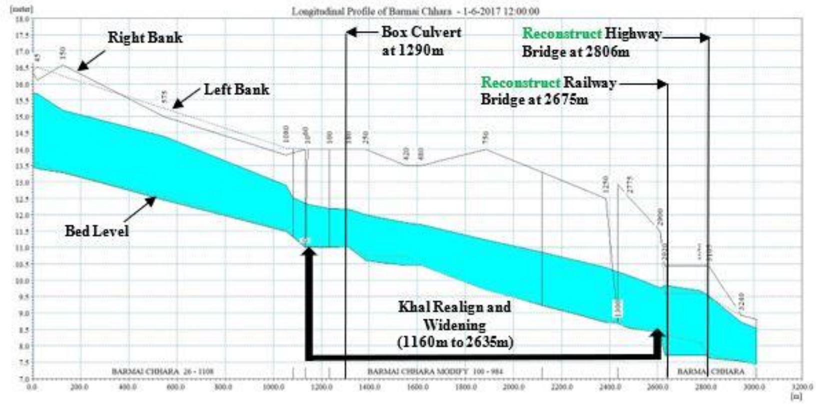

Figure 10. Longitudinal profile of Barmai Chhara for Option 6

5. CONCLUSIONS

The study area is located in the foot hill of low hill ranges near east side of Dhaka-Chittagong highway and railway. Detail quasi-2D hydraulic model has been developed using MIKE11 software for the study area. Quasi-2D model is an efficient tool to address the cause of problem, to identify critical reaches, to locate inundated area, to generate reliable boundary conditions for small scale studies, to select suitable mitigation strategies, etc. (Castellarin, et al 2011).

Investigating the model results for Base and Option scenarios, it has been understood that flash flood always occurred in the study area prevailed for 3 to 4 hours normally. But now a day, the occurrence is frequent to the project area due to several reasons such as land use change (agricultural retention area to industrial area), blockage of drainage route due to hindrance by human interventions, insufficiency of conveyance capacity of drainage route due to siltation, and inadequate opening of the existing cross-drainage structures, etc.

To improve the drainage situation of the area, options have been tested like removal of the structures having inadequate opening, excavation and widening of khals, increase the storage capacity in the project area etc. Finally, a set of interventions have been suggested for improving the drainage situation of the area. Here long-term solution suggested to the improvement of the opening of Dhaka-Chittagong railway and highway cross-drainage structures and continuous monitoring & maintenance of the drainage networks from sedimentation and blockage by human interventions. And all of the interventions suggested for immediate implication are the short-term solution for the drainage improvement around the study area. The model study also reveals that the suggested interventions has positive hydrological impact in the study area that is to keep the study area free from 100-year return period flood.

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Performance of Agricultural Activated Carbon in Removing of Pollutants from Wastewater

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Abstract

In this study, the adsorption process was considered to treat contaminated wastewater. Agricultural activated carbon was used as adsorbent which is made from garden waste as a raw material in order to remove hexavalent chromium Cr(VI) from sample of contaminated wastewater. The N_2 adsorption isotherms were used to obtain the surface physical parameters. The surface area, pore volume, micropore surface area and micropore volume of garden waste activated carbon (AC-GW) were 1190.41 m^2/g, 0.43 cm^3/g, 568.752 m^2/g and 0.299 cm^3/g, respectively. The prepared activated carbon had the maximal surface area equal to 1190 m^2/g and pore volume of 0.430 cm^3/g. Different adsorbent doses 1, 2, 3, 4 and 5 g/L of AC-GW were used to adsorb contaminates from the wastewater sample at different contact time intervals from 30 to 360 min. The initial concentration of Cr (VI) was equal to 70 mg/L in wastewater sample. The maximum removal percentages were obtained at 5 mg/L of adsorbent dose and 180 min of contact time for all different doses of parameters. The removal efficiency of hexavalent chromium Cr(VI) using the prepared activated carbon was found to be equal to 93%. Equilibrium adsorption study was analysed using two models (Langmuir and Freundlich). From the results, the Freundlich isotherm of Cr(VI) better fits to experimental data than the Langmuir isotherm.

Keywords: Activated carbon, Agricultural waste, Adsorption, Wastewater, Hexavalent chromium, Adsorbent.

1. INTRODUCTION

Water pollution results when contaminants are introduced into the natural environment. For example, releasing inadequately treated wastewater into natural water bodies can lead to degradation of aquatic ecosystems. In turn, this can lead to public health problems for people living downstream. They may use the same polluted river water for drinking or bathing or irrigation. So that, the wastewater from treatment plant should be treated before submitted to rivers and other water sources.

The high concentration of hexavalent chromium is considered one of the most toxic pollutants in wastewater which affect human healthy. Hexavalent form of chromium affects the kidney and liver and causes dermatitis, diarrhea (Mohan et al 2006). So that it’s important to treat wastewater effluent before discharging it to environmental. Different methods, physical and chemical have been investigated to treat wastewater (Wang et al 2013).

Adsorption is considered one of the most useful methods which have several advantages, primarily as a very simple technology and more efficient in removing high molecular weight compounds from aqueous matrix. Activated carbon is good adsorbent low cost and availability (Daneshvar et al 2006).

This study aimed to treat sample of wastewater which was collected from sewage treatment plant by batch adsorption process using low cost adsorbent with high porosity for removal of hexavalent chromium.

2. EXPERIMENTAL

2.1. Analysis of Sample Solution

Sample of wastewater used in this study was collected from mini sewage treatment plant which is located in Serdang at Selangor state in Malaysia. The levels of organic and inorganic contaminations were analysed according to the Examination of Water and Wastewater methods. Table 1 shows the parameters limits of sample and effluent of Standard B which stated in the Sewage and Industrial Effluents Regulations 1979 by Department of Environmental Malaysia.

Table 1. Initial characteristics of raw wastewater sample

Parameters	Unit	Value	Malaysian Standards*
pH	-	7.11	5.5 – 9.0
TDS	ppm	270	-
TSS	mg/L	1050	100
Salinity	ppm	330	-
Turbidity	NTU	276	-
Electric conductivity	µS/cm	688	-
COD	mg/L	470	100
BOD	mg/L	135	50
NH_3-N	mg/L	65	
Zn	mg/L	0.1	1.0
Cr (VI)	mg/L	70	0.05
Mn	mg/L	0.1	1.0

*Sewage and Industrial Effluents (Standards B), 1979, DOE Malaysia.

2.2. Batch Adsorption study

In this test, different adsorbent doses (1, 2, 3, 4 and 5 g/L) of AC prepared from garden waste (AC-GW) were mixed with 100 mL volume of electrolyzed leachate sample. Incubation of the conical flasks was at room temperature, and then agitated at 200 rpm using a mechanical shaker (Orbital Shaker, 100-240 VAC, HS4010A). Different retention times at 30, 60, 90, 120, 180, 240, 300, and 360 min, respectively, were employed. The following formula is used to evaluate the removal efficiencies:

$$RE\% = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (1)$$

Where C_0 initial concentration, Ce concentration at time t. Ascertainment of AC's sorption capacity was done by calculating using following equation:

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (2)$$

Where m adsorbent mass and V volume of leachate sample.

2.3. Adsorption Equilibrium Isotherms

Equilibrium adsorption study was analysed using two models Langmuir and Freundlich as follows:

$$\frac{1}{q_e} = \frac{1}{K_L\, q_m C_e} + \frac{1}{q_m} \qquad (3)$$

Where KL (L/mg) and qm (mg/g) are represent energy of adsorption and adsorption capacity, respectively. The constant qm and KL are characteristics of the Langmuir equation which can be determined from the slope and intercept of the plot Ce/qe against Ce. The equilibrium parameter $R_L$can be found from the following equation:

$$R_L = \frac{1}{(1+K_L * C_o)} \qquad (4)$$

Unfavourable adsorption was assumed when R_L>1, while linear adsorption at R_L =1, favourable (0< R_L<1), and irreversible when R_L= 0.

3. RESULTS AND DISCUSSION

3.1. AC Characterizations

The N_2 adsorption isotherms are used to obtain the surface physical parameters which were indicated in Table 2. The surface area, pore volume, micropore surface area and micropore volume of AC-GW was 1190.41 m²/g, 0.43 cm³/g, 568.752 m²/g and 0.299 cm³/g, respectively.

Table 2. Porosity characteristics of prepared AC

Properties	Value
Surface area	1190.41 m²/g
Pore volume	0.430 cm³/g
Micropore surface area	568.752 m²/g
Micropore volume	0.299 cm³/g

3.2. Batch Adsorption Process

3.2.1. Effect of contact time and Adsorbent Dose on Removal Efficiencies of Parameters

The adsorption process was done using prepared activated carbon. The final concentration of Cr (VI) were analysed after different intervals of contact time (30, 60, 90, 120, 180, 240 and 300 min). Figure 1 illustrates the effect of contact time and adsorbent dose of AC-GW in the removal efficiencies of Cr (VI). Different adsorbent doses 1, 2, 3, 4 and 5 g/L of AC-GW were used to adsorb contaminates from the sample at different contact time intervals from 30 to 360 min.

It is clear from the figure that the removal efficiencies (RE) of parameters were increased with increasing of contact time and reach the maximum removal percentages after 180 min of contact time. Cr (VI) has their optimum removal efficiencies with 5 g/L adsorbent dose and contact times from 30 to 360 min. Maximum RE for Cr (VI) are 83, 86, 87, 91, 93, 91, 93 and 93%, respectively.

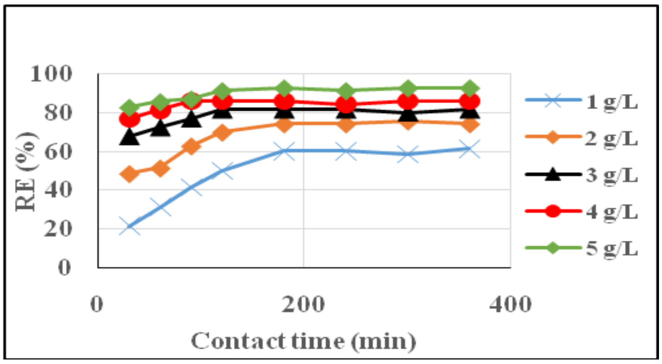

Figure 1. Effect of adsorbent dose and contact time on removal efficiency of Cr (VI)

As a result, the removal efficiencies Cr (VI) increased with increasing of contact time due to the active sites abundance on the surface of adsorbent (Aroua et al 2008 and Zhang et al 2008). The slow removal capacity with the subsequent time may be due to the diffusion of heavy metal ions onto the surface of AC and fewer binding sites (Li et al 2010). The same results were conducted by Kyzas who concluded that the end of adsorption was at 180 min (Kyzas et al 2016). Babel and Kurniawan (2004) observed that removal efficiency increased with an increase in contact time.

The adsorbent dose is strongly effected removal percentage in adsorption process (Pab et al 2016). It can be observed that removal efficiencies of Cr (VI) improved with increasing adsorbent doses due to availability of more adsorption sites (Mall et al 2006).

Maximum removal percentages were obtained at 5 mg/L adsorbent dose and 180 min of contact time for all different dosages of parameters. These results were noted as optimum conditions for subsequent studies.

3.2.2. Equilibrium Adsorption Models

The Langmuir constants and their correlation coefficients R_2 for adsorption of Cr (VI) via AC-GW are listed in Table 3. Value of R_L equal to 0.001 and correlation coefficient is equal to 0.870. While Freundlich adsorption isotherm for Cr (VI) showed that high correlation coefficient (0.992) with value of n (1.137) between 1 and 2 and represented good adsorption. From the results, the Freundlich isotherm of Cr (VI) better fits to experimental data than Langmuir isotherm.

Table 3. Langmuir and Freundlich isotherms parameters

Parameters	**Cr (VI)**
Langmuir	
KL(L/g)	14.232
RL	0.001
qm (mg/g)	3.268
R2	0.870
Freundlich	
KF	2.163
1/n	0.879
R2	0.992

4. CONCLUSIONS

The treatment of wastewater was examined using agricultural waste collected from garden waste activated carbon assisted adsorption process. The porosity characterizations of prepared activated carbon indicated that garden waste is good adsorbent due to its highly surface porosity and effective precursor for adsorption of pollutants from wastewater such as Cr (VI). The results illustrated that the Freundlich isotherm of Cr (VI) better fits to experimental data. The removal efficiency of Cr (VI) using AC-GW was found as 93%.

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Estimation of Dominant Discharge in the Old Brahmaputra River of Bangladesh

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Abstract

Determination of dominant discharge is very important in studying the river characteristics as it produces maximum morphological activities for a regime channel. In case of flood plain management estimation of the frequency of dominant discharge in the rivers is necessary. It is also important for flood mitigation and estimation of flood damage. As a case study, dominant discharge of the Old Brahmaputra River of Bangladesh is determined here using bed generative discharge concept, stage-discharge concept and meander wavelength concept, considering importance of this river as it is one of the major rivers in the north-central region of Bangladesh. In this study the frequency of dominant discharge of the Old Brahmaputra River at Mymensingh was estimated at Mymensingh station (station ID: 228.5) for 44 years, collecting data from Bangladesh Water Development Board (BWDB). Analyzing the data, it was found that the dominant discharge for the Old Brahmaputra River at Mymensingh was around 2100 cumec and from flood frequency analysis it was found that the return period of the dominant discharge was around 1.85 years.

Keywords: Old Brahmaputra, Dominant Discharge, Mymensingh, Flood Frequency.

1. INTRODUCTION

The concept of dominant discharge is very important for sedimentation problem in the river as dominant discharge is the flow doing most geomorphic work and it is also stated as the channel forming discharge. It is also very useful for river stabilization and fish habitats. Inglis (1941) said that "Dominant discharge is the discharge which controls the meander length and breadth. It appears to be slightly in excess of bank-full stage". Benson and Thomas (1966) defined that dominant discharge is the discharge which transports the most sediment in suspended load as only information on suspended sediment load is generally available and it is necessary therefore to assume that total sediment load is proportional to suspended load. in an analysis of factors controlling bank erosion, Wolman (1959) showed that lateral cutting of the cohesive channel bank of a small stream in Maryland occurred mostly during the winter months, when flows of a size which occurred eight to ten times per year attack previously wetted banks. According to Wolman, the effective magnitude apparently is considerably lower than that of bankfull stage.

Leopold et al (1964) stated that the effective discharge can be approximated by bankfull discharge that has a recurrence interval of about 1.5 years in many rivers. Carlston (1965) has conducted that the dominant discharge which controls meander wavelengths is a range of flows, possibly falling-stage flows, between the mean of the month of maximum discharge and mean annual discharge. The dominant discharge is also defined as the discharge or a flood of fixed frequency such as 1-2 years flood and it is defined as the discharge which exhibits the best statistical correlation with various channel morphological characteristics. Erskine and Keshavarzy (1996) investigated that the dominant discharge on South Creek in New South Wales, in Australia had an average recurrence interval (ARI) of 1.89 to 2.40 years on the partial series. Williams (1978) found that the dominant discharge is a bankfull discharge of approximately 1.5 years. Keshavarzi and Nabavi (2006) found recurrence interval of dominant discharge as 1.11 years in the Kor River in Iran.

In Bangladesh, Hossain (1992) computed dominant discharge of the Ganges and Jamuna River by bed generative discharge concept using the observed sediment discharge at Hardinge Bridge and Bahadurabad, respectively. Ahammad and Musfequzzaman (2014) applied different concepts (flow duration concept, bankfull discharge concept, bed generative discharge concept and meander wavelength concept) to estimate dominant discharge in the Gumti River.

In this study, suspended sediment load transport was used to estimate the dominant discharge of the Old Brahmaputra in Mymensingh considering that total load is proportional to suspended sediment load. The stage-discharge curve and meander wavelength methods were also used to find the dominant discharge and flood frequency analysis was done to estimate its recurrence interval.

2. STUDY AREA, DATA AND METHODOLOGY

As a case study, different concepts (bed generative discharge concept, bankfull discharge concept, meander wavelength concept) were adopted here for the computation of dominant discharge of the Old Brahmaputra River. This river originates from the Jamuna River in the North Central Region of Bangladesh at Kholabarichar, Jamalpur. From its source it flows about 225 km along a meandering course and follows a south-easterly course via Mymensingh and Toke upto Bhairab Bazar - at the confluence with the Upper Meghna River. The Old Brahmaputra River is at present reduced to a left bank spill channel of the Brahmaputra River and only active during the high stage of the Brahmaputra River. The highest recorded discharge of the river at Mymensingh is 4890 m^3/s during monsoon in 1988 and the lowest recoded discharge at the same station was 6 m^3/s during the dry period in 1998.

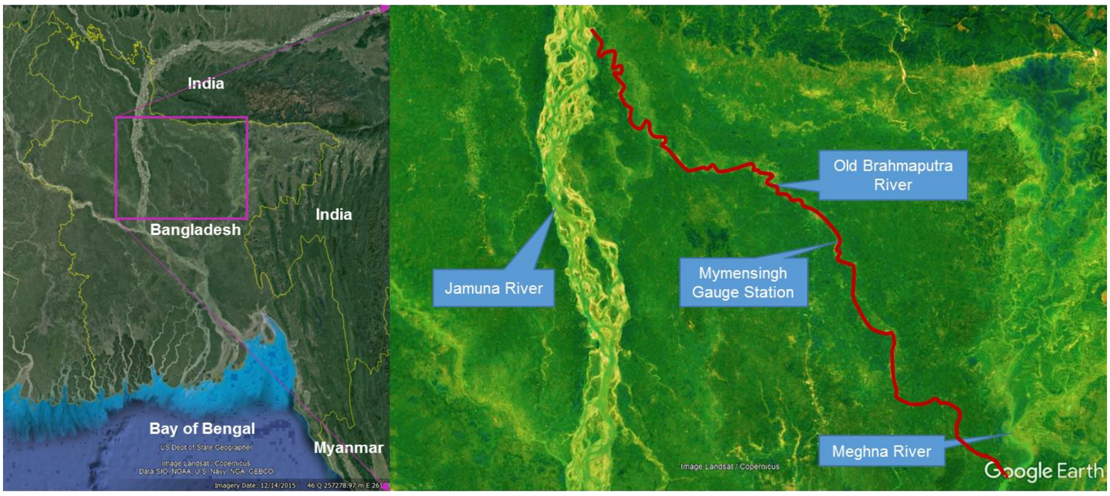

Figure 1. The Old Brahmaputra River in Bangladesh

To estimate the dominant discharge, methodology suggested by Benson and Thomas (1966) was adopted. Firstly, a graphical relationship was established between discharge and the frequency of discharge. Then another graphical relationship was developed between flow discharge and sediment load discharge at the same station. Finally, the two relationships were used to develop a third histogram which relates discharge and product of sediment load and frequency. The dominant discharge corresponds to largest volume of sediment discharge which can be read directly from the histogram. The computed dominant discharge was compared to the discharge at bankfull stage using rating curve of that station. The Inglis (1949) and Dury's method (1965) of dominant discharge using meander wavelength were also used. Meander wavelengths were measured from the satellite images of USGS covering the Old Brahmaputra River of 2016 using ArcGIS-10.1 software. To check the return period of dominant discharge, flood frequency analysis was applied to the 44 flood data at Mymensingh station. Water level and discharge data (1964-2014) and sediment data (1988-1994) of the same station were collected for this study from Bangladesh Water Development Board (BWDB).

3. RESULTS AND DISCUSSIONS

Results obtained from different methods are given in the following sub-sections.

3.1. Suspended Load Transport

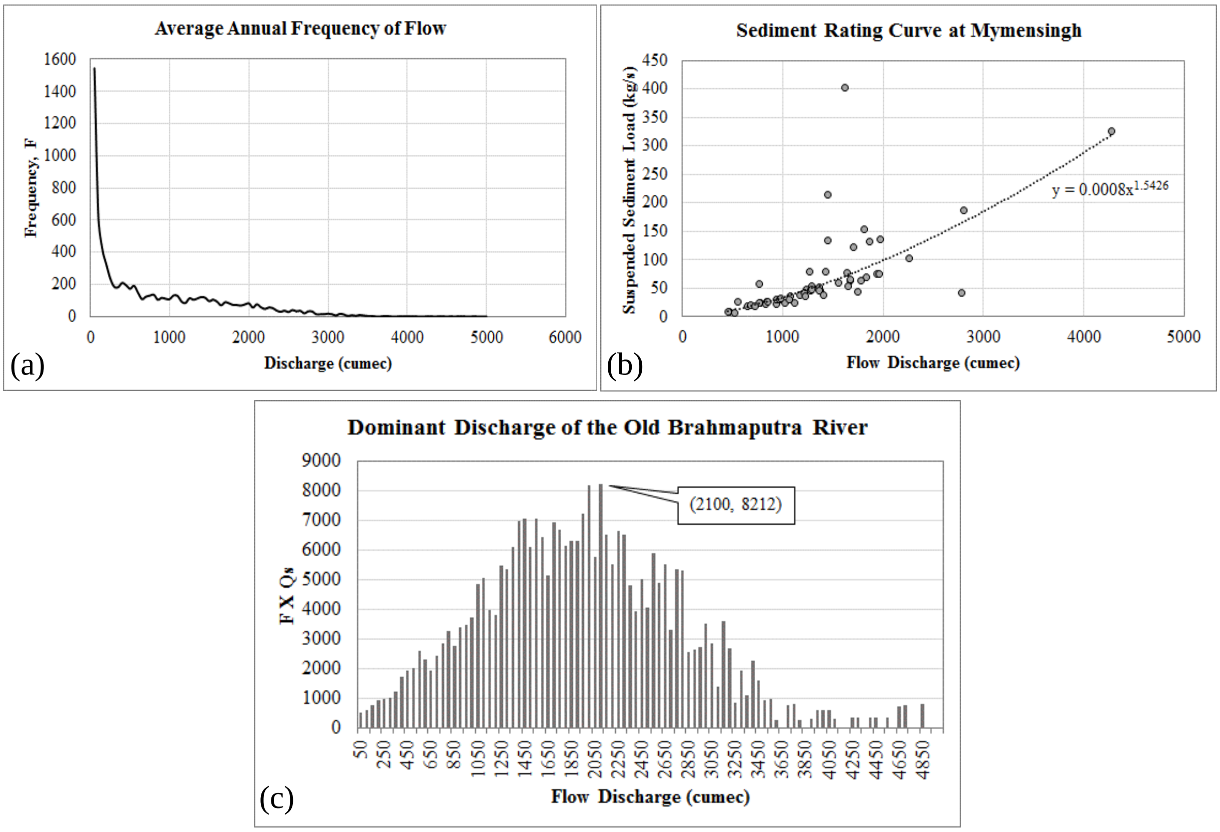

Figure 2. Steps to estimate the dominant discharge (a) Discharge-Frequency relation of the Old Brahmaputra River at Mymensingh, (b) Relationship between discharge and Total sediment load and (c) Dominant discharge of the Old Brahmaputra River at Mymensingh

Figure 2 shows the steps involved in the estimation of dominant discharge as described earlier. From the histogram of Figure 2(c), the mode was identified which corresponds to the dominant discharge. According to this concept, the bed generative discharge was found to be around 2100 cumec. Therefore, it can be stated that most suspended sediments are transported in the Old Brahmaputra River when flow discharge is around 2100 cumec and the river is morphologically very much active at this time.

3.2. Stage-Discharge Curve

As mentioned previously, a definition of dominant discharge was equal to the bankfull discharge and in the stage-discharge curve it is the point at which the rating curve exhibits an abrupt flattening in slope. When discharge increases beyond the effective flow, water begins to spill over the bank tops at more and more locations. The effective discharge should be compared to the bankfull discharge. This can be accomplished as well by identifying the bankfull stage during stream reconnaissance of the study reach and calculating the corresponding discharge. It is to be mentioned that, the right bank of the river section at Mymensingh is around 2 m higher than that of left bank. Therefore, stage-discharge relation at this station represents a 3-stage rating curve. However, for the consideration of dominant discharge, discharge corresponds to the lower bank level was taken here rather than the discharge corresponds to average bank level. From the rating curve of Old Brahmaputra River at Mymensingh station, the flow for bankfull level was found to be around 2100 m^3/s, shown in Figure 3.

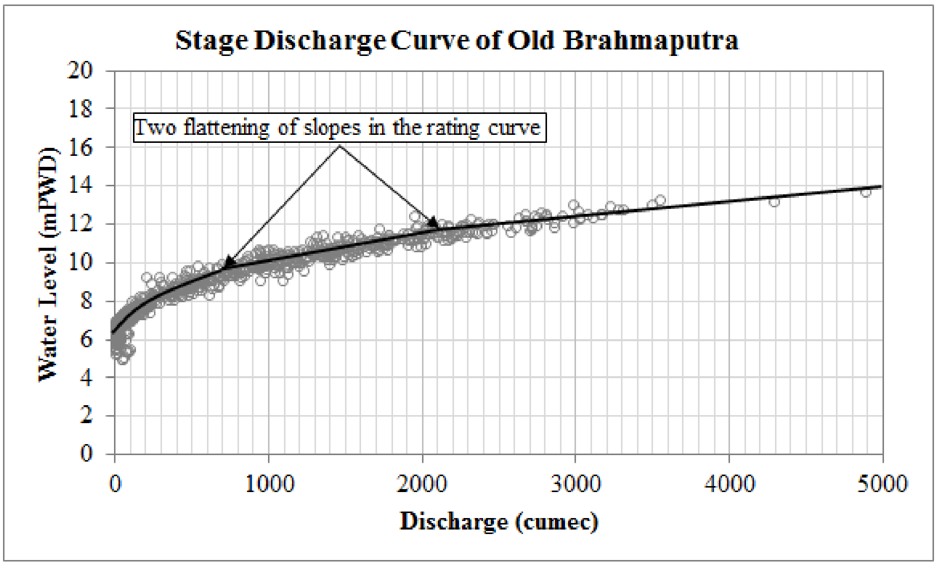

Figure 3. Rating curve for the Old Brahmaputra River at Mymensingh

3.3. Meander Wavelength

Meander wavelength varies with the square root of bankfull discharge and any empirical relationship between wavelength (L) and bankfull discharge (Q_{bf}) may be statistical rather than causal (Dury, 1965). Wolman and Leopold (1957) concluded that bed width is determined directly by discharge, whereas wavelength depends directly on width and thus only indirectly on discharge. Then;

$$L = K.q^b \quad (1)$$

Where L is meander wavelength, q is dominant discharge, K is coefficient and b is the exponent. The above parameters are in FPS unit.

Inglis (1949) found following relationship:

$$L = 36q^{0.5} \quad (2)$$

Dury (1965) used a very large data set and found that

$$L = 30q^{0.5} \quad (3)$$

The above relationship was applied to the meander wavelength in the Old Brahmaputra River. The numbers of selected bends were 15 and the average meander wavelength (L) was 2485 m (Table 1). Therefore, bankfull discharge calculated by the Inglis and Dury's methods (Equation 2 and Equation 3) were found to be 1453 cumec and 2092 cumec, respectively. The discharge calculated from the Dury's method agrees closely with the discharge which was determined from stage-discharge curve.

Table 1. Bend number along with their meander wavelength

Bend No	Wavelength (m)	Bend No	Wavelength (m)	Bend No	Wavelength (m)
1	3050	6	2050	11	1780
2	3970	7	1300	12	1490
3	2850	8	2300	13	1180
4	1930	9	2050	14	2525
5	2730	10	4425	15	3650

3.4. Flood Frequency Analysis

Wolman and Leopold recommended that bankfull discharge has an Average Recurrence Interval (ARI) of 1-2 years ($Q_{bf} = Q_{1\text{-}2years}$) on the annual series. Dury (1965) suggested that bankfull discharge is a discharge with ARI of 1.58 years or $Q_{bf} = 0.97Q_{1.58}$. In this study 44 flood data were used for the flood frequency analysis using Gumble, Log-Normal and Log-Pearson III probability distributions to determine the best probability frequency of the data where probability of exceedence of Chi-square value were found 0.0348, 0.0174 and 0.0171, respectively. With the comparison of the Chi-square value, it was found that the best fitted frequency distribution to the data was Log-Pearson III as it gives lowest value in Chi-square test. Therefore, the annual exceedence probability (AEP) of dominant discharge in Old Brahmaputra River was found using Log-Pearson III distribution.

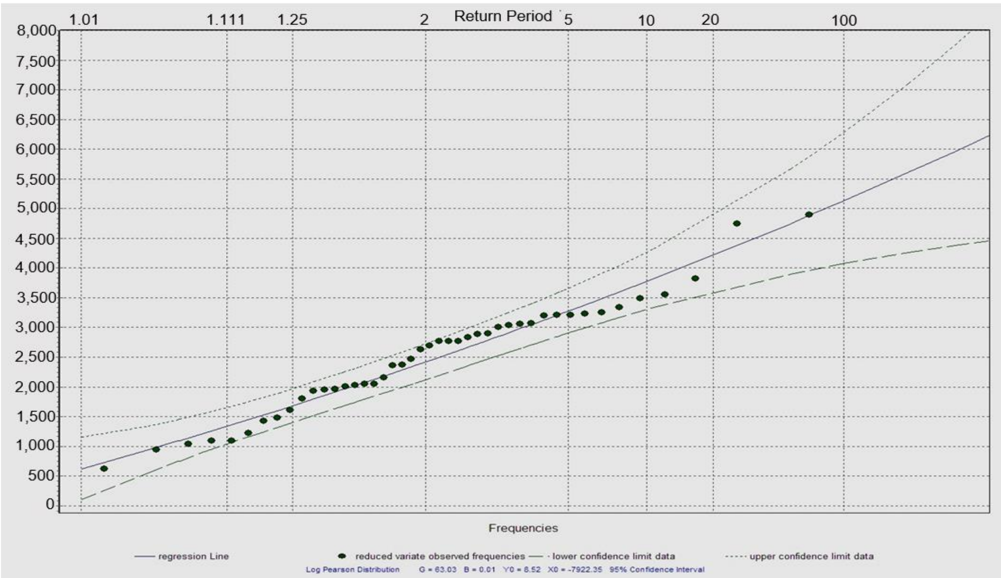

Figure 4. Flood Frequency Analysis using Log-Pearson III distribution

From the previous analysis, the value of dominant discharge was found to be around 2100 m^3/s. This agrees closely with the bankfull discharge and characteristic discharge which is determined from meander wavelength. Therefore, the ARI of dominant discharge for the Old Brahmaputra River was found from the Log-Pearson III distribution and it was 1.85 years.

4. CONCLUSION

In this work, the bed generative discharge along with rating curve method and meander wavelength methods were used to determine the dominant and bankfull discharge in the Old Brahmaputra River using the historical discharge data (44 years) and suspended sediment data (7 years) at Mymensingh station measured by BWDB. It was found that the value of dominant discharge and the bankfull discharge were same for this River at Mymensingh station to be 2100 m^3/s which has an ARI of 1.85 years. This calculated value of dominant discharge is very much suitable for the river reach near Mymensingh station and for other reaches, such as, near offtake or around the outfall of this river, this may vary along with its ARI.

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Experimental Study on Wave Interaction with Vertical Pile Breakwater

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Abstract

Porous structures offer an alternative to conventional solid breakwater. The functional performance of the porous breakwater is evaluated by examining the wave reflection, transmission and wave energy dissipation caused by this breakwater. The reflected waves and the dissipated wave energy are strongly affected by water depth, wave properties such as period and height, and structure properties. In this study, experimental investigation has been carried out in a two-dimensional wave flume at Hydraulics and River Engineering Laboratory of BUET to study the wave interaction with vertical pile breakwater. At 50 cm still water depth (h), interactions between regular waves (wave period, T = 1.5 sec, 1.6 sec, 1.8 sec and 2.0 sec) and the pile breakwater of two different porosities (n= 0.65 and 0.80) and three different structure heights (h_b= 40 cm, 50 cm and 60 cm) have been studied experimentally. Experimental results reveal that, minimum transmission co-efficient (K_t= 0.55) is obtained for breakwater with lowest porosity (n= 0.65) and with emerged condition (h_b/h = 1.2) for short wave period (T= 1.5 sec). Minimum reflection co-efficient is obtained for breakwater with highest porosity (n = 0.80) and with submerged condition (h_b/h = 0.8). From this study it is revealed that not only the porosity of the breakwater, but also the relative submergence and relative width of the breakwater have strong influences on wave reflection, wave transmission and dissipation of wave energy. This study may help the coastal engineers for efficient design of the submerged or emerged pile breakwater to be constructed for wave energy dissipation.

Keywords: Pile breakwater, porosity, relative submergence, wave transmission coefficient.

1. INTRODUCTION

The use of perforated breakwaters consisted of piles has been widely studied recently, as an alternative solution to conventional breakwaters, for coastal protection under mild wave conditions. Vertical pile structures protect lee side wave attack by reflecting and dissipating wave energy through the viscosity-induced resistance in the porous media.

Many experimental and theoretical studies have been done for determining the efficiency of vertical emerged and submerged permeable or impermeable types of breakwaters. Koftics et al (2012) performed experimental investigation on multiple row pile breakwaters. The effect of the structure's dimensions and the relative water depth on the transmission coefficient is studied under regular water waves. Herbich and Douglas (1988) investigated experimentally wave transmission through a double row pile breakwater. Results were found that two-row breakwater had less wave transmission than the single-row breakwater. Hayashi et al (1966) performed hydraulic research on the closely spaced pile breakwater both experimentally and theoretically. A theory is presented for the transmission of waves past the breakwater and also for the thrust and bending moment to be exerted by the waves upon each pile in the breakwater. Rahman and Womera (2013) investigated the interaction between waves and rectangular submerged impermeable breakwater. Afroz and Rahman (2016) performed both experimental and numerical study on horizontal slotted submerged porous breakwater. They found that the transmission coefficient decreases as relative breakwater width increases. Rahman and Akter (2014) investigated experimentally the hydrodynamic performance of rectangular porous breakwater both submerged and emerged condition. Minimum transmission co-efficient was obtained for breakwater with minimum porosity.

In this study, experimental investigation has been carried out in a two-dimensional wave flume to investigate the effect of porosity of pile breakwaters in emerged, waterline and submerged conditions on wave reflection, wave transmission and eave energy loss coefficients.

2. LABORATORY EXPERIMENT

Experiments were carried out in a two-dimensional wave flume (21.3 meters long, 0.76 meter wide and 0.74 meter deep) at the Hydraulics and River Engineering Laboratory of Bangladesh University of Engineering and Technology. Multiple row pile breakwater had been made using plastic hollow pipes which were filled with sand and concrete cap for stability against wave action (Figure 1). Piles were 9.8 cm in diameter. There was an iron made grill structure made with ¼" diameter rod in the bottom to keep the pile stable under wave action. The length of the breakwater was 73 cm and width was 100 cm. The orientation on piles was changed for making different porosities as shown in Figure 1.

Figure 1. Side view of pile breakwater (Porosity, n= 0.65, 0.80)

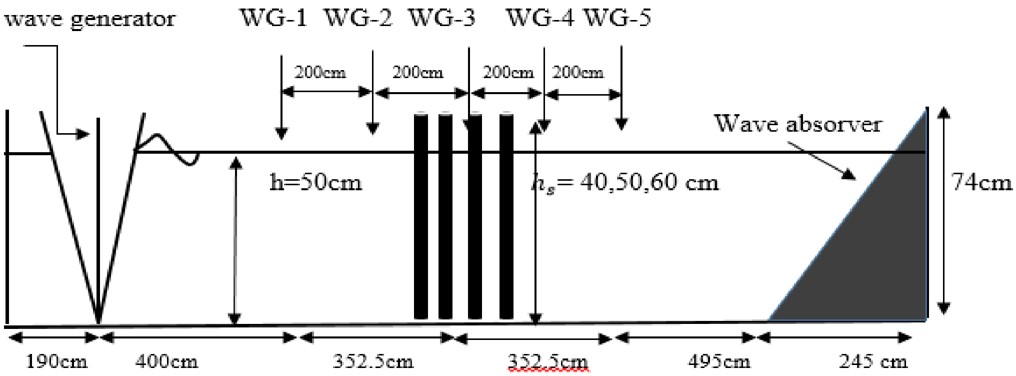

Figure 2 (a). Experiment setup in detail

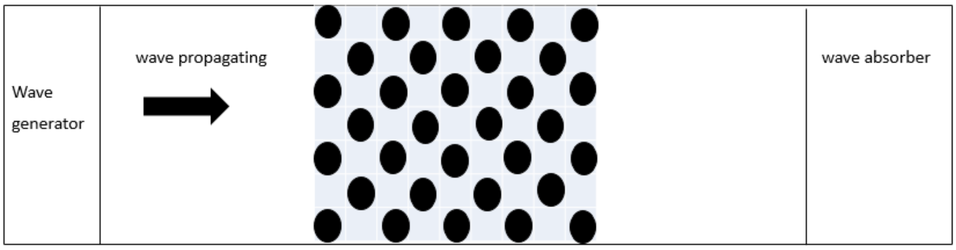

Figure 2(b). Experimental setup plan view for porosity 0.65

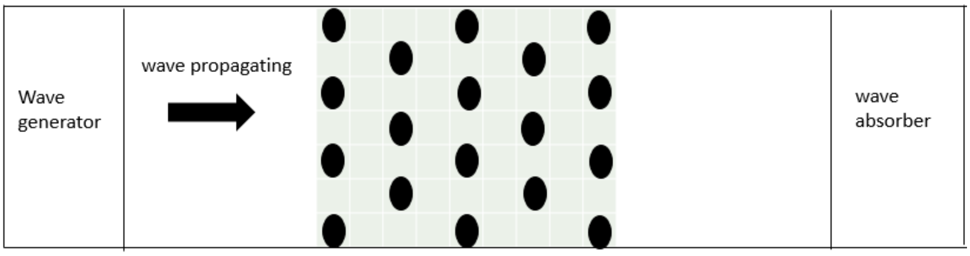

Figure 2(c). Experimental setup plan view for porosity 0.80

Figure 3. Photos of wave interaction with pile breakwater

Still water depth was maintained in the laboratory flume for all experimental runs as 50 cm. Regular waves with four different wave periods (T=1.5 s, 1.6 s, 1.8 s and 2.0 s) were generated from a flap type wave generator installed at the upstream end of the wave flume. To damp the transmitted wave after passing the breakwater a wave absorber was installed at the end of the wave flume. For each type of porous breakwater, three different heights of breakwater (h_b) as 40 cm, 50 cm and 60 cm were used, which made relative structure height (relative submergence), h_b/h = 0.8 (submerged), 1.0 (waterline) and 1.2 (emerged). Interaction of regular waves of four different wave periods with the breakwater of two different porosities and each breakwater having three different heights made twenty-four laboratory runs. For each experimental run, wave heights were measured at five locations, two were in front of the breakwater, third one was over the breakwater and the last two were behind the breakwater. The detail of experimental setup is shown in Figure 2. Photos of wave interaction are shown in Figure 3.

The maximum and the minimum wave heights ($H_{\max}$ and $H_{\min}$) at the wave generator side (upstream the breakwater) and the transmitted wave heights (H_t) at the wave absorber side (downstream the breakwater) were measured to estimate the reflection and the transmission coefficients (K_r and K_t). Incident wave height (H_i) and reflected wave height (H_r) are calculated as $H_i=(H_{\max}+H_{\min})/2$ and $H_r=(H_{\max}-H_{\min})/2$ respectively, where $H_{\max}$= maximum wave height measured at antinodes and $H_{\min}$= minimum wave height measured at nodes. Then reflection coefficient, $K_r=H_r/H_i$ and transmission coefficient, $K_t = H_t/H_i$ are calculated, where H_t = transmitted wave height. The energy loss coefficient, K_L, was calculated from the relation (Thornton and Calhoun 1972): $K_r^2 + K_t^2 + K_L^2 = 1$. For measuring maximum and minimum wave heights, two wave gauges were placed at fixed distances of $L/4$ and $L/2$ from the breakwater, where L is the wave length. At each position (antinode, $L/4$ and node, $L/2$) data of water surface were collected for one-minute duration at five seconds interval. Then maximum or minimum wave heights (H_{max} or H_{min}) in cm were calculated by taking difference between the maximum and minimum water surface reading at antinode and node respectively.

3. RESULT AND DISCUSSIONS

3.1. Effect of relative submergence (h_b/h) and relative breakwater width (kB) on transmission coefficient (K_t)

Figure 4 shows the relationship between the transmission coefficient (K_t) and relative breakwater width (kB $=2\pi B/L$, where k is the wave number) for the breakwater height ratios (h_b/h) are 0.8, 1.0 and 1.2 for two different values of breakwater porosity (n= 65%, 80%). The figure shows that the transmission coefficient (K_t) decreases as kB increases. This means that, the breakwater reduces the transmitted waves as the breakwater width (B) increases or the wave length (L) decreases.

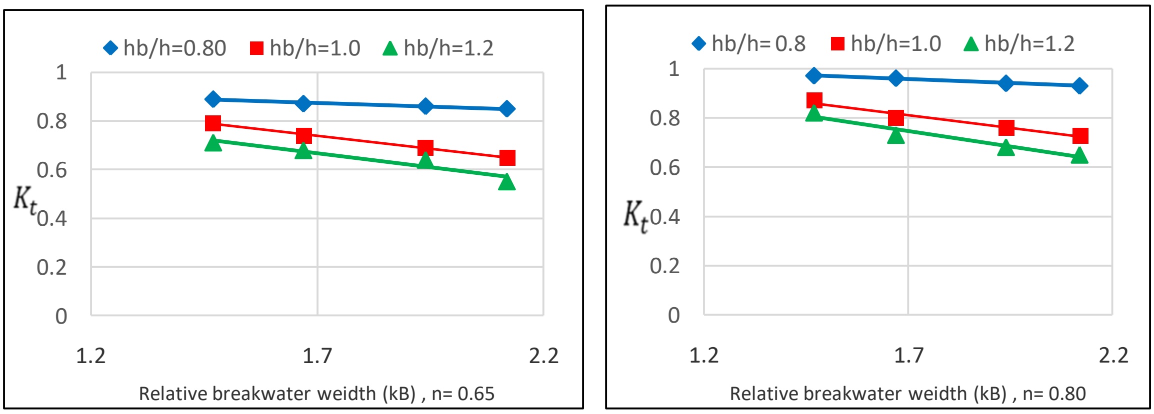

Figure 4. Effect of relative breakwater width on transmission co-efficient (K_t)

The above mentioned behaviour could be attributed to two reasons. First, the increase of breakwater width causes the increase of the friction between the breakwater surface and the transmitted waves, causing more wave energy loss. Second, as the wave becomes short, the water particle velocity and acceleration suddenly change, and the turbulence caused due to this sudden change causes dissipation in the wave energy. Moreover, the transmission coefficient decreases as h_b/h increases. When porosity n= 0.65, the transmission coefficient decreases from 0.71 to 0.55 for h_b/h =1.2, decreases from 0.79 to 0.65 for h_b/h = 1.0, decreases from 0.89 to 0.85 for h_b/h = 0.8 with increasing kB 1.47 to 2.12. When porosity n= 0.80, the transmission coefficient decreases from 0.82 to 0.65 for h_b/h=1.2, decreases from 0.87 to 0.73 for h_b/h= 1.0, decreases from 0.97 to 0.93 for h_b/h=0.80.

3.2. Effect of breakwater porosity on the transmission co-efficient (K_t), reflection co-efficient (K_r), wave energy loss co-efficient (K_L)

Figure 5 shows the variation of the transmission co-efficient, reflection co-efficient and the wave energy loss co-efficient for two different porosities (n= 0.65, 0.80) of breakwater for relative submergence 1.2. At relative submergence of h_b/h=1.2, it is observed that transmission co-efficient increases with increasing the porosity of the breakwater. As porosity of breakwater increases, most of the wave energy can be easily transmitted, as a result transmission co-efficient also increases. Whereas more reflection coefficient attained for less porous breakwater (when n=0.65). The wave energy loss co-efficient is less for higher porous breakwater (when n= 0.80). The transmission co-efficient and the reflection co-efficient decrease as the relative breakwater width (kB) increases, while the wave energy loss co-efficient takes the opposite trend. Figure shows that the transmission co-efficient increases as the porosity increases from n= 0.65 to n=0.80 by about 15% to 18% with increasing kB from 1.47 to 2.12. For h_b/h=1.2, the reflection co-efficient decreases by about 51% to 64% as the porosity increases from 0.65 to 0.80 with increasing kB from 1.47 to 2.12.

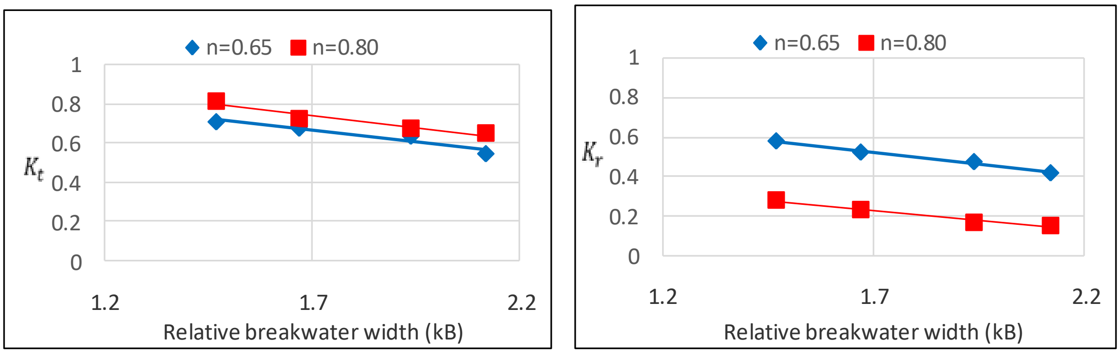

Figure 5. Effect of breakwater porosity on transmission and reflection coefficient (relative submergence 1.2)

3.3. Relation among K_t, K_r and K_L with respect to relative submergence (h_b/h)

Figure 6 shows the effect of increasing relative submergence (h_b/h) on the transmission co-efficient (K_t), reflection co-efficient (K_r), and the wave energy loss co-efficient (K_L). With increasing submergence the transmission co-efficient decreases, where as the reflection co-efficient increases. The wave energy loss co-efficient also increases with increasing relative breakwater height. For porosity, n= 0.65 and wave period T=1.5 sec, transmission co-efficient decreases 35% with increasing submergence from 0.8 to 1.2, whereas reflection co-efficient increases 23% with increasing submergence from 0.8 to 1.2. The wave energy loss co-efficient increases 41% with the increasing submergence from 0.8 to 1.2.

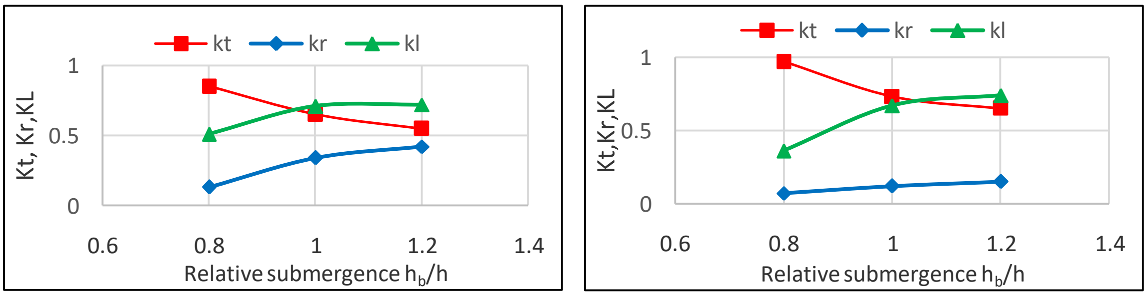

Figure 6. Relation among K_t, K_r and K_L with respect to relative submergence (For n=0.65, 0.80 and T=1.5sec)

4. CONCLUSION

In this study the performance of the vertical thick submerged (h_b/h=0.8), water line (h_b/h=1.0) and emerged (h_b/h=1.2) breakwaters with different porosities has been evaluated experimentally under various wave conditions. Twenty-four laboratory runs for the interaction between wave and porous breakwater in a two dimensional wave tank were conducted. The functional efficiency of porous breakwater is measured by wave reflection, transmission and wave energy loss co-efficient. Experimental data have been analyzed to calculate the wave reflection, transmission and wave energy loss co-efficient under various scenarios. Experimental results reveal that, minimum transmission co-efficient (K_t=0.55) is obtained for breakwater with lowest porosity (n=0.65) and with emerged condition (when h_b/h=1.2) for short wave, i.e. when T = 1.5 sec. Minimum reflection co-efficient (K_r=0.07) is obtained for breakwater with highest porosity (n=0.80) and with minimum submerged (h_b/h=0.8) condition. From this study it is revealed that not only the porosity of the breakwater, but also the relative submergence and relative width of the breakwater have strong influences in reflecting wave, transmitting wave and dissipating wave energy. This study may help the coastal engineers for efficient design of the porous submerged or emerged breakwater to be constructed for different purposes.

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Application of CORDEX data to Assess Meteorological Droughts of Rajshahi using Standard Precipitation Index (SPI)

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Abstract

Drought is a common natural calamity defined as the deficiency of water to meet demand. Climate change impersonates its frequency and severity as frequent and severe. North western part of Bangladesh is the most drought prone region and Rajshahi is one of the most affected districts. In this study drought analysis has been performed for Rajshahi by Standardized Precipitation Index (SPI) for the historic period 1981-2010 and future period 2011-2100 using MIROC5 GCM (RCP8.5) projected data for four different time scales 3, 6, 9 and 12 months. Short term drought from CORDEX data is well fitted with SPI from observed data from Bangladesh Meteorological Department. Future drought is analysed in three time span 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). Future SPI analysis shows an increase in both drought severity and frequency. It is predicted that around 13.89% time of future period (2011-2100) may be covered by drought and the long-term extreme drought frequency will be approximately double.

Keywords: Drought, Rajshahi, SPI, CORDEX.

1. INTRODUCTION

Drought is a natural disaster that Bangladesh has to deal with frequently. It implies the deficiency of water to meet the demand for a prolonged period. Drought can be classified as a) Agricultural Drought, b) Meteorological Drought, c) Hydrological Drought and d) Socio-economical Drought. Meteorological or climatological drought refers to as the degree of dryness or magnitude of precipitation shortfall on monthly, seasonal, or annual time scales where amount of evaporation and evapotranspiration exceeds the precipitation.

Drought is one of the most concerning natural disaster in Bangladesh due to its adverse effect in agricultural production (BBS 2017). The North-western part of Bangladesh is greatly affected by drought due to its location on high Barind Track (Banglapedia 2017) and Rajshahi is one of the most affected districts (Datta 2005). According to 'Agricultural Statistics Year Book of Bangladesh 2017' published by Bangladesh Bureau of Statistics (BBS) and Islam (2014) there were seven major drought events (1981, 1982, 1989, 1994-95, 2000, 2006 and 2009) years during the time span of 1981-2010. Bangladesh possesses agro based economy whereas 10.98% of total GDP is contributed by her agricultural production as mentioned in Statistical Year Book of BBS (2017). Drought cause immense damage to agriculture as well as our economy. It is important to analysis its pattern and frequency by with prediction can be made that will be very helpful to our resources planner, policy makers to take remedial measures against its devastation.

There are many indices available to quantify drought among them Standardize Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) are the most widely used indices (Shahid 2010; Patel 2007). SPI is the most popular index to assess drought due to its simple methodology, only needs monthly precipitation as input parameter to calculate. In this study drought is quantified using SPI to assess the drought pattern and probable prediction will be done on basis of this index.

In this study the main objectives are:

- Evaluation of CORDEX monthly precipitation data from MIROC5 GCM for Rajshahi by comparing the drought features from CORDEX data with the features from observed data.
- Assessment of drought features using Standardized Precipitation INDEX (SPI) computed from both observed and CORDEX data for the historic period 1981-2010.
- Prediction of future (2011-2100) drought features using CORDEX projected data for the emission scenario of RCP8.5.

2. DATA AND METHODS

Monthly precipitation data of Rajshahi for the period 1981-2010 is collected from Bangladesh Meteorological Department (BMD). Simulated data is collected from CORDEX (Coordinated Regional Downscaling Experiment) of MIROC5 Global Climate Model (GCM) data of resolution 50kmX50km regional grid for the historic period 1981-2010. Projected data is taken from CORDEX of emission scenario RCP8.5 (Representation Concentration Pathways) for the period 2011-2100. Future period is classified as early 21st century, 2020s (2011-2040); mid-century, 2050s (2041-2070) and late century, 2080s (2071-2100).

MIROC5 data for the control period (1981-2010) shows some bias and therefore the bias is corrected by linear regression analysis. Projected period precipitation data is corrected based on the regression relation obtained for the control period. SPI is then calculated from observed and corrected MIROC5 precipitation data for four different time scales 3 months, 6 months, 9 months and 12 months SPI. SPI computed from both BMD and corrected CORDEX data has been compared to evaluate the performance of MIROC5 data in assessing the drought feature of control period. Then SPI of projected period is calculated in three time interval 2020s, 2050s and 2080s.

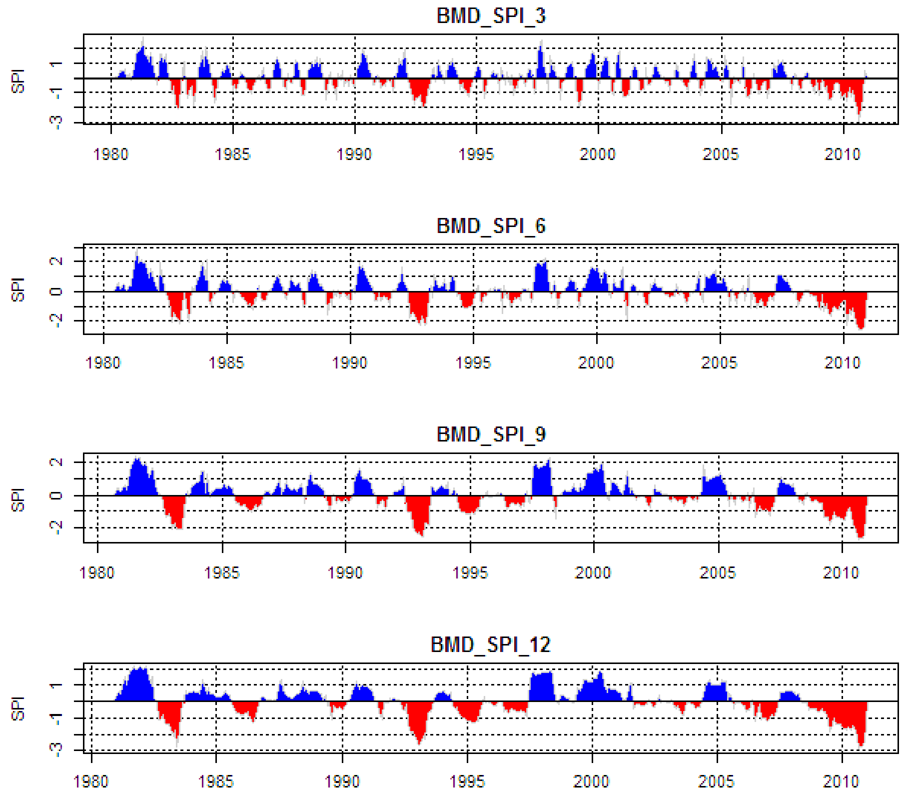
McKee et al (1993) developed the Standardized Precipitation Index (SPI) to understand that deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snowpack and stream flow. The SPI is based on the probability of precipitation for any time scale. The probability of observed precipitation is then transformed into an index. It is being used in research or operational mode in more than 70 countries (WMO 2012). It categorizes severity of drought in to mild, moderate, severe and extreme with the ranges as stated in **Error! Reference source not found.**. Different time scales like three months SPI indicates short term drought, six months SPI as medium-term drought whereas nine and twelve months SPI indicate long term drought. In this study SPI is calculated using Gamma Distribution as probability distribution and parameters are fitted based on Unbiased Probability Weighted Moments method by SPEI package of RStudio.

Table 1: SPI Value Range

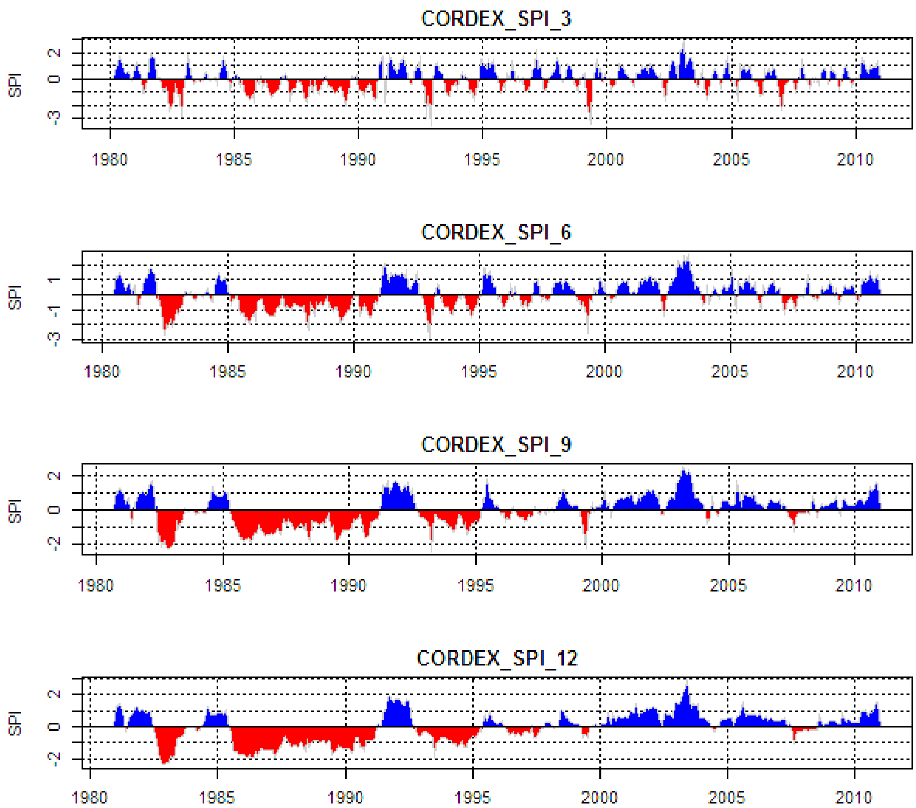
No.	SPI Value	Severity
1	-.99 to .99	Near Normal
2	-1.0 to -1.49	Moderate Drought
3	-1.5 to -1.99	Severe Drought
4	-2 and less	Extreme Drought

3. RESULTS AND DISCUSSION

According to 'Agricultural Statistics Year Book of Bangladesh 2017' published by Bangladesh Bureau of Statistics (BBS) and Islam (2014), there were seven major drought events (1981, 1982, 1989, 1994-95, 2000, 2006 and 2009) during the time span of 1981-2010. SPI computed from observed and simulated data could capture those historic drought events though severity variation. Among those 7 historic drought events reported in BBS, 3-month SPI from BMD data could capture 6 of them while 3 month SPI from MIROC5 could capture 5 of them.



(a)



(b)

Figure 1. SPI of different time scales for both observed (a) BMD) and (b) CORDEX data.

CORDEX_SPI and BMD_SPI of different time scales are shown in Figure 1(a,b) where CORDEX_SPI overestimate drought from 1985-1990 and underestimates from 2000. That may be due to the error in CORDEX precipitation data which needed more attention in precise bias correction analysis.

Drought events number found from two datasets at historic period are close and seem realistic. 6 months SPI from BMD shows 23 moderate drought events with 5 extreme drought events whereas CORDEX 6 months SPI demonstrates 22 moderate drought events with 6 extreme drought events as stated in Table 2 . Table 3 shows the drought occurring months.

Table 2. Number of Drought Events

Drought Severity	BMD(1981-2010) n=30years				CORDEX(1981-2010) n=30 years			
	SPI_3	SPI_6	SPI_9	SPI_12	SPI_3	SPI_6	SPI_9	SPI_12
Moderate	25	23	10	11	24	22	14	16
Severe	9	7	4	5	14	10	8	10
Extreme	2	5	3	3	7	6	4	1

Table 3. Duration (no of months) of Different Drought Events

Drought Severity	BMD(1981-2010) n=30years				CORDEX(1981-2010) n=30 years			
	SPI_3	SPI_6	SPI_9	SPI_12	SPI_3	SPI_6	SPI_9	SPI_12
Moderate	36	29	28	29	31	33	33	39
Severe	10	9	6	7	15	16	20	23
Extreme	2	7	10	8	8	6	7	4
total	48	45	44	44	54	55	60	66

Though BMD SPI shows more drought events in different time scales but CORDEX SPI shows longer duration drought in different drought events. For long duration drought (12 and 9 month droughts) CORDEX SPI overestimates both duration and frequency. BMD and CORDEX SPI demonstrate 12% and 18% of study time period, (1981-2010) was covered by long term drought respectively. Whereas short term drought covered 13% and 15% of time period found from BMD and CORDEX SPI respectively.

Future period drought is analysed in three time span, i.e. 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100). The SPI value of future period is shown in Figure 2. In future it has been found that 12 month SPI may occur more frequently than the observed period. Within the past 30 years there was 11 and 16 long term (12 month) moderate drought events found from BMD and CORDEX accordingly. But in future 90 years (2011-2100) there may be 53 long term drought events. It demonstrates that drought may occur more frequently in future due to rapid climate change. Number of drought events and its durations are demonstrated in Table 4.

Future period SPI analysis demonstrates 74 short term drought events covering 98 months of total study period within 53 long term drought events covering 109 months. It also reveals that 24 short term (3 months) extreme drought events covering 34 months and 6 long duration (12 months) extreme drought events covering 22 months. It may be elucidating that the duration of extreme drought is quite a matter of perturbation to deal with. From Figure 2 it is seen that severity of drought is high in 2080s rather than 2050s and 2020s while frequency is high in 2020s.

Table 4. Future Period Drought Events and no of months covering the events

Drought Type	No of Drought Events				No of months covering drought events			
	Future(2011-2100) n=90 years				Future(2011-2100) n=90 years			
	SPI_3	SPI_6	SPI_9	SPI_12	SPI_3	SPI_6	SPI_9	SPI_12
Moderate	74	60	55	53	98	105	106	109
Severe	35	26	23	14	43	40	29	19
Extreme	24	12	6	6	34	26	23	22

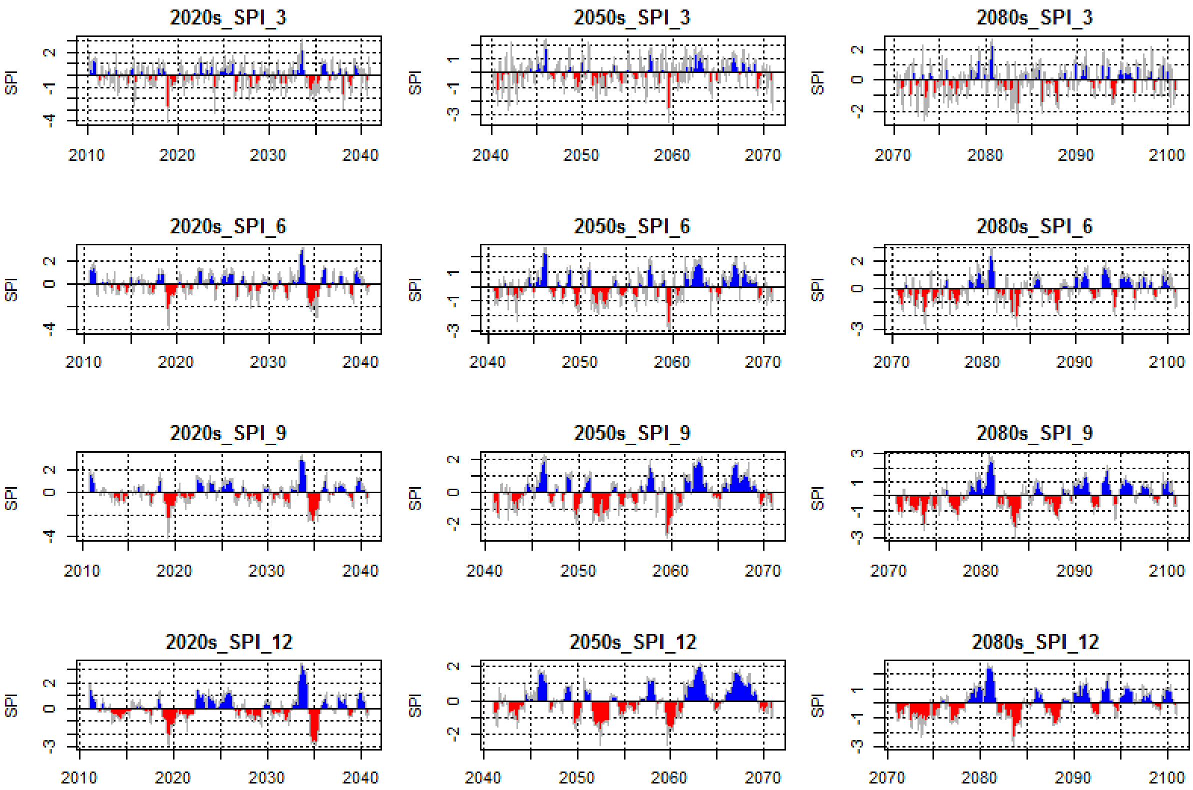


Figure 2. Future Period (2011-2100) SPI

4. CONCLUSION

In this study drought features were studied from CORDEX (MIROC5) precipitation data for the historic period (1981-2010) and future period (2011-2100). CORDEX precipitation data showed bias in the historic period and therefore the bias was corrected using regression analysis. Among the 7 historic drought events reported in BBS, 3 month SPI from BMD data could capture 6 of them while 3 month SPI from corrected CORDEX data (MIROC5) could capture 5 of them. Short term SPI from CORDEX data is well fitted with short term SPI from observed data where as long term SPI shows deviation. For long duration drought (12 and 9 month droughts) CORDEXSPI overestimates both duration and frequency. This problem could be mitigated if bias could completely be removed from CORDEX precipitation data. SPI for future period shows that in future drought frequency will be higher than the current pattern. Severity may also increase due to rapid climate change. This study will provide valuable information for water resources planning and disaster management in the coming decades.

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Climatology of Thunderstorm activities over Bangladesh and its association with Convective Available Potential Energy (CAPE)

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Abstract

Convective available potential energy (CAPE) is a physical quantity that is used by the meteorologists to evaluate the potential for thunderstorm development and to issue severe-weather warnings. The severe thunderstorms associated with thunder squall, hail, tornado, and lightning cause extensive damage and losses to lives, especially in the densely populated sub-tropical countries like Bangladesh. Based on the observed thunderstorm (TH) data from Bangladesh Meteorological Department and ERA Interim CAPE data from 1979 to 2017, monthly to seasonal variations in thunderstorm and its relationship with CAPE were investigated over two selected densely populated regions of Bangladesh. The results indicate an increase in CAPE is associated with an increase in thunderstorm activity and the time series of monthly TH is found to vary in synchrony with corresponding CAPE with correlation coefficients varying from 0.73 to 0.78. Monthly thunder data averaged over 39 years (1979–2017) were regressed against corresponding CAPE. The results indicate that CAPE can explain 83% to 88% of the variance of thunderstorm for the selected stations. For the pre-monsoon season, the correlation coefficient between CAPE and TH vary from 0.60 to 0.66 for the selected stations. As climate models project increase in summer time CAPE over the tropical and sub-tropical region, a positive association between these two variables indicates the possibility of increase in thunderstorm in the future.

Keywords: Bangladesh, Thunderstorm, CAPE, Season.

1. INTRODUCTION

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2. METHODOLOGY

2.1. Study Area

Dhaka (23.81°N, 90.41°E) and Chittagong (22.36°N, 91.78°E) are the two largest cities of Bangladesh with a population of 18.89 million and 2.5 million, significantly important for economic, political, cultural activities. Dhaka located in central Bangladesh, lies on the lower reaches of the Ganges Delta, makes it susceptible to flooding during the monsoon seasons owing to thunderstorms, heavy rainfall. Chittagong located in the southern part of the Bangladesh, lies on the banks of the Karnaphuli River between the Chittagong Hill Tracts and the Bay of Bengal, often makes it vulnerable to tropical oceanic cyclones owing to strong thunderstorms. For these reason, two weather station located at Dhaka (Agargaon) and Chittagong (Patenga) have been considered as the study area.

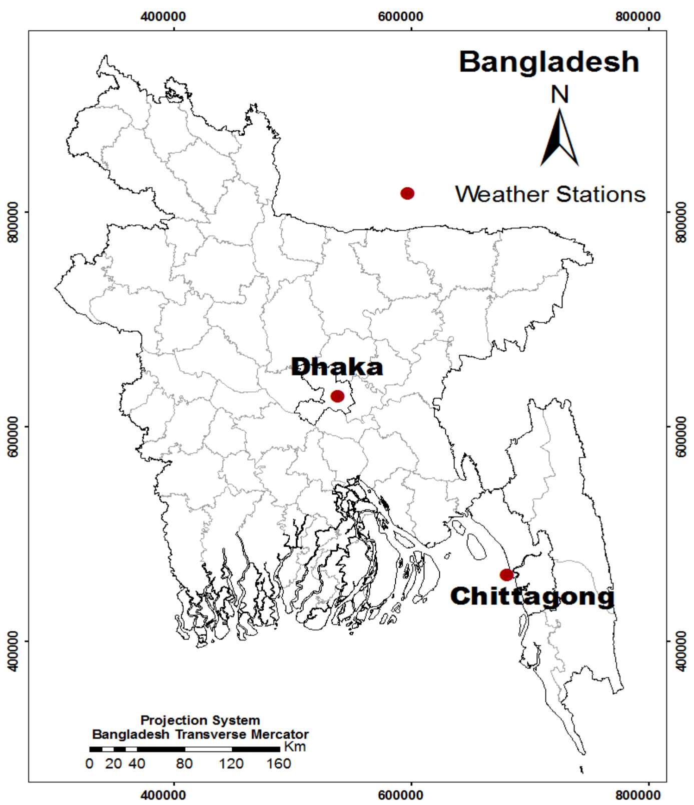

Figure 1. Map showing two weather station (Dhaka and Chittagong) of Bangladesh.

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The monthly thunderstorm data (including both day and night) used in this work covers 39 years (1979-2017) of data for Dhaka and Chittagong stations belonging to the Bangladesh Meteorological Department (BMD). Using a time span of 39 year should hopefully be sufficient to capture a decent variety of thunderstorm activity in Bangladesh. It is noted that there are few occasions in Chittagong station when data are not available. These missing data have not been used in the statistical analysis. Thunderstorms events are reported in every 3-h interval in a day at each station according to World Meteorological Organization (WMO) observation hour standard. Again, these events are categorized according to different surface code predicting thunderstorm slight, moderate and severe (BMD,1982).

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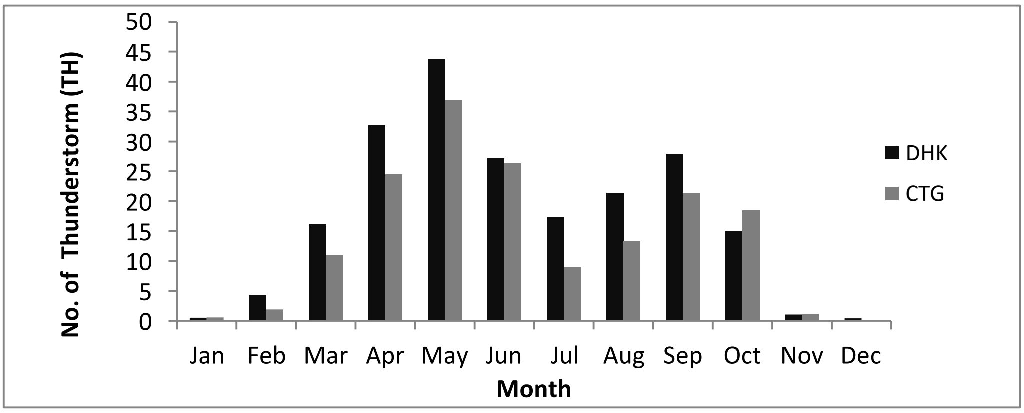
Figure 2 depicts the average monthly thunderstorm data (TH) of Dhaka and Chittagong based on the years from 1979–2017. It is seen that the number of TH is more frequent in April (32, 25), June (28, 27), September (29, 22) with the highest TH in May (44, 37) in Dhaka and Chittagong station respectively. An exception has been seen in Dhaka station for the month of April being its second highest TH frequent month instead of June, which is in contrast with Saha et al (2016). There is a very slight increase in TH in September than June in Dhaka station. This may be due to the available sufficient moisture in the lower levels of troposphere resulting in higher relative humidity to sustain more thunderstorm development (Tinmaker et al 2015). The monsoon season consisting of July and August have relatively low TH (18, 9 and 22, 14) in Dhaka and Chittagong respectively. TH gets more lesser in Winter season having the lowest in December. Table1 represents the seasonal and annual variation of TH in two weather station. It reveals that the total TH is more during the monsoon (94) than pre-monsoon (93) in Dhaka. While in Chittagong the scenario is different from Dhaka, having total TH 73 and 72 for pre-monsoon and monsoon season respectively. Overall scenario shows that Dhaka is more prone to thunderstorm than Chittagong because of having more TH in seasonal and annual basis.



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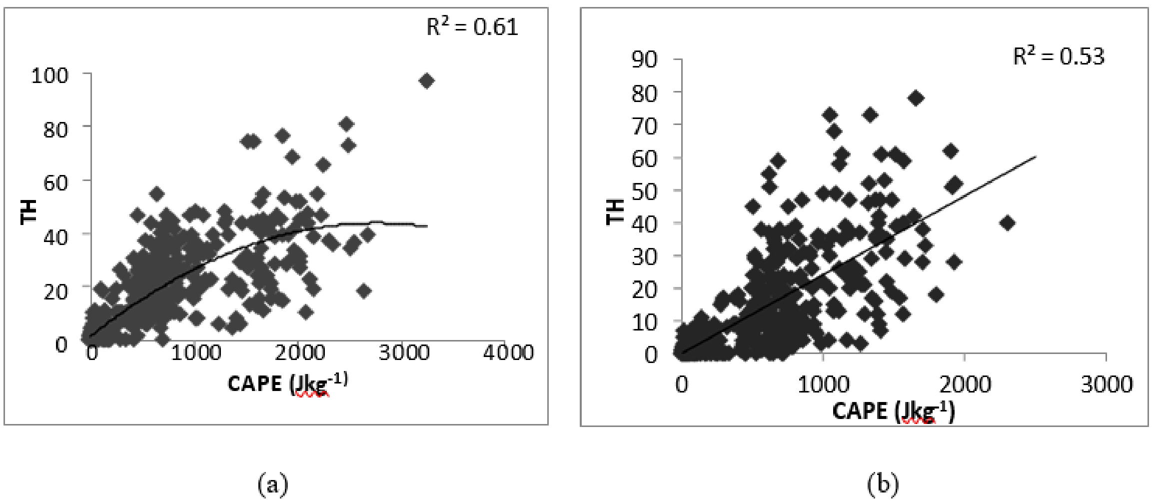

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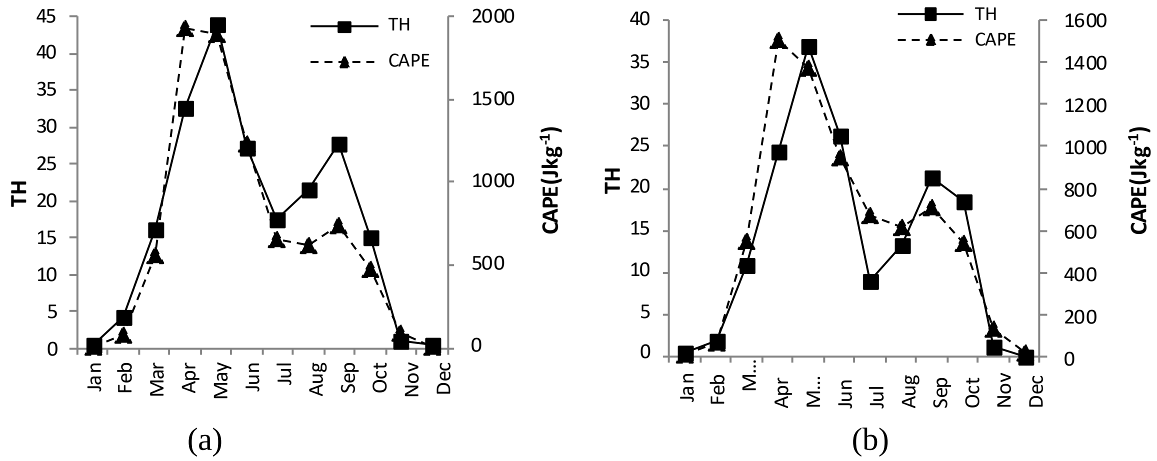
It is seen that CAPE can explain 53% to 61% variance in thunderstorm activity for both of the station. Coefficient of Correlation (r) between TH and CAPE varies from 0.73 to 0.78 at 99.99% confidence level which indicates a strong positive correlation in between them. Since the pre-monsoon season is predominant to thunderstorm activity, other seasons have not been considered in this case. During the pre-monsoon season a moderate relationship (r=0.60 to r=0.66; $p<0.01$), is found in between CAPE and TH which predicts an increasing trend between them.

In Figure 4, monthly CAPE averaged over 39 years is plotted against the corresponding TH to show the significance of CAPE in developing the thunderstorm environment. It is observed that the highest peak of TH is found in May followed by the highest peak of CAPE in April. After May, TH tends to decrease up to July whereas CAPE decreases till August. There is a lag seen again between increasing period of TH and CAPE. The second highest peak of both CAPE and TH occurs in the month of September. This may be due to the withdrawal phase of southwest monsoon and the onset of northeast-monsoon. No lag is seen in the occurrence of secondary peak of both variables, which is similar to the study of Tinmaker et al (2015).



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The relationship between these two variables exhibits a strong relationship (r=0.91 to r=0.94). This indicates an increase in CAPE is associated with an increase in thunderstorm activity and trends of them are temporally coincident. Correlations between CAPE and TH for different timescale are summarized in Table2.

Table 2. Summary of Correlation coefficients (r) and Significance level (*p*-value) between monthly, seasonal and monthly thunderstorm (TH) averaged over 39 years and corresponding CAPE.

Station	Period					
	Monthly		Seasonal (Pre-monsoon)		Monthly (Averaged over 39 years)	
	r	*p*<	r	*p* <	r	*p* <
Dhaka	0.78	0.01	0.66	0.01	0.94	0.01
Chittagong	0.73	0.01	0.60	0.01	0.91	0.01

4. CONCLUSION

In this study, the climatology of thunderstorm and its association with CAPE have been analysed for Dhaka and Chittagong stations. The overall thunderstorm activity follows a quite similar pattern in both stations, with only a slight discrepancy. It is revealed that, Dhaka is more susceptible to thunderstorms than Chittagong. From the results, CAPE is found to be an important factor for the development of thunderstorms. The time series of monthly TH is found to vary in synchrony with corresponding CAPE with correlation coefficients varying from 0.73 to 0.78. Monthly thunder data averaged over 39 years (1979–2017) were regressed against corresponding CAPE. The results indicate that CAPE can explain 83% to 88% of the variance of thunderstorm for the selected two stations. For the pre-monsoon season, the correlation coefficient between CAPE and TH vary from 0.60 to 0.66 for the selected stations. As thunderstorm increases with the increase in CAPE, the future thunderstorm activity may also be affected by the increasing CAPE in tropical and subtropical climate.

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Climatology of Thunderstorm activities over Bangladesh and its association with Convective Available Potential Energy (CAPE)

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Abstract

Convective available potential energy (CAPE) is a physical quantity that is used by the meteorologists to evaluate the potential for thunderstorm development and to issue severe-weather warnings. The severe thunderstorms associated with thunder squall, hail, tornado, and lightning cause extensive damage and losses to lives, especially in the densely populated sub-tropical countries like Bangladesh. Based on the observed thunderstorm (TH) data from Bangladesh Meteorological Department and ERA Interim CAPE data from 1979 to 2017, monthly to seasonal variations in thunderstorm and its relationship with CAPE were investigated over two selected densely populated regions of Bangladesh. The results indicate an increase in CAPE is associated with an increase in thunderstorm activity and the time series of monthly TH is found to vary in synchrony with corresponding CAPE with correlation coefficients varying from 0.73 to 0.78. Monthly thunder data averaged over 39 years (1979–2017) were regressed against corresponding CAPE. The results indicate that CAPE can explain 83% to 88% of the variance of thunderstorm for the selected stations. For the pre-monsoon season, the correlation coefficient between CAPE and TH vary from 0.60 to 0.66 for the selected stations. As climate models project increase in summer time CAPE over the tropical and sub-tropical region, a positive association between these two variables indicates the possibility of increase in thunderstorm in the future.

Keywords: Bangladesh, Thunderstorm, CAPE, Season.

1. INTRODUCTION

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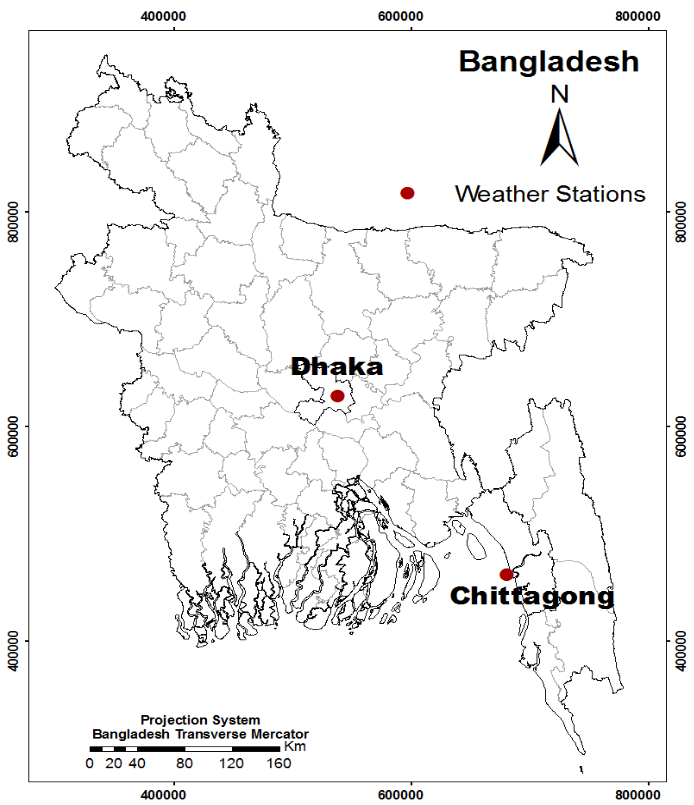

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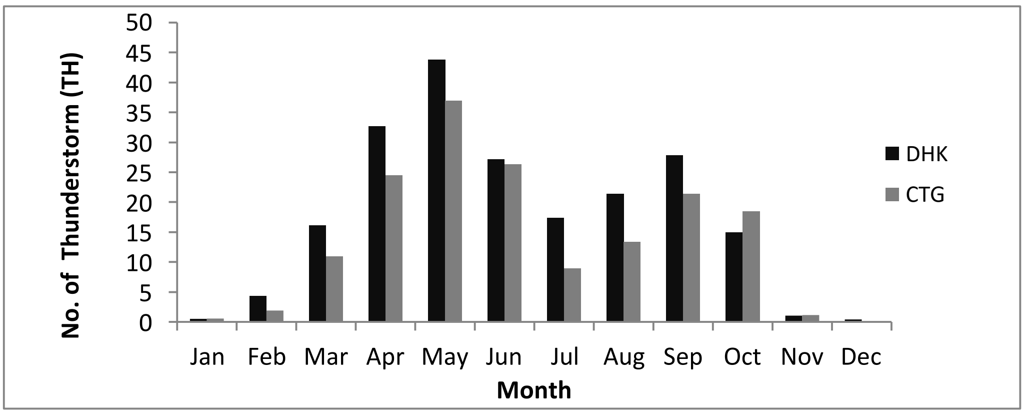

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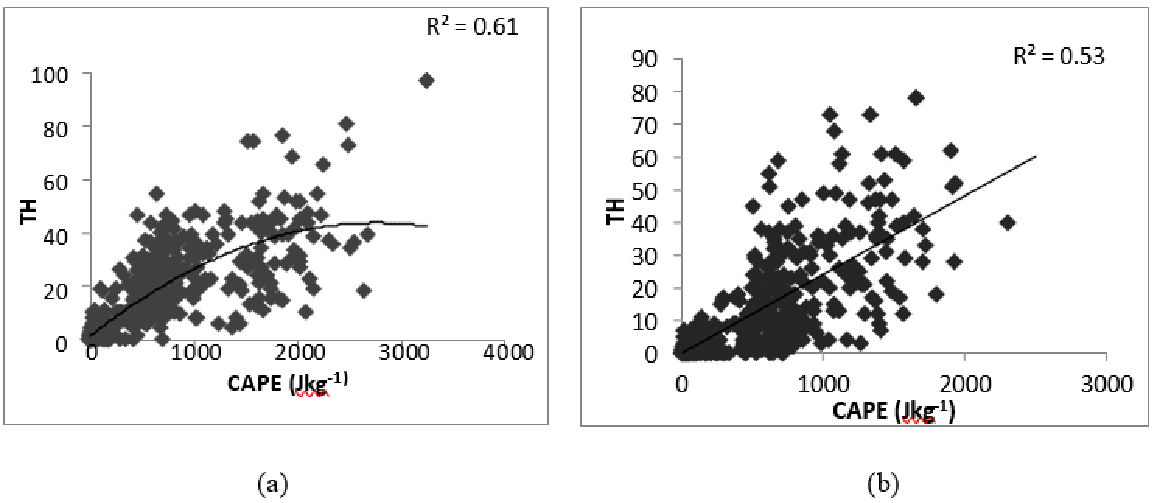

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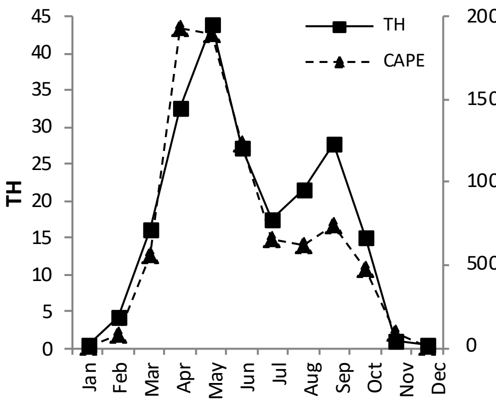

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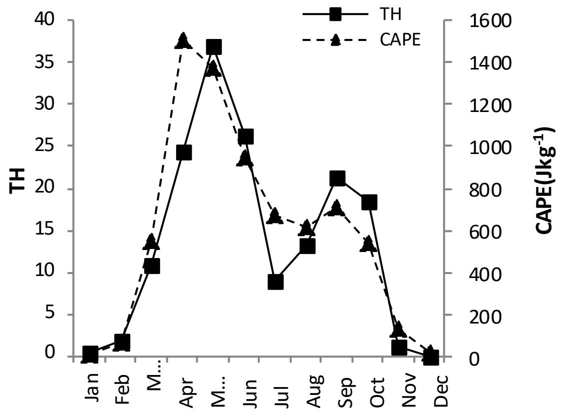

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Predicting Sediment Transport in Karnafuli-Halda River

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Abstract

Suspended sediment is an essential part of river systems and plays a vital role in structuring the landscape, sustaining ecological habitats as well as transporting nutrients. Due to absence of information on sediment conveyance, management problems arise with sediment quantity and quality. Thus, there negative impacts on ecological communities, increment of flood hazard and lifespan of infrastructure turns shorter. Due to less comprehensive study of sediment dynamics in Karnafuli-Halda river, a number of problems often faced including improper pump lifting, flood control system failure frequently, poor drainage system. A morphodynamic study is expected to detail this migration pattern. Hydrodynamic along with sediment transportation in Karnafuli-Halda River was simulated using Delft3D. Navier-Stokes equation for an incompressible fluid was selected for hydrodynamic simulation while hydraulic characteristics are determined for transient conditions. General input requirements for this 2D model include topography, bathymetry, channel roughness, upstream discharge, and downstream stage. During sediment transportation analysis, sediment particle density, particle fineness, sediment concentration and their details were needed. Daily hydrograph and water level time series were provided as input boundary for upstream and downstream respectively. The validated model could reasonably match with field records. Due to lack of real time records second part of this study (not reported here) will focused on field monitoring and create a sediment data bank for the decision support system.

Keywords: Delft3D, sediment transportation, hydrodynamic simulation, 2D model, bed load.

1. INTRODUCTION

Due to the inherent alluvium nature, the rivers of Bangladesh are morphologically dynamic and characterized by sedimentation and erosion. These influence river morphology changes in hydraulic geometry, planform and longitudinal profile of the rivers. In an average yearly 844,000 million cubic meters of water flows into Bangladesh, the input sediment loads along with the flow is more than a billion ton (Bhuiyan et al 2010) (Figure 1). Although Karnafuli and Halda Rivers play important economic role in Bangladesh, there are very few field studies as well as numerical modelling covered the detail sediment transport in these rivers as well as few modelling studies covered these rivers. In the last decade one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) numerical models have been implemented to simulate either river-floodplain hydraulics (Bates et al 2006; Horritt & Bates 2002; Wilson et al 2006) or suspended sediment transport and deposition processes (Asselman & van Wijngaarden 2002; Hardy et al 2000; Nicholas et al 2006). Usually, the 1D and 2D models have been applied to reproduce observed hydrographs, to derive water extent inundation maps, or to estimate sedimentation rates along river reaches up to 60-km long, with floodplains less than 3-km wide, and without the presence of an important hydrographic network of floodplain channels. 3D models, in turn, have been applied to reach scales on the order of a km. But all of these models required finer resolution of data, and this is the main challenge to overcome for Karnafuli-Halda rivers. Thus, an intensive study on sediment hydrodynamics and transport of these rivers can be achieved.

Figure 1. Study area (google earth)

The Delft3D modeling system, developed by Delft Hydraulics (www.wldelft.nl), is usually apply on simulating hydrodynamic processes due to waves, tides, winds, currents in rivers and coastal environment. Hydrodynamic flow, is simulated with the FLOW module, solves the unsteady shallow water equations in two (depth averaged) or three dimensions. This has been applied to model conditions of flow, sediment transport and morphological developments in the present study due to the highly flexible tool for various applications. To predict sediment transport in the study area, Delft3D was employed in this reported study.

2. MATERIALS AND METHODS

Firstly, Arc-GISv9.3 was involved in processing river topography from the ASTER Global Digital Elevation Model (ASTER GDEM) 30m DEM. Acquiring stream network, the bathymetry of the cross sections was manually reconstructed from the hydrographic survey by Chittagong Port Authority. Discharge and water level data for the boundary section were collected from the Bangladesh Water Development Board (BWDB). Then, the geometric shape of river was setup using the grid module of Delft3D, here, 'Rgfgrid' was used for setting up bank and river cross section and 'Quickin' was engaged for setting up the bathymetry of the river. The model consisted of 43654 cells having grid points in M-direction and in N-direction are 299 and 146 respectively. Finally, the flow module of Delft3D was engaged to do the hydrodynamic simulation and sediment transport simulation of the model.

Delft3D solves horizontal momentum, continuity and transport equation for hydrodynamic simulation. In this connection, Navier-Stokes equation is applied for an incompressible fluid. The depth-averaged continuity equation is derived by integrating the continuity equation for incompressible fluids over the total depth, taken into account the kinematic boundary conditions at water surface and bed level (Deltares 2011):

$$\frac{\partial \zeta}{\partial t} + \frac{1}{\sqrt{G_{\xi\xi} G_{\eta\eta}}} \frac{\partial((d+\zeta)U\sqrt{G_{\eta\eta}}}{\partial \xi} + \frac{1}{\partial G_{\xi\xi} G_{\eta\eta}} \frac{\partial((d+\zeta)V\sqrt{G_{\xi\xi}})}{\partial \eta} = (\mathbf{d}+\zeta)\mathbf{Q} \quad (1)$$

$G_{\xi\xi}$ =coefficient used to transform curvilinear to rectangular coordinates
$G_{\eta\eta}$ =coefficient used to transform curvilinear to rectangular coordinates
ζ =water level above some horizontal plane of reference (datum)
d = depth below some horizontal plane of reference (datum)
Q = global source or sink per unit area

Here, Q is the contributions per unit area due to the discharge or withdrawal of water, precipitation and evaporation:

$$Q = \int_{-1}^{0} (qin - qout)d\sigma + P - E \quad (2)$$

The overall sediment transport in rivers in governed by the following equation, this is the sediment mass-balance equation integrated over the water depth *h* (Deltares, 2011):

$$(1-\boldsymbol{\rho}')\frac{\boldsymbol{f z_b}}{\boldsymbol{f t}} + \boldsymbol{D_b} - \boldsymbol{E_b} = 0 \quad (3)$$

where,
z_b = the local bed level above datum and z_s the level of the surface.
ρ' = porosity of the bed material
D_b = deposition rate
E_b = entrainment rate
Boundary condition was set to three terminal portion of the study area. Two boundaries for upstream and one in downstream, these include: discharge dataset for the Kaptai and Nazirhat locations and water level in the estuary.

3. RESULTS AND DISCUSSION

The depth average velocity and the consequent total transport of sediment in the study area of the river Karnafuli and Halda River during pre-monsoon showed higher velocity near the Chittagong port, East Charandwip and close to the Kaptai. This seems higher flow velocities ranging from 0.15-1.5 m/s, passed through the meandering portions of the river, these areas are prone to erosion. This is evident from the figures that the zones with higher velocity carry more sediment than the other zones. From (Figure 2 to 9), it also can be noticed that the flow velocity increased in the successive years similarly the amount of sediment transport has been increased.

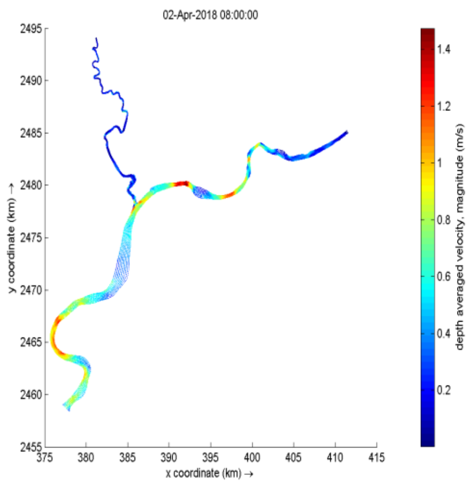


Figure 2. Depth Averaged Velocity in 2/4/2018

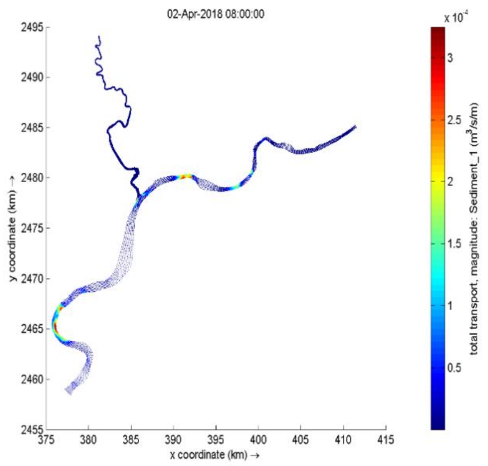


Figure 3. Total Sediment Transport in 2/4/2018

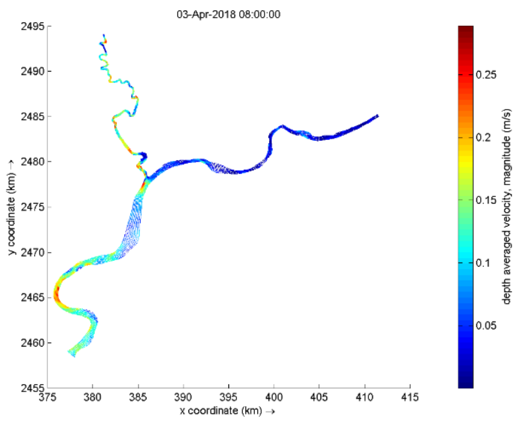


Figure 4. Depth Averaged Velocity in 3/4/2018

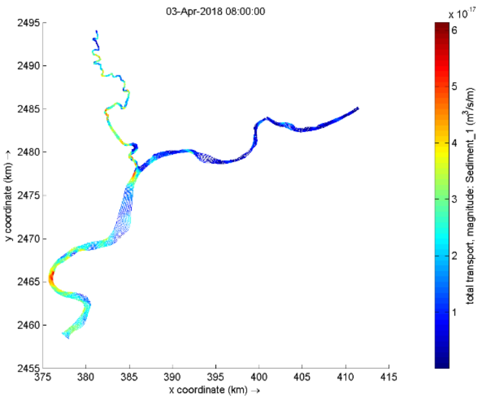


Figure 5. Total Sediment Transport in 3/4/2018

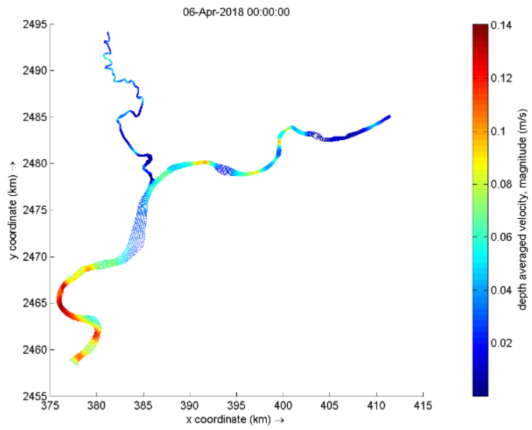


Figure 6. Depth Averaged Velocity in 6/4/2018

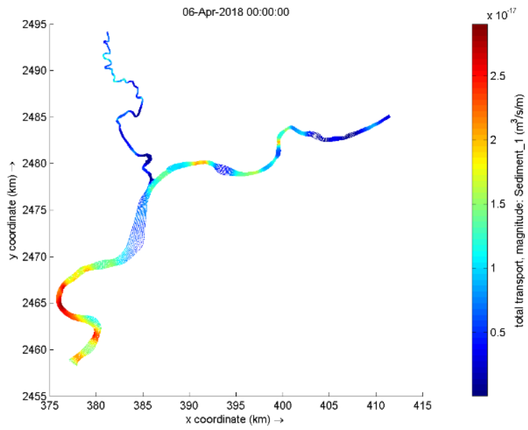
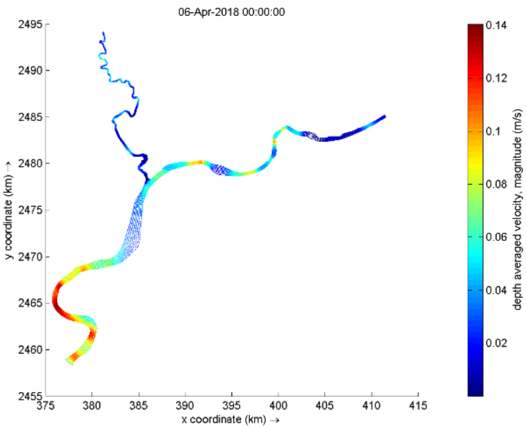


Figure 7. Total Sediment Transport in 6/4/2018



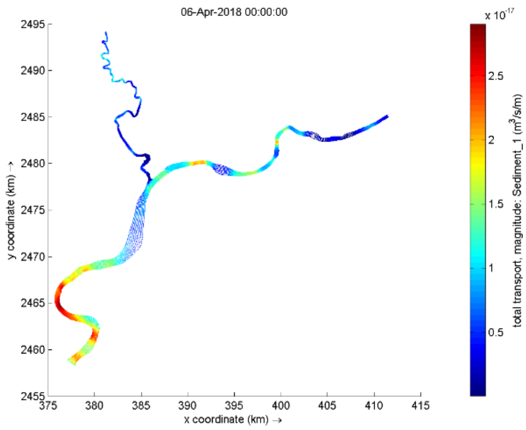


Figure 8. Depth Averaged Velocity in 6/4/2018 **Figure 9. Total Sediment Transport in 6/4/2018**

The calculated and observed water level showed reasonable agreement with slight variation at some locations throughout the year. The model predicts that the water levels remains reasonable except few overestimations. Variable roughness values were used throughout the model which acted as the calibration parameter. Roughness values were ranged between 0.023 to 0.030 (Manning's roughness). During model validation, the computed water surface elevations comapred with observed water surface elevations at Kalurghat during April 2018 and found reasonable match.

4. CONCLUSIONS

Sediment transport is rather a dynamic process and better knowledge on the changes in morphologic conditions of the Karnafuli and Halda River could be achieved once the historical data series is available. To predict sediment transport in Karnafuli and Halda River, an initiative has taken using Deltf3D model followed by field survey. Thus, a frequent time interval dataset on discharge, water level, sediment concentration, cross sections are required both high and low tide as well as seasonal variations are also in need. In this connection, the first phase of this study could reasonably mimic the measured data and the next phase of this study is working on the details field data accumulation. The expected outcome would reasonably represent the sediment concentration and velocities throughout the river change with the tidal effect and thus future prediction of river morphology and the change of bed level of river could be analyzed by the Delft3D model.

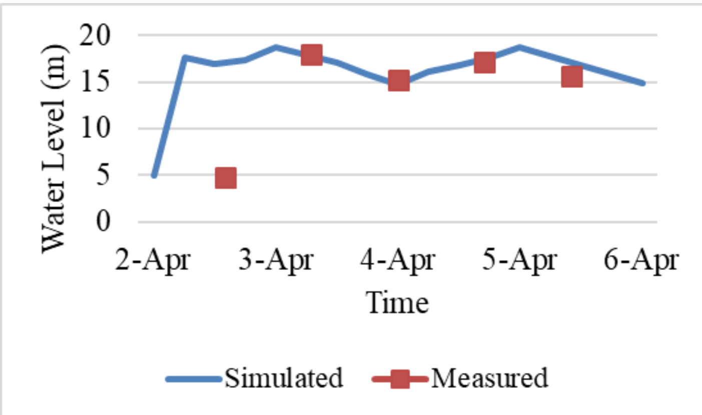


Figure 8. Comparison of simulated and measured water levels of Karnafuli-Halda River

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Trend Analysis in Flood Data in the Brisbane River Catchment, Australia

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Abstract

Flood is one of the most pervasive natural hazards to impact negatively upon the human beings. During 2010-2011 Queensland state of Australia experienced one of the worst flood events in Australia's history causing over $5 billion damage and 31 deaths. To minimise the risk, impact and damage due to flood, it is important to understand the causes of such flood and, frequency of occurrence. Due to climate and/or land use change, hydrological characteristics of the catchment may change; consequently, flood data may show trends. If there is significant trend in the observed flood data, stationary flood frequency analysis cannot be applied for design flood estimation. Statistical tests are used to identify trend in time-series data. In this paper, trend analysis has been carried out on Brisbane River catchment of Queensland, Australia. A total of 26 stations are selected with annual maximum flood data with record length ranging from 20 to 87 years. Twelve different trend tests including non-parametric Mann-Kendall (MK) test and Spearman's Rho (SR) test are applied to examine the trends in the annual maximum flood data of the selected stations. The identified trends are discussed in this paper. It has been found that only few stations show statistically significant trends for the selected stations.

Keywords: Flood data, design flood estimation, trend analysis, Queensland, Brisbane.

1. INTRODUCTION

In recent decades; floods account nearly half of all weather-related disasters worldwide and affected more than two billion people as mentioned in CRED (2015). Frequencies of major floods in Australia are changing in recent years. In the last 35 years of the 20th century, 77 notable floods were recorded in Australia; eight major floods were recorded in the 19th century and six in the first decade of the 21st century as mentioned in OQCS (2016). Improved understanding of the causes of these changes (frequency and magnitude) is crucial to minimise flood risks, to manage and mitigate future impacts of floods on Australian economy and society.

Several factors can cause changes in flood time series, such as climate change, bush fires, land-use changes, anthropogenic activities, relocation of gauging stations and volcanic eruptions as mentioned by Yue et al (2012). Climate drivers can be distinguished from anthropogenic-induced changes when a study focuses on pristine basins with reduced human interventions as stated by Svensson et al (2006). Climate change and human activities impacting flood runoff is a global phenomenon as stated by Xiong et al (2017). IPCC (2014) suggested that the possible impacts of climate change on flood control measures needed to be understood to minimize the risk of climate change. Existence of the climate change, land-use changes, and anthropogenic-induced changes in hydrologic time series (i.e., flood data) is being researched worldwide. The assessment of changes in annual maximum flood (AMF) data carries notable significance as AMF is widely used in design flood estimation.

Changes in hydro-meteorological series can take place in many ways. A change can occur abruptly (step change) or gradually (trend) or may take more complex forms. A time series is said to have trends, if there is a significant correlation (positive or negative) between the observations and time as stated by Machiwal and Jha (2009). A simple but effective procedure for screening hydrological data is to examine AMF data for trends (increasing and decreasing) and for significant increases or decreases in the mean of the data set after a particular time period by applying statistical tests. Trend and periodicity related statistical tests are used to check the stationarity of hydrologic time series. Roughly speaking, a random process is said to be stationary if it is not changing over time, or if it's statistical measures remain constant. Many statistical tests can be performed to help determine whether hydrological time series record displays a significant trend that might indicate non-stationarity.

With growing concerns about the impacts of climatic changes, researchers have employed various statistical and stochastic techniques to identify trends and shifts in hydrological time series at different temporal scales of aggregation as highlighted by Caloiero et al (2011).

Khaliq et al (2009) in their research stated that numerous studies have been undertaken in different regions of the world to investigate the existence of abnormalities in the form of trends in hydrological time series data. Several trend analyses on flood time-series have been carried out recently around the globe as stated by Hajani and Rahman (2017) in Australia, Hajani et al, (2017) in Australia, Chowdhury and Beecham (2013), Giuntoli et al (2012) in Franch; Hannaford and Buys (2012) in the UK, Khaliq et al (2009) in Canada, Hannaford and Buys (2012)in England; Macdonald et al (2010) in Wales, Murphy et al (2013) in Ireland, and Javari Majid (2016) in Iran.

The initial results of trend analyses in Australian AMF series had shown a trend for over 30% of the stations investigated according to research by Ishak et al (2010), although further investigation is needed before any firm conclusion can be made about the trends in Australian flood data. Rahman et al (2012) in their research highlighted that it was not possible to confirm whether the detected trends were due to climate change or due to climate variability . Ishak et al (2013) investigated the presence of trends in Australian flood data using the most extensive database on AMF data in Australia. The assessment of trends showed that 21-33% of stations had significant downward trends, which was considerably greater than the percentage of stations with significant upward trends (1-6%). Hajani and Rahman (2017) investigated trends in rainfall time series in NSW, Australia and they found mixed trends in different type of rainfall series. Barua et al (2013) found decreasing trend in annual rainfall series in Yarra River catchment, Australia. Many researchers in Australia found trends in rainfall data series by Li et al (2012), Chowdhury and Beecham (2013), Chen et al (2013a) and Laz et al (2014) in their investigation.

2. DATA

Availability of a quality-controlled time series dataset is essential for a meaningful trend analysis (Kundzewicz and Robson 2004). The AMF data series have been used in this study, which have a relatively long period of quality-controlled streamflow record. All gauging records have 2011 flood flow record, which is one of the most recent severe flood events after 1974 in Queensland, Australia.

For statistical analyses of flood data, data should be error free; however, at some stations this assumption may be grossly violated. Stations graded as 'poor quality' or with specific comments by the gauging authority regarding quality of the data were assessed in greater detail, and stations deemed 'low quality' was excluded.

The streamflow record at a stream gauging location should be long enough to characterise the underlying probability distribution with reasonable accuracy. Selection of a record length is important as this affects the total number of stations available for the study (Ishak et al 2013). For this study, the stations having a minimum of 20 years of AMF records were selected. The AMF record lengths of the selected 26 stations are in the range of 20 to 91 years, with a mean value of 47 years.

Priority was given to small/medium sized catchments with an upper limit of 1000 km^2, except for one catchment where catchment area is more than 1000 km^2. Trend detection in large catchments is considered more challenging as there are many different land uses and hydrological processes are generally involved in a large catchment (Ishak et al 2013).

3. METHOD OF TREND DETECTION

In this study 12 statistical tests are used to test for trend, change and randomness in AMF data. All the tests are applied at the 1%, 5% and 10% significance levels. The significance level is a means of measuring whether the test statistic is very different from the (critical) values that would typically occur. Test statistic is a means of comparing null hypothesis and alternative hypothesis. Trend analysis is carried out using TREND software developed by Chiew and Siriwardena (2005). Seven non-parametric tests i.e., Mann-Kendall, Spearman's Rho, Median Crossing, Rank Difference, Rank-Sum, Turning Points and Distribution-Free CUSUM test methods are used in this study. Five parametric tests i.e., Autocorrelation, Cumulative Deviation, Linear Regression, Student's t and Worsley Likelihood Ratio test methods are also used in this study.

4. RESULT

Tables 1 and 2 show the significance levels, values of the test statistic, the critical values of the test statistics, the critical values of the test re-sampling statistic of 12 different statistical tests at α = 0.01, α = 0.05 and at α = 0.1 significance levels for AMF data at stations 143001C and 143015B, respectively.

Table 1. Trend test critical value and test statistics for data at station 143001C

Test Name	Test Statistic for Each Test	Critical Values of Trend test statistics for Significance Levels at			Critical Values of Trend test Re-Sampling statistics for Significance Levels at			Result
		α=0.1	α=0.05	α=0.01	α=0.1	α=0.05	α=0.01	
Mann-Kendall	-1.51	1.65	1.96	2.58	1.65	1.94	2.57	NS
Spearman's Rho	-1.45	1.65	1.96	2.58	1.60	1.99	2.54	NS
Linear regression	-0.42	1.67	2.00	2.66	1.71	1.91	2.46	NS
Cusum	7.00	9.45	10.54	12.62	9.00	10.00	12.00	NS
Cumulative deviation	0.82	1.15	1.27	1.53	1.12	1.22	1.38	NS
Worsley likelihood	1.83	2.87	3.16	3.79	3.98	5.61	6.47	NS
Rank Sum	1.32	1.65	1.96	2.58	1.72	2.02	2.67	NS
Student's t	0.67	1.675	2.00	2.66	1.59	1.82	2.11	NS
Median Crossing	0.13	1.65	1.96	2.58	1.69	1.95	2.73	NS
Turning Point	-0.21	1.65	1.96	2.58	1.76	2.07	3.01	NS
Rank Difference	-1.52	1.65	1.96	2.58	1.69	1.95	2.64	NS
Auto Correlation	0.97	1.65	1.96	2.58	1.48	1.99	3.06	NS

(NS means not significant at α = 0.1 (10%); S means statistically significant, with the significance level shown in brackets)

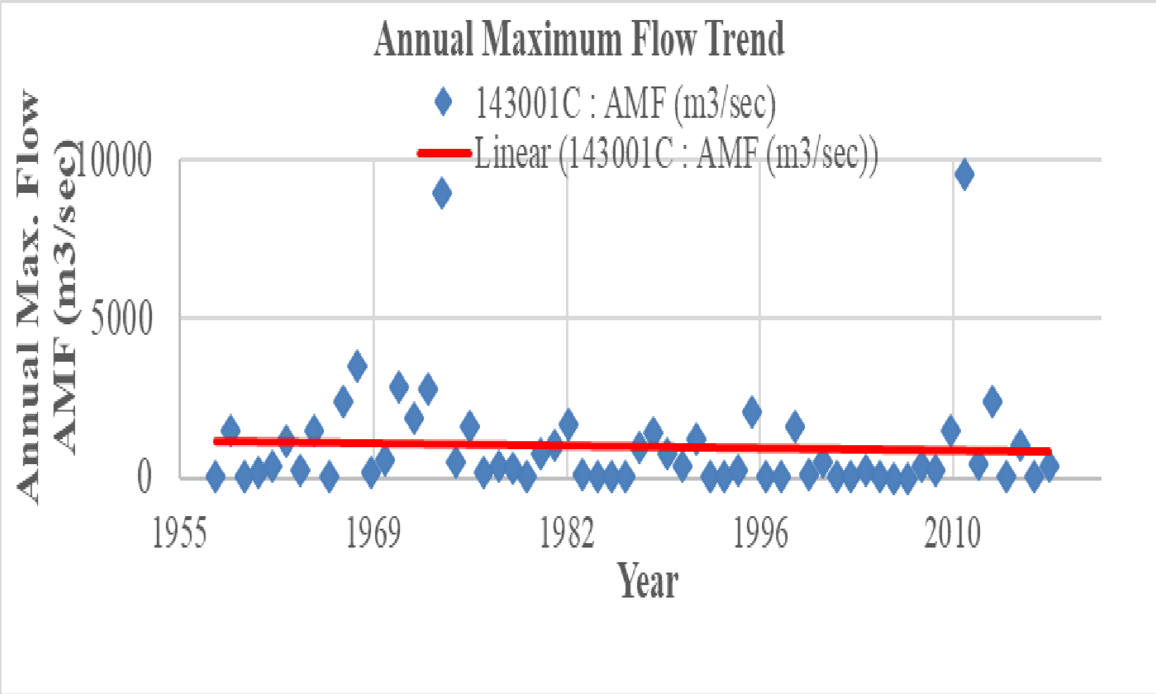

Figure 1. Plot of the annual maximal discharge and the corresponding linear trend line for station 143001C.

Table 2. Trend test critical value and test statistics for data at station 143015B

Test Name	**Test Statistic for Each Test**	**Critical Values of Trend test statistics for Significance Levels at**			**Critical Values of Trend test Re-Sampling statistics for Significance Levels at**			**Result**
		α=0.1	**α=0.05**	**α=0.01**	**α=0.1**	**α=0.05**	**α=0.01**	
Mann-Kendall	-1.80	1.65	1.96	2.58	1.64	1.92	2.51	S (0.1)
Spearman's Rho	-1.73	1.65	1.96	2.58	1.69	1.98	2.57	S (0.1)
Linear regression	0.28	1.68	2.01	2.69	1.72	2.09	2.75	NS
Cusum	8.00	8.54	9.52	11.41	9.00	10.00	12.00	NS
Cumulative deviation	0.84	1.14	1.27	1.52	1.14	1.28	1.48	NS
Worsley likelihood	2.35	2.87	3.16	3.79	3.64	5.98	7.48	NS
Rank Sum	1.87	1.65	1.96	2.59	1.67	1.99	2.65	S (0.1)
Student's t	-0.01	1.68	2.01	2.69	1.66	1.92	2.27	NS
Median Crossing	0.58	1.65	1.96	2.58	1.73	2.021	2.31	NS
Turning Point	0.23	1.65	1.96	2.58	1.84	2.19	2.99	NS
Rank Difference	-1.07	1.65	1.96	2.58	1.61	1.85	2.61	NS
Auto Correlation	1.22	1.65	1.96	2.58	1.50	1.77	2.71	NS

(NS means not significant at α = 0.1 (10%); S means statistically significant, with the significance level shown in brackets)

The AMF data and linear regression line of the data for stations 143001C, 143015B and for station 143033A are shown in Figures 1, 2 and 3 respectively. It is seen from these figures and tables that there is no sudden drop or rise in the AMF flood data.

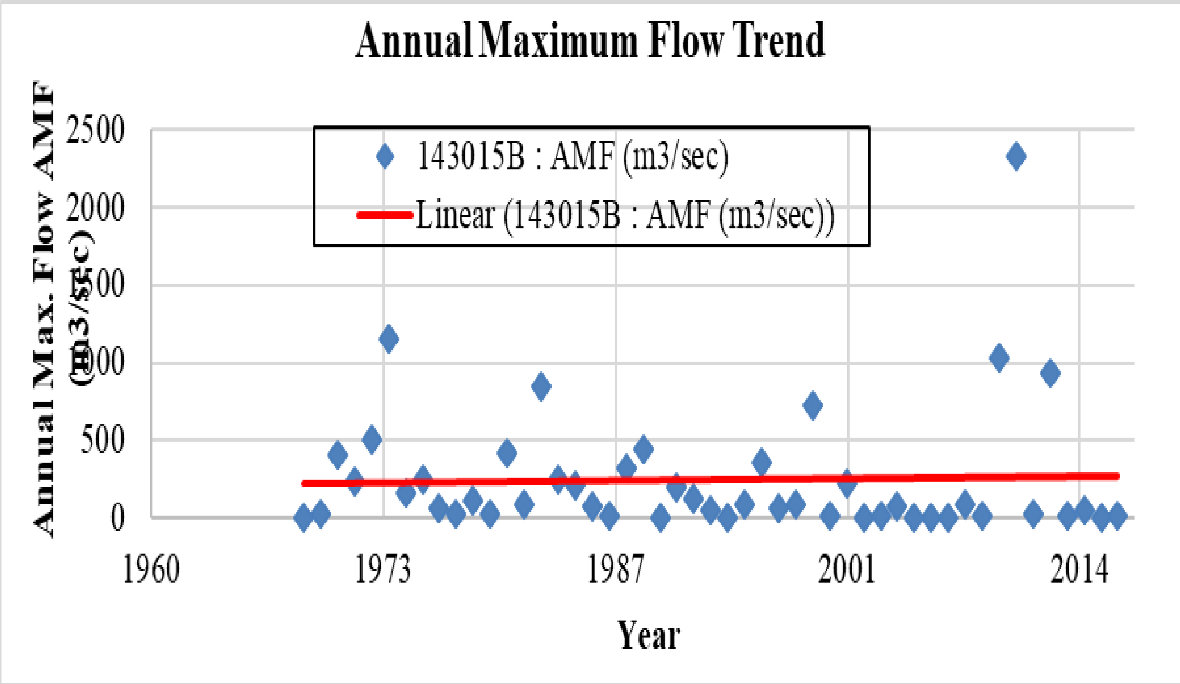

Figure 2. Plot of the annual maximal discharge and the corresponding linear trend line for station 1430015B.

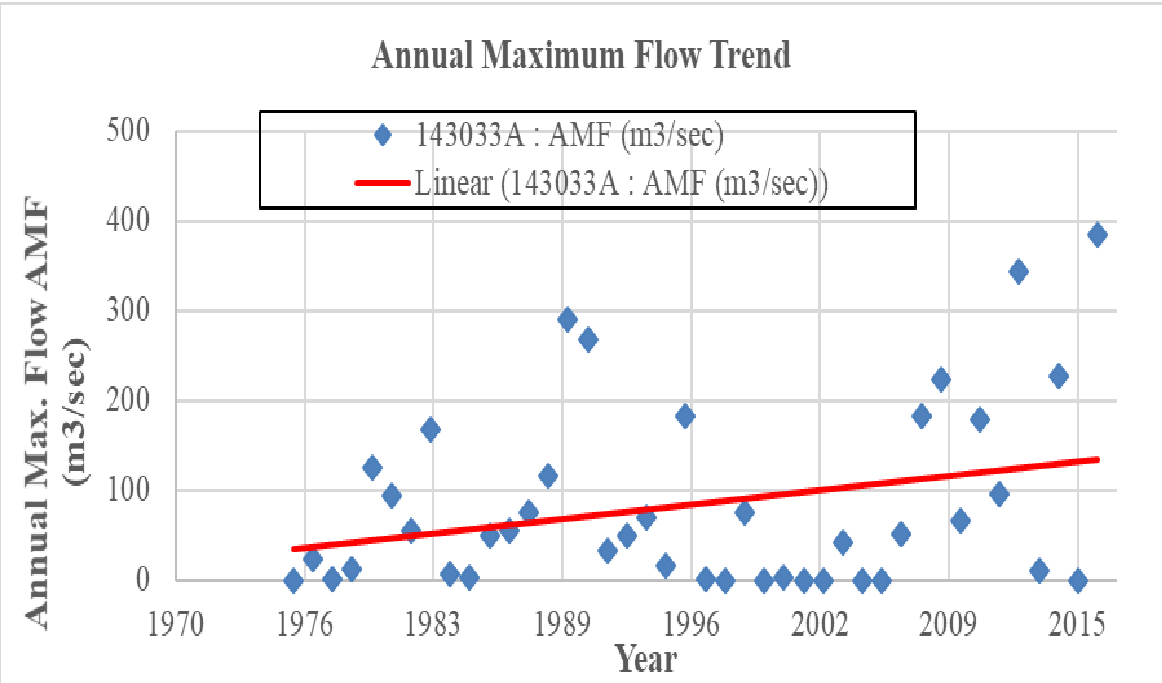

Figure 3. Plot of the annual maximal discharge and the corresponding linear trend line for station 143033A.

Trend analysis result of AMF data series at station 143001C (Table 1) shows that there is no significant trend (Mann-Kendall, Spearman's Rho and Linear Regression tests), no step jump in mean (Distribution-Free CUSUM, Cumulative Deviation, Worsley Likelihood Ratio tests) and does not have difference in median from two data periods (Rank-Sum, Student's t test). Figure 1 shows mild downward slope in linear regression line in AMF data for station 143001C. Trend analysis result of AMF data at station 143015B (Table 2) does not show existence of statistically significant trend according to Mann-Kendall and Spearman's Rho tests although data shows existing of difference in median between two data periods (Rank-Sum). Figure 2 shows mild upward linear regression line slope in data for stations 143015B. However statistical Linear Regression trend test does not show any significant trend for these stations (Table 1 and 2). Step jump in data are found with CUSUM and Cumulative Deviation statistical tests for station 143028A (Table 3). Figure 3 shows upward linear regression line slope in AMF data for station 143033A. The statistical Linear Regression trend test also shows significant trend for these stations (Table 3, column 4). However, Mann-Kendall and Spearman's Rho tests do not show any significant trend.

Table 3 shows the summary of trend test result with upward (+Ve) or downward (-Ve) trends for each station's AMF data. Presence of step jump in the mean value is tested using Distribution-Free CUSUM, Cumulative Deviation and Worsley Likelihood Ratio test. Time series data of most of the stations (21) show positive slope, while 5 stations show negative slope. Maps showing the trend detection results for the AMF data at the 10% significance level are presented in Figure 4.

A trend in a time series is considered to be present if it has been detected by most of trend tests as described section 3.0. The trend analysis with 12 (twelve) different trend tests results does not show statistically significant trend at the 10% significance level for the AMF data of the majority stations (Table 3). The two widely used tests (Mann-Kendall and Spearman's Rao tests) on the AMF data in one station (143015B) show presence of statistically significant trend. This station is located on Cooyar Creek at Taromeo CK further upstream of Brisbane River (Figure. 4). The geography of this catchment indicates that there has not significant human intervention on this catchment. This is a relatively large catchment. However, the highest AMF for this station is 853 m^3/s in 2011, with a catchment area of 953 km^2.

The Linear Regression test, Cumulative Deviation test, Worsley Likelihood test, Median Crossing and Rank Difference test show statistically significant trend in AMF data for station 143033A. However widely used Mann-Kendall test and Spearman's Rao test do not indicate any significant trend at this station. Figure 3 shows that the AMF data in this station is more fluctuating compare to that of other stations. The geographical location of this catchment with linear regression trend is shown in Figure 4. This station is located on Oxley creek at New Beith. Oxley Creek extends from its confluence with the Brisbane River at Graceville some 50 km through Brisbane City. Historically, there have been significant mitigation and sand extraction works carried out along the length of Oxley Creek and in some parts of Blunder Creek. These works have had considerable impacts on the creek configurations and have contributed to the highly mobile nature of the channels, with loops, meanders, anabranches and oxbows being created along the length of the creeks as stated by BCC (2014). It may be possible that AMF has been influenced by the above-mentioned activities.

Table 3 Summary of Trend Test for all 26 stations data

Station Number	Mann-Kendall	Spearman's Rho	Linear regression	Cusum	Cumulative deviation	Worsley likelihood	Rank Sum	Student's t	Median Crossing	Turning Point	Rank Difference	Auto Correlation	Linear Regression Slope
143001C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve
143007A	NS	NS	NS	NS	NS	NS	S (0.05)	NS	NS	NS	NS	NS	+Ve
143009A	NS	NS	NS	NS	NS	NS	S (0.1)	NS	NS	NS	NS	NS	-Ve
143010B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143015B	S (0.1)	S (0.1)	NS	NS	NS	NS	S (0.1)	NS	NS	NS	NS	NS	+Ve
143028A	NS	NS	NS	S (0.1)	S (0.1)	NS	NS	NS	NS	NS	NS	NS	+Ve
143032A	NS	NS	NS	NS	NS	NS	NS	S (0.1)	NS	NS	NS	NS	-Ve
143033A	NS	NS	S (0.1)	NS	S (0.05)	S (0.05)	NS	NS	S (0.1)	NS	S (0.1)	NS	+Ve
143107A	NS	NS	NS	NS	S (0.1)	S (0.1)	NS	NS	NS	NS	NS	NS	+Ve
143108A	NS	NS	NS	NS	NS	NS	NS	NS	S (0.05)	S (0.1)	S (0.1)	NS	-Ve
143110A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143113A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve
143203C	NS	NS	S (0.1)	NS	NS	NS	NS	S (0.1)	NS	NS	NS	NS	+Ve
143207A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve
143209B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve
143212A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143219A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143229A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143303A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	S (0.1)	S (0.1)	-Ve
143921A	NS	NS	S (0.1)	NS	S (0.05)	NS	NS	NS	NS	NS	NS	NS	+Ve
143210B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve
143306A	NS	NS	NS	NS	NS	S (0.05)	NS	NS	NS	NS	NS	NS	+Ve
143213C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143232A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143233A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+Ve
143307A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-Ve

NS means not significant at α = 0.1 (10%); S means statistically significant, with the significance level shown in brackets

Figure 4 show that linear regression line slope in data for majority stations (especially upstream catchments) are upward (+ve, increasing) and station showing downstream trends are few and are mainly in downstream catchments. The change point in the data has been tested using the Cumulative Deviation test within the Trend software. The test does not show any significant change point for all station's data. The Cumulative Deviation test also does not sow show trend in AMF time series data at 10% significance level for all stations except for two stations (142028A and 143107A).

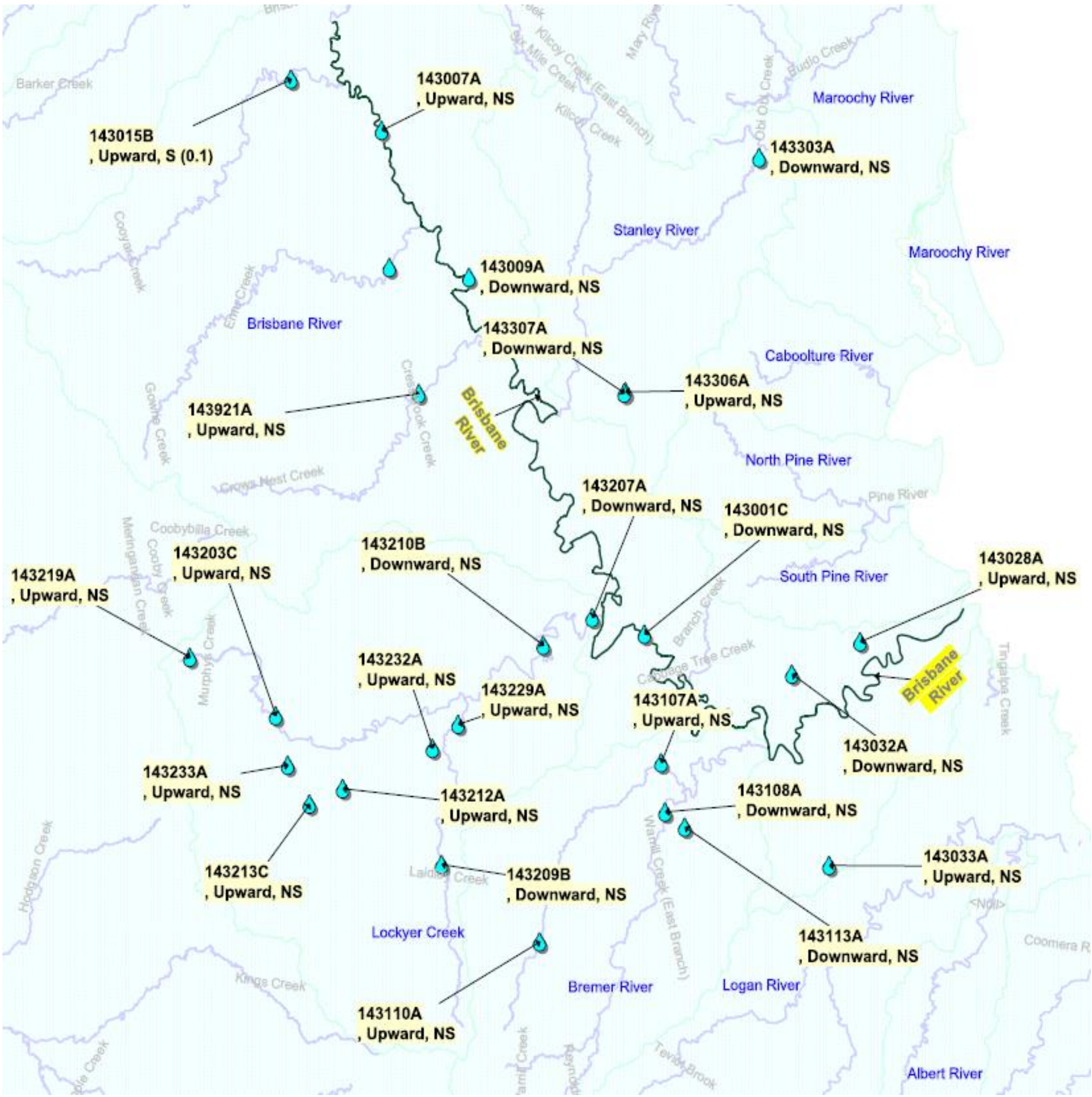

Figure 4: Distribution of stations with Linear Regression Trend (Upward/Downward) and statistical significance trend level (S/NS).

5. CONCLUSION

Trend analysis result shows that more than 80% of the stations' AMF data in the Brisbane River catchment does not show statistically significant trend. Similar result was obtained by Haddad and Rahman (2010) in their study on Tasmania in Australia, they found only 3 stations having significant trend out of 53 stations. Similar results were obtained by Robson et al (1998) where no trend in the AMF data was detected for a dataset in the United Kingdom. It can be concluded that the presence of trend in AMF data is not significant in Brisbane River catchment; however further study on trend analysis with more stations and longer data period are recommended in near future.

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Coagulation of Tannery Waste Water

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Abstract

Tannery effluent is a hazardous pollutant. It can cause adverse environmental problems related to its high biological oxygen demand (BOD) and chemical oxygen demand (COD). Total dissolved solids (TDS), conductivity, turbidity and other inorganic pollutant, coagulation flocculation is a common waste treatment process. The aim of our study was to develop a treatment method that can efficiently reduce pollutant without any additional costs. In this research we used de liming waste water to coagulate fat liquoring waste water. The process gives a very good removal of biological oxygen demand (BOD) 81.24%, chemical oxygen demand (COD) 88.47%, total dissolved solid (TDS) 84.25%, turbidity 93.63% and conductivity 84.37%. The results indicate that waste water can be successfully used to coagulate fat liquoring waste water.

Keywords: waste water, de-liming, fat liquoring, tannery, removal.

1. INTRODUCTION

The tannery industry is renowned for high consumption of water. Approximately 20-30 m^3 of effluents discharged to the environment during the processing of every ton of raw hide (Ozgunay et al 2007). Tannery effluents contains high level of chemical oxygen demand, biological oxygen demand, inorganic salt, dissolved and suspended solids ammonia organic nitrogen and various toxic metal salt residues (Shams et al 2008). More than 200 tannery industries are located in horizontal area and every day 22000 m^3 of liquid waste are dumped into river Burigonga without any treatment which causes environmental pollution and health risk (Cooman et al 2003). Treatment of tannery effluent has been a very vital issue for leather manufacturer and also an economic burden for tannery owner. A number of research works on treatment of tannery waste water has been investigated such as electro coagulation (Chawdury et al 1997), adsorption (Carlos et al 2002), Coagulation, flocculation, sedimentation (Ayoul et al 2001). Most of the research reports on tannery effluents in Bangladesh have emphasized on characterization and environmental impact assessment (Espinoza et al 2009; Sony et al 2000; Fernando 2009; Sayuaya et al 1998). In this research we use effluent as a coagulant of other effluent. The aim of the study was to evaluate the treatment of tannery waste water without any additional cost.

2. MATERIALS AND METODS

2.1. Process description of tannery industries

Tanning is a processing that turns animal skin (called hide) into leather. The whole process is done by stage by stage. The first stage is the pretreatment for tanning (curing), second stage is the actual tanning and other chemical treatments. The third stage is re-tanning and the final stage is called finishing. Preparing hides begins by curing them with salt. Curing is employed to preserve the hide (protein substance, such as collagen) from bacterial growth during the time lag from procuring the hide to when it is processed. Curing removes water from the hides and skins material to provide the physical strength and sustainability. Then it is preserved for next process is called tanning. Tanning is performed to modify the protein called collagen in the hide. There are many types of tanning process such as chrome, vegetable, mineral, towing tanning etc. All are based on type of materials/chemicals used for the tanning processes. In Bangladesh, most of the tanneries use chrome tanning because it the most efficient one. Before tanning the preserved hide is soaked first for several hours to re-hydrate. In chrome tanning, the hides are soaked a lime and sulfide solution which either loosens or dissolves the attached hair for several hours. The hides are checked for tanning. Tanning is also done in a rotary drum. In chrome salt tanning, chromium sulfate solution is added in the drum and kept for a time being resulting in wet light blue colored leather. Then the leather is dehydrated and dried. The process increases the spacing between protein chains in collagen and makes the leather softer and thinner. In re-tanning, mineral agents and dyes are applied to the tanned leather in the same manner. Again, leather is dehydrated and dried. The finishing stage depends on the use of the leather.

2.2. Study area

The study area is comprised of Hazaribagh tannery industry area, Dhaka. It is situated between 23º45` to 23º49` latitudes and 90º21.85` to 90º22.15` East longitudes. Three tanneries named as Samina, Ruma and Chowdhury tannery were selected for effluent collection. They export good quality leather to the USA and European countries.

2.3. Sample collection

The study was conducted during the year of 2016 and the liming and dying effluents were collected from the outlet of the three selected industries located in Hazaribagh leather processing zone, Dhaka. For the present investigation all samples were collected directly from the discharge point of the industrial tanning stage operation. All the samples were collected by following Pearson method and stored in the polyethylene bottles at 4±1ºC in the laboratory. It was stored such way until further use.

2.4. Treatment process

At first the untreated effluents of all three industries were characterized. Its properties were measured. Then the dying and liming stage effluents were mixed in different proportions. In first treatment sample 50 ml of each effluent was mixed in a beaker. Then it was allowed to settle for 48 hours at room temperature. After 48 hours the mixture was filtered by Whitman filter paper. After that, the filtrate was characterized to evaluate the level of treatment of the effluents. Same method was used for rest of the tannery effluents. After investigating the treatment of samples for 1:1 proportion, similar treatment method was applied for 50ml of dying and 100ml of liming (1:2 dying and liming stage effluent) and 100ml of dying and 50ml of liming stage effluents (2:1 dying and liming stage effluent) mixtures. The characterization data were recorded carefully.

2.5. Tannery effluent characteristics

The physical parameters including BOD (biological oxygen demand), COD (chemical oxygen demand), TDS (total dissolved solid), and turbidity, pH and conductivity in raw effluents were measured at 20oC. BOD and COD were measured as per standard method of APAH. Turbidity was measured using digital direct reading turbidity meter (orbeco-Hellige), HACH meter for TDS. Conductivity and pH were measured using digital conductivity-meter and pH-meter.

3. RESULTS AND DISCUSSION

3.1. Characterization of tannery effluent

The BOD, COD, TDS, turbidity, conductivity and pH range of the unrelated tannery effluents were found to be 30 mg/l to 6018 mg/l, 113 Delime 30 mg/l to 19923 mg/l, 49155 mg/l to 55219 mg/l, 921 NTU to 1040 NTU, 98110 us/ cm to 112100 us/cm and 9.0 to 5.0 respectively. The color of raw tannery effluent was yellowish brown.

Table 1: Characterization of Tannery Effluent

Name of Tannery	**Name of Operation**	**BOD mg/l**	**COD mg/l**	**TDS mg/l**	**Turbidity NTU**	**Conductivity us/cm**	**p^H**
Ruma	Delime	3015	113330	49155	980	98110	8.9
	Fat liquoring	5710	18155	50150	950	100110	5.1
Samina	Delime	3000	12165	55219	964	112100	9.0
	Fat liquoring	5750	17755	50535	970	99950	5.5
Chowdhury	delime	3259	13150	49380	921	98155	8.9
	Fat liquoring	6018	19923	51220	1040	102110	5.0

The analysis reports illustrated that the raw tannery effluents were highly polluted and quite unexpected for fish and aquatic lives. The analyzed results also indicated that BOD, COD and TDS were very high than those of prescribed standard. Fat liquoring effluents contain organic fat compounds and de liming effluents contain ammonium sulfate. Ammonium sulfate is a coagulant and, in our research, we use de-liming effluents as a coagulant for the fat liquoring effluents.

3.2. Reduction of Biological Oxygen Demand (BOD)

Table 2 shows the effluent on the removal of BOD. After the addition of the de-liming waste water at a different proportion with fat liquoring waste water. The BOD concentration of the solution decreased by 81.24% to 73.6%. optimum removal of BOD was achieved at a proportion of delime 1:1 fat liquoring. Increased of de-liming or fat liquoring dose is associated with a decreased in the BOD removal.

Table 2: Reduction of percentage of BOD

Name of Tannery	Proportion 1:1 Delime :Fat liquoring 50 ml: 50 ml			Proportion 2:1 Delime : Fat liquoring 100 ml: 50 ml			Proportion 1:2 Delime : Fat liquoring 50 ml: 100 ml		
	BOD after treatment	Removal %	p^H	BOD After treatment	Removal %	p^H	BOD after treatment	Removal %	p^H
Ruma	1815	79.20 %	5.7	1915	78.05 %	6.8	2219	74.75 %	5.3
Samina	1715	80.4 %	5.8	1800	79.43 %	6.7	2310	73.60 %	5.2
Chowdhury	1740	81.24 %	5.7	1890	79.63 %	6.4	2310	73.10 %	5.2

3.3. Reduction of COD

Table 3 illustrated the effect of waste water mixture on the percentage removal of COD, after the addition of the de-liming waste water in different proportion with fat liquoring waste water the COD concentration decreased by 88.47 % to 83.44 % the optimum removal of COD was achieved at a proportion of delime 1: 1 fat liquoring, as the de-liming and fat liquoring dosed increased the reduction of COD decreased.

Table 3: Reduction of percentage of COD

Name of Tannery	Proportion 1:1 Delime :Fat liquoring 50 ml: 50 ml			Proportion 2:1 Delime : Fat liquoring 100 ml: 50 ml			Proportion 1:2 Delime : Fat liquoring 50 ml: 100 ml		
	COD after treatment	Removal %	p^H	COD After treatment	Removal %	p^H	COD after treatment	Removal %	p^H
Ruma	4012	86.39 %	5.7	3915	86.72 %	6.8	4558	84.54 %	5.3
Samina	3818	87.24 %	5.8	4050	86.46 %	6.7	4954	83.44 %	5.3
Chowdhury	3815	88.47 %	5.7	4157	87.43 %	6.4	5014	84.84 %	5.2

3.4. Removal of TDS

Table 4 illustrated Removal percentage of TDS is around 84.25% to 79.64% and the optimum removal of TDS was achieved using 1:1 proportion. If the proportion of de-liming and fat liquoring increase the removal percentage dramatically decreases because the amount of anion and cation increases.

Table 4: Removal percentage of TDS

Name of Tannery	Proportion 1:1 Delime : Fat liquoring 50 ml: 50 ml			Proportion 2:1 Delime : Fat liquoring 100 ml: 50 ml			Proportion 1:2 Delime : Fat liquoring 50 ml: 100 ml		
	TDS after mg/l	Removal %	p^H	TDS after mg/l	Removal %	p^H	TDS after treatment mg/l	Removal %	p^H
Ruma	17715	82.16 %	5.7	18130	81.74 %	6.8	20220	79.64 %	5.3
Samina	16654	84.25 %	5.8	18110	82.88 %	6.7	20230	80.87 %	5.2
Chowdhury	16480	83.62 %	5.7	18130	81.20 %	6.4	20215	79.91 %	5.2

3.5. Removal of Turbidity

Table 5 shows Removal percentage of turbidity is around 93.73% to 90.13% and the optimum removal of turbidity was achieved using 1:1 proportion. If the proportion of de-liming and fat liquoring increase the removal percentage dramatically decreases because the amount of anion and cation increases.

Table 5: Removal percentage of Turbidity

Name of Tannery	Proportion 1:1 Delime : Fat liquoring 50 ml: 50 ml			Proportion 2:1 Delime : Fat liquoring 100 ml: 50 ml			Proportion 1:2 Delime : Fat liquoring 50 ml: 100 ml		
	Turbidity after treatment NTU	Removal %	p^H	Turbidity after treatment NTU	Removal %	p^H	Turbidity after treatment NTU	Removal %	p^H
Ruma	121	93.73 %	5.7	143	92.59 %	6.8	184	90.47 %	5.3
Samina	138	92.87 %	5.8	163	91.57 %	6.7	191	90.13 %	5.3
Chowdhury	125	93.63 %	5.7	146	92.56 %	6.4	182	90.72 %	5.2

3.6. Removal percentage of Conductivity

Table 6 shows the influence of waste water mixture on the removal of conductivity. After the addition of de-liming effluent with fat liquoring effluent at a different proportion delime: fat liquoring the conductivity decreased by 84.73 % to 79.38 % the maximum removal efficiency of conductivity was achieved at a mixture of delime 1:1 fat liquor.

Table 6: Removal percentage of Conductivity

Name of Tannery	Proportion 1:1 Delime : Fat liquoring 50 ml: 50 ml			Proportion 2:1 Delime : Fat liquoring 100 ml: 50 ml			Proportion 1:2 Delime: Fat liquoring 50 ml: 100 ml		
	Conductivity after treatment us/cm	Removal %	p^H	Conductivity after treatment us/cm	Removal %	p^H	Conductivity after treatment us/cm	Removal %	p^H
Ruma	34150	82.77 %	5.7	39955	81.86 %	6.8	40884	79.38 %	5.3
Samina	33150	84.37 %	5.8	37100	82.51 %	6.7	40448	80.93 %	5.3
Chowdhury	32250	83.90 %	5.7	36250	81.90 %	6.4	40520	79.77 %	5.2

As the de-liming and fat liquoring does increase the reduction percentage of conductivity decreased. A major proportion of the soluble matter in the waste water is removed by physical chemical treatment.

4. CONCLUSION

This investigation has demonstrated that coagulation of fat liquoring waste water with de liming waste water is an effective method to treat tannery waste water. The maximum removal of BOD 81%, COD 88% TDS 84% turbidity 93% and conductivity 84% respectively. The results indicate that the cost of treatment and discharge of waste water will be greatly reduced by this method. A significant proportion of pollutant remain in the tannery waste water so further treatment is required prior to discharge. Due to low operation cost this method can be successfully used for the treatment of waste water.

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Modification to Permeable Pavement Structure to Achieve Improved Nitrogen Attenuation in Stormwater Runoff

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Abstract

The objective of the present study is to improve the removal of nitrogen in stormwater runoff by modifying the permeable pavement structure. To achieve this, different mechanisms for nitrogen attenuation such as nitrification and denitrification, ion exchange and adsorption have been promoted in the permeable pavement structure. Treatment performances of these columns were monitored over a 6-month period of dosing with synthetic stormwater maintaining a rainfall intensity and duration at 40 mm / 4 hours. Results confirm that stormwater treatment performance of permeable pavement systems can be significantly improved by changing the layer setting of the pavement subbase. The modified permeable pavement structure will have wider application in urban stormwater management.

Keywords: Permeable pavements, stormwater pollutants, biodegradation, filtration, adsorption.

1. INTRODUCTION

Urbanisation affects urban water cycle in many different ways including increased runoff quantity and reduced water quality (Zanuttini and Rahman 2017). It can affect the health of urban water ways by increasing the level of nutrients and heavy metals in river water (Kuruppu and Rahman 2015).

Sydney is urbanising rapidly as many other cities around the world. The growth of Sydney's urban border has been documented in a map produced by the Department of Planning in 2005 for the then urban plan for Sydney (Figure. 1). The city remained incredibly compact through to the turn of the 20th century, focused on the Sydney CBD and its port. The extent of impervious surface (e.g. roof, road and parking lot) is generally taken as an indicator of the intensity of urbanisation (Arnold and Gibbons 1996). As presented in Figure. 1, if Sydney continues to grow outwards at the same rate, then by 2031 it is likely to include the areas shown above in yellow. Thus, the environmental issues associated with impervious surfaces are set to increase. Hence, the urban runoff needs to be sustainably managed to protect urban water cycle and to enhance water quality and to conserve environmental values of urban ecosystems.

Stormwater management strategies have shifted more recently from simple flood control practices to more environmentally sustainable methods known as water sensitive urban design, which comprise of sustainable methods such as onsite retention systems, storage, treatment and reuse of stormwater runoff. Permeable pavements are one of the best stormwater management practices, which provide multiple advantages such as reduced impervious factor that mitigates numerous negative impacts arising from urbanisation including increased flood risk, change in water balance, reduced evaporation, heat island effect, soil erosion and standing water issues like odour and mosquito breeding. However, it has been found that uptake of permeable pavement as a stormwater best management practice is relatively limited and slow due to lack of in-depth scientific understanding and limitations in its usefulness to a few hydrogeological conditions (Kuruppu et al 2018).

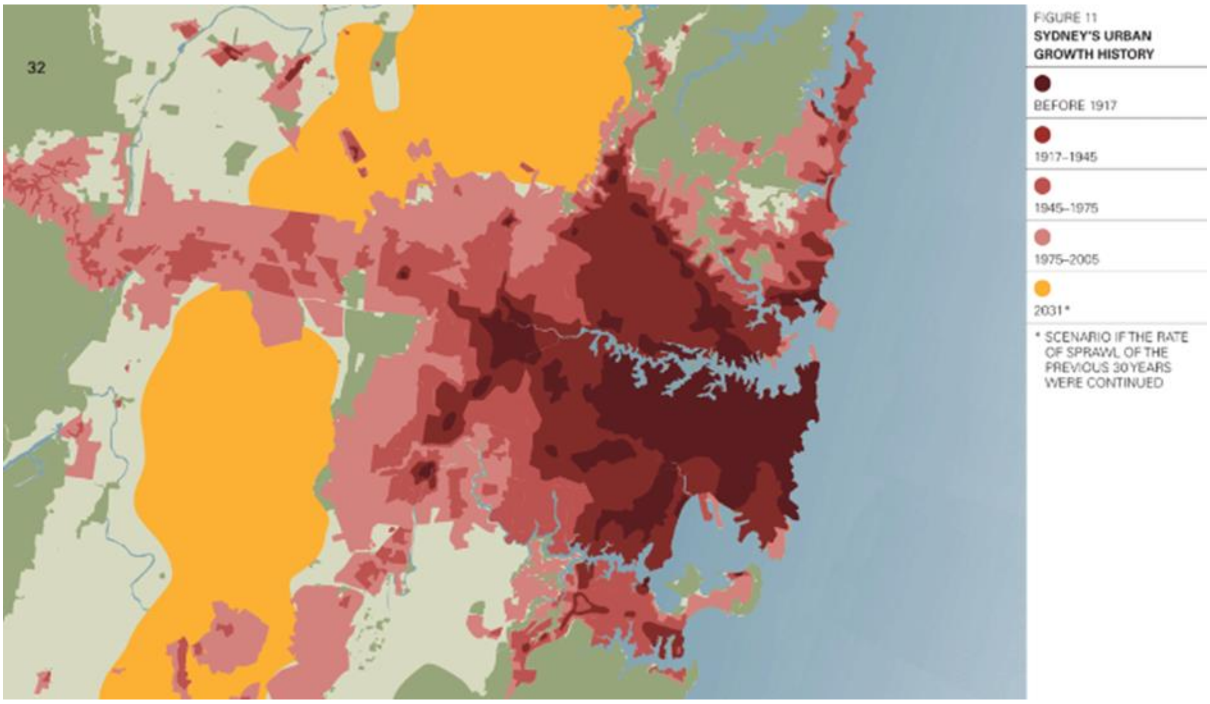


Figure 1. Growth of Sydney's urban boundary (City of Cities – A Plan for Sydney's Future, Department of Planning 2005.)

In this study, six permeable pavement columns with different subbase configurations were tested for attenuation of pollutants found in stormwater runoff. Column subbases were constructed considering the following hypothesis for enhanced physical, chemical and biological treatment of pollutants: (i) a layer of natural zeolite in subbase of the PPS to enhance pollutants by ion exchange and adsorption; (ii) a layer of bark chips as a carbon donor for biodegradation; (iii) providing required moisture content and reduced oxygen level by maintaining a saturated zone and increasing retention time for enhanced biodegradation; and (iv) thin sand layers to limit oxygen transport and to create an anoxic zone. A series of experiments were carried out over a six-month period, dosing with synthetic stormwater having different pollutant concentrations while maintaining varying rainfall intensities to simulate extreme runoff conditions.

2. MATERIALS AND METHODS

2.1. Experimental set-up

Six permeable pavement columns with different aggregate material and bed thicknesses (with a control constructed as per the HydroStone design guide) as presented in Figure 2 were constructed in the laboratory. Columns were constructed with an opaque black plastic material to simulate the natural conditions of PPS subbase. The column liner dimensions were determined based on the Representative Elementary Volume (REV) for porous media (Bear 1972). Aggregate layer setting was varied by changing bed thickness and including different filter media to improve adsorption. In some columns, a favourable environment for microbial growth was created by having sufficient nutrients, oxygen and detention time.

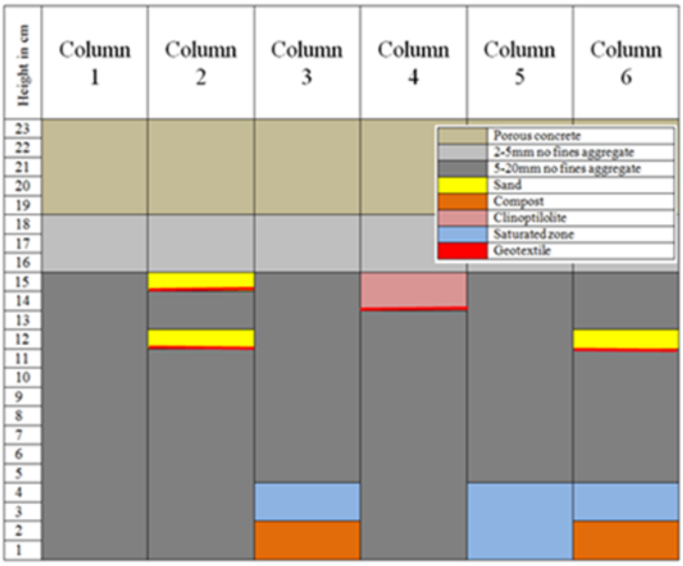


Figure 2. Colum cross sections

2.2. Preparation of synthetic runoff

Due to limitations associated with the use of real stormwater, synthetic stormwater was used for this experiment. All chemicals that were used in preparation of synthetic stormwater solutions were dissolved in normal tap water. Here, 1 M H2SO4 and 1 M NaOH were used for pH adjustments. The characteristics of synthesized runoff are presented in Table 1. Pollutant composition of synthetic runoff was varied (from 1.5 mg/L to 2.5 mg/L) during the later stage of the experiment to identify the effect of inlet concentration on treatment performance.

2.3. Rainfall simulation

Synthetic runoff was applied to permeable pavement columns continually for 4 hours. Experiments were carried out maintaining three different average rainfall intensities as 20 mm, 40 mm and 120 mm. The median rainfall intensity which is 40 mm for 4 hours duration was selected as close to the commonly adopted design rainfall for Sydney NSW, Australia.

The effect of rainfall intensity on nitrogen attenuation was tested by changing the rainfall intensities. As the 2nd step, experiments were carried out starting with a rainfall intensity of 19-21 ml/min (low intensity rainfall). It was maintained for 1 hour and the rainfall intensity was increased to 118-122 mL/min (high intensity rainfall).

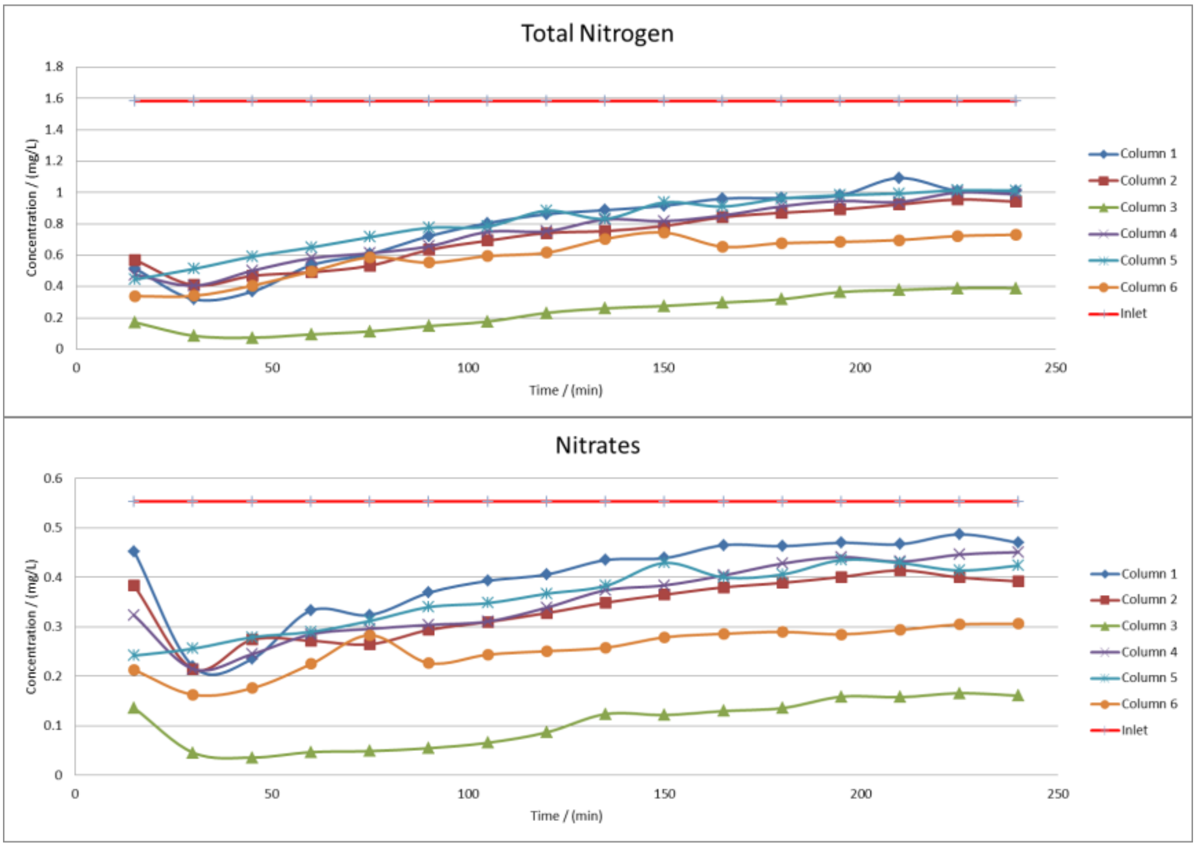
For each repetition, the input stormwater was stored in a 300 L fiberglass container and was well-mixed. During the experiment, stormwater was pumped into the columns from the top through a weeper hose and outlet samples were collected from the bottom. Over each 4-hour repetition, samples were collected every 15 minutes and tested.

3. RESULTS AND DISCUSSION

Figure 3 and Table 1 present the results of nitrogen attenuation of six PPS columns over 4 hours. During the first hour, all six columns were able to attenuate more than 70% of total nitrogen. When considering the percentage reduction over time, the standard traditional permeable structure which represents by column 1 can only retain 35% of total nitrogen during 4th hour. Correspondingly, there are many researches which observed the inefficient nitrate removal from standard traditional PPSs (Drake et al 2014, Yazdi et al 2015 and Niu et al 2016). Davis et al (2001; 2006) identified the possibility of leaching nitrates to groundwater through bio-retention systems). Thus, standard traditional permeable pavement structure needs to be modified to improve denitrification.

Column 3, which incorporated with an organic carbon source and a saturated zone, had been able to attenuate 75% of total nitrogen even in 4th hour. The Column 6, which has an organic layer combined with a saturated zone and a thin sand layer, also have shown a better performance compared to other 4 columns. Having a sand layer (Column 2), zeolite (Column 4) or a SZ alone (Column 5) have not improved the total nitrogen attenuation. Column 6, which incorporated a SZ, an organic carbon source and a thin sand layer have been able to improve the total nitrogen attenuation (55%). An improved nitrate removal has been demonstrated in Columns 3 and 6 compared to standard/traditional PPS structure (Column 1).

These results indicate that a new permeable pavement unit with a saturated zone and an organic carbon layer has the potential to make a notable contribution in stormwater best management practice by improving the stormwater quality while infiltrating the runoff effectively.



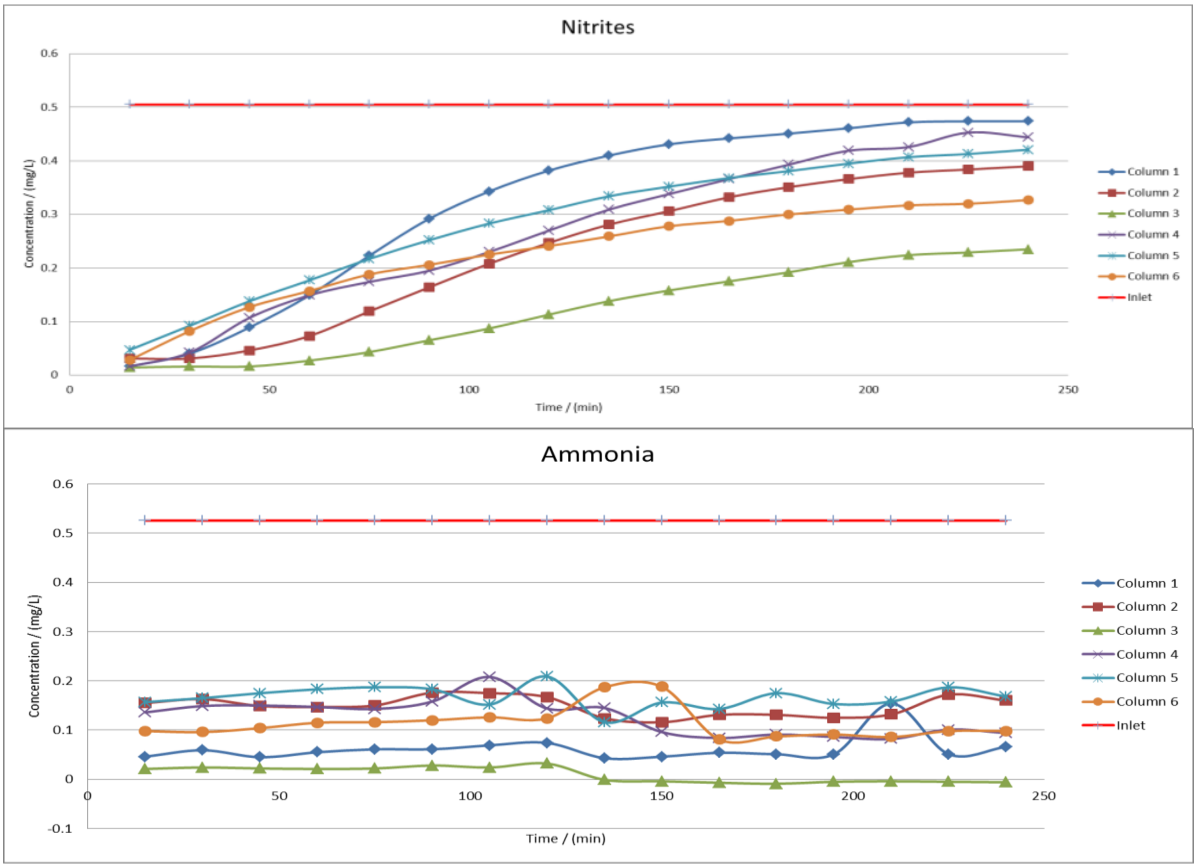


Figure 3. Nitrogen attenuation performance of 6 PPS Columns

Table 1. Hourly average reduction of total nitrogen

Column	Average Percentage Reduction of Total Nitrogen			
	1st hour	2nd hour	3rd hour	4th hour
1	72.56	52.71	41.14	35.35
2	69.40	58.93	48.64	41.40
3	93.28	89.41	81.79	**75.97**
4	69.01	56.26	46.16	38.86
5	65.27	50.17	42.52	36.82
6	75.01	62.90	56.12	55.25

Experiments were extended to investigate the effect of rainfall intensity on attenuation of nitrogen through different permeable pavement columns. Results (Figure 4) highlight the importance of maintaining the necessary retention time for biodegradation. It shows nitrogen attenuation capability is heavily dependent on rainfall intensity and duration. Even the modified structures have not performed well during the heavy rainfall. However, Column 6 has shown a minor feat over the other columns.

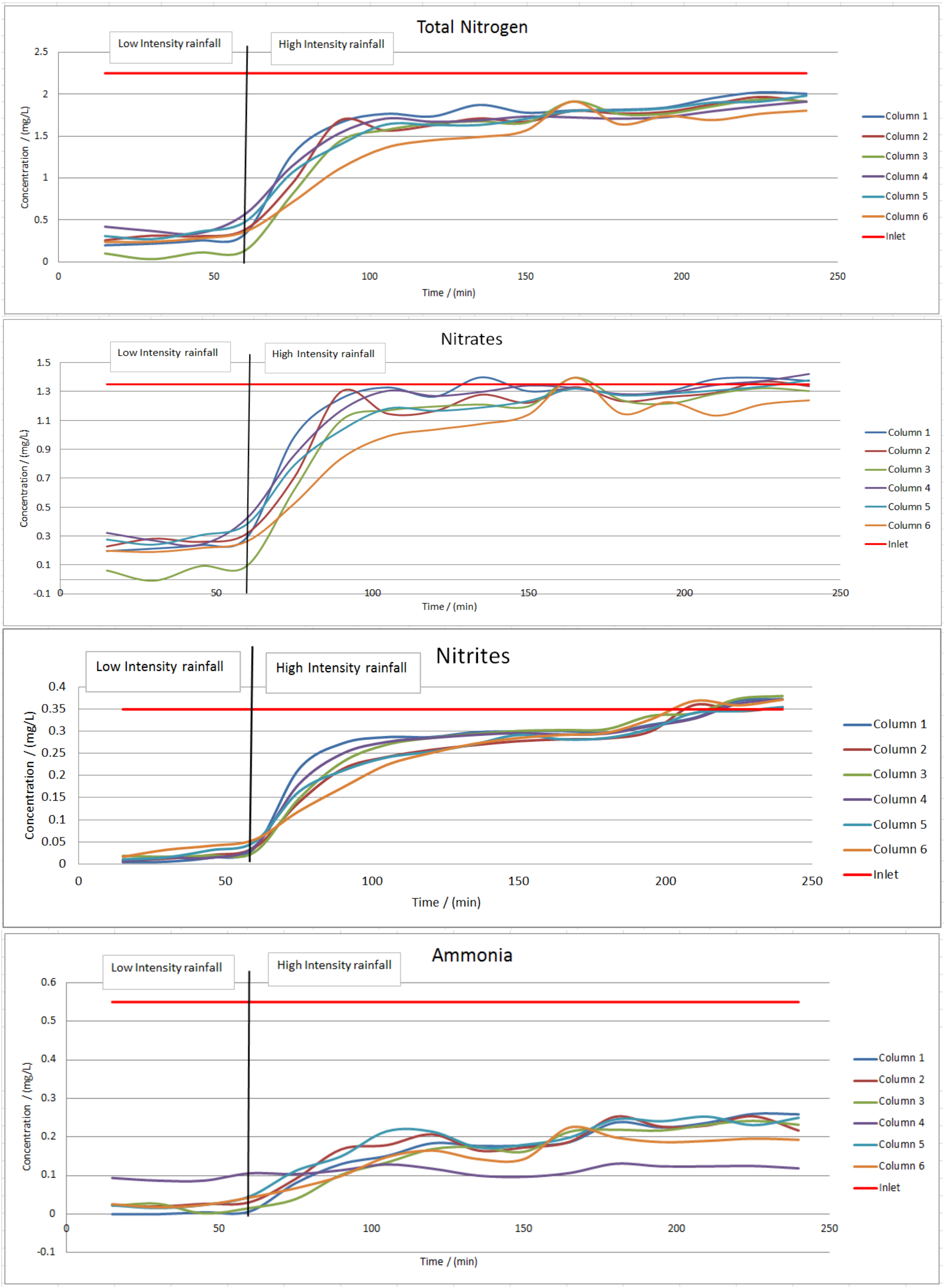


Figure 4. The effect of rainfall intensity of on attenuation of different nitrogen compound

4. CONCLUSION

This paper investigates the influence of subbase materials on attenuation of nitrogen compounds in stormwater runoff through permeable pavements. Results indicate that permeable pavement with an organic carbon source and a saturated zone can significantly improve the stormwater quality during small to medium rainfall intensities (up to 40 mm per hour). Compared with the standard/traditional permeable pavements, the modified structure was able to attenuate twice the amount of the total inorganic nitrogen in stormwater runoff. Also, the attenuation capacity of nitrogen compounds by the standard structure was observed to be diminishing over rainfall duration (e.g., 54% during the first hour and only 3.5% during the 4th hour). However, the modified structure was able to attenuate 68% of total inorganic nitrogen even during the 4th hour. The experimental results confirmed the possibility of achieving improved nitrogen attenuation by maintaining a saturated zone, a thin sand layer and incorporating an organic carbon source in the subbase of the pavement structure. However, this capability is heavily dependent on rainfall intensity and duration. Experiments will be continued to improve the stormwater treatment performance of permeable pavement systems by design modifications as a part of the ongoing study.

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Sea Outfall Assessment in Qatar: Lessons for Bangladesh

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Abstract

Pollution in coastal waters is a major concern in the Arabian Gulf countries. In Qatar, the untreated water mainly consisting of stormwater is discharged into the Doha coastline via several surface/shoreline type outfalls. This may cause adverse impacts to the sea environment of a fragile ecosystem of the coastal zone in Qatar. The Ministry of Municipality and Environment (MME), Qatar has carried out a comprehensive sea outfall study to identify existing outfalls and assess theirs impacts on planning, regulation, design and implementation of environment friendly outfall schemes. Direct discharge of large quantity of domestic and industrial wastewater, pesticides and agricultural chemicals into the rivers and the Bay of Bengal is a major concern in Bangladesh. The pollution levels in the Bay of Bengal affect fish and other living things. In addition to the biological and chemical pollutants, heavy metals pollution has also been reported in coastal and riverine waters of Bangladesh which presents an enormous challenge of monitoring, environmental management and conservation efforts. The recommendations and outcome of Qatar sea outfall study could provide government stakeholders in Bangladesh with adequate information for a sustainable coastal management and the proper tools for planning, maintenance, and monitoring of sea outfalls as discussed in this paper.

Keywords: Sea outfall, Bay of Bengal, Qatar, pollution, ecosystem.

1. INTRODUCTION

Coastal and aquatic pollution is now global concern Siddeek et al (1999); Alam et al (1998). UNEP (1991) reported that about 65% of existing large cities with population over 2.5 million are located along the coastline. Islam and Tanaka (2004) identified pollutants of major concerns in the coastal areas which include fertilizers, pesticides and agrochemicals; domestic and municipal wastes and sewage sludge; oils, heavy metals and trace elements; organic compounds; plastics; sediments; eutrophication; algal bloom; aquaculture activities; and biological pollution.

Until now, untreated stormwater in Qatar is being discharged into the Doha Bay coastline via several stormwater outfalls. The untreated water consists of stormwater, but it is also anticipated to include discharges from non-stormwater sources (e.g. dewatering effluents, loss from septic tanks and foul sewers, water from excess landscape watering, gardening, car washing), which may contribute additional pollutant loadings to the receiving waters (MME 2017). It should be noted that municipal wastewater in Qatar is mainly reused and is not discharged into the sea directly.

Sewage discharges are major sources of pollution in the coastal areas of the Arabian Gulf countries. In addition to the biological and chemical pollutants, heavy metals are also present in the sewage effluents. These may result in the contamination of fish, which eventually may enter the food chain affecting human health (Dawoud and Mulla, 2012; Mamoon et al 2016). Al-Sayed et al (1996) detected high levels of lead and zinc in a fish group called Epinephelus Coioides, caught from coastal waters of Bahrain. The heavy metal concentrations in the outfall locations in the gulf countries are likely to increase due to increased discharge of brine from desalination plants. The disposal of ballast water from the oil tankers into sea water of the Arabian Gulf may have a serious impact on the marine environment as noted by Sheppard et al (2010).

Rapid industrialization and expansion of urban development activities have also significantly increased pollution loads in some of the developing countries and this trend is expected to continue in the near future. Release of pesticides and fertilizers from agricultural activities is viewed as major sources of pollution of coastal waters in many Asian countries. It has been reported that about 1800 tons/year of pesticide residues are added to the coastal waters through runoff in Bangladesh (Islam and Tanaka, 2004).

Pollution from intensive ship-scrapping activities, sewage disposal and antifouling paints are reported to have serious impact in countries like India, Bangladesh, Thailand, Indonesia, Vietnam, Taiwan, Australia, Papua New Guinea and the Solomon Islands (Kannan et al 1995). Ship-scrapping activities may release poisonous chemicals into the environment, which include polycyclic aromatic hydrocarbons (PAHs), heavy metal ions, PCBs and TBTs (from paints) and even radioactive elements. Currently, nearly 1.5 million tons of scrapped iron is produced per year by ship-scrapping in Bangladesh (Rahman 2006). In addition, antibiotics and chemicals used in the shrimp culture may also cause water pollution endangering aquatic lives. Shrimp culture in the coastal city of Cox's Bazar, Bangladesh, uses 620 tons of urea annually and also generates 15 tons of waste daily, which eventually end up in the ocean (Rahman 2006).

Plastic bottles and other plastic products are mostly common form of litter in the coastal waters. They pose great threats to marine organisms. However, estimates for the total mass of plastic debris floating in the coastal waters vary between 7,000 ton to > 250,000 ton (Cózar et al 2014; Eriksen et al 2014). Abayomi et al (2017) found micro-plastics in the sediments and seawaters of eight beaches examined along the coast of Qatar.

Among the gulf countries, Abu Dhabi and Saudi Arabia have made notable progress in monitoring the marine water quality and developing the necessary guidelines (Mamoon et al 2016; EAD 2015). The ambient marine quality in Qatar was studied at different locations of the coastal area of Qatar as part of various development projects (Khan & Younes, 2013; GHD, 2010). The Ministry of Municipality and Environment (MME) has recently completed a sea outfall assessment study in Qatar (MME 2017). The outcomes of this outfall study are currently being utilized to develop Qatar's ambient water quality and effluent guidelines, which in turn could be used for enhanced coastal management across the gulf region.

The main objectives of this paper are to provide a review of the sea outfall assessment study carried out by MME in Qatar and make recommendations for developing a conceptual framework for sustainable management of coastal waters and sea outfalls in Bangladesh based on this findings in Qatar.

2.0 ASSESSMENT OF SEA OUTFALLS IN QATAR

Qatar is a peninsular nation situated midway along the western coast of the Arabian Gulf (MDPS 2015). Qatar has about 563 km of maritime coastline, while only a 60 km land border to the south separates Qatar from Saudi Arabia (Burt et al 2017; Mamoon et al 2017).

MME's sea outfall assessment study assessed the potential risks to public health and the marine environment by discharged pollutants in the direct vicinity of the receiving waters of four major stormwater outfalls located along Doha Bay in the eastern coast of Qatar. The current marine environment was also characterised in terms of defining the presence of ecological communities and their relative sensitivity, water and sediment quality, as well as identifying public areas used for recreation, bathing and the local fishery economy.

2.1 Discharged Water Quality

The discharge effluents were sampled and analyzed at the following stormwater outfalls located in Doha Bay: Souq Waqif, Tennis Court, Rumailah, and Diplomatic Area outfalls. The location map of the above outfalls is shown in Figure 1.

Figure 1. Overview of the study area and outfall location

The sampling was conducted during both rainfall events and dry weather conditions. During dry weather conditions, one sample was collected every week from each of the outfall for a period of one year from January 2016 to January 2017, resulting in 52 samples per outfall. However, rainfall events in Doha are typically confined to the period between October and May. In order to produce a reliable dataset of discharged pollutants, five (5) rainfall events between these months were sampled and tested for their chemical constituents.

In order to determine sea outfall effluent characteristics, samples were taken before the effluent was mixed with the ambient seawater, during both dry weather and rainfall event conditions. Therefore, samples were collected from mixing chambers just before the outfall discharge as shown in Figure 2. Sampling was carried out with extra caution to prevent cross contamination.

Figure 2. Collection of samples illustrated in Qatar

On-site measurement of several parameters such as temperature, pH, salinity, dissolved oxygen and conductivity were made during each sampling activity. Laboratory testing of 23 water quality parameters were performed as listed in Table 1. The concentrations of the test parameters were compared against Qatari Standards for Discharge to Marine Environment (Executive By-law No. 4 of 2005) and Discharge Limits in Kingdom of Saudi Arabia (PME, 2012a, b).

Table 1. Stormwater Outfall Discharge Parameters

Test Parameters	Analytical Methods
Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Oil & Grease, Arsenic, Mercury, Lead, Zinc, Iron, Copper, Cadmium, Nickel, Cobalt, Manganese, Vanadium, Barium	The American Public health Association (APHA) 21st edition
Total phosphorus, Chloride, Total Coliform, Faecal coliform	AS/NZA standards
Chromium, Total Petroleum Hydrocarbons (TPH), Poly-aromatic Hydrocarbons (PAH)	USEPA

2.2 Evaluation of Test Results

The test results showed that during dry weather conditions, discharged water quality did not exceed the standard limits of BOD, Oil and Grease, Barium, Cadmium, Chromium, Cobalt, Zinc, Total Phosphorus as P, PAH, and TPH in any of the selected outfalls. COD, Total Coliforms and TSSs were the common pollutants, which were found above the Qatari standards limits in samples collected from the effluent discharges of all the four outfalls during dry weather conditions. For example, the results of COD in dry weather samples are shown in Figure 3.

The results of COD were found to be above both Qatari and Saudi standards limits during the rainfall events 2, 4 and 5 events in samples collected from Diplomatic Area outfall as shown in Figure 4. The outfalls with the observation of more exceedance of COD during dry weather conditions were Diplomatic Area, Tennis Court, Rumailah and Souq Waqif respectively. Souq Waqif was the only outfall, which had BOD levels above the standards (during rainfall event 4).

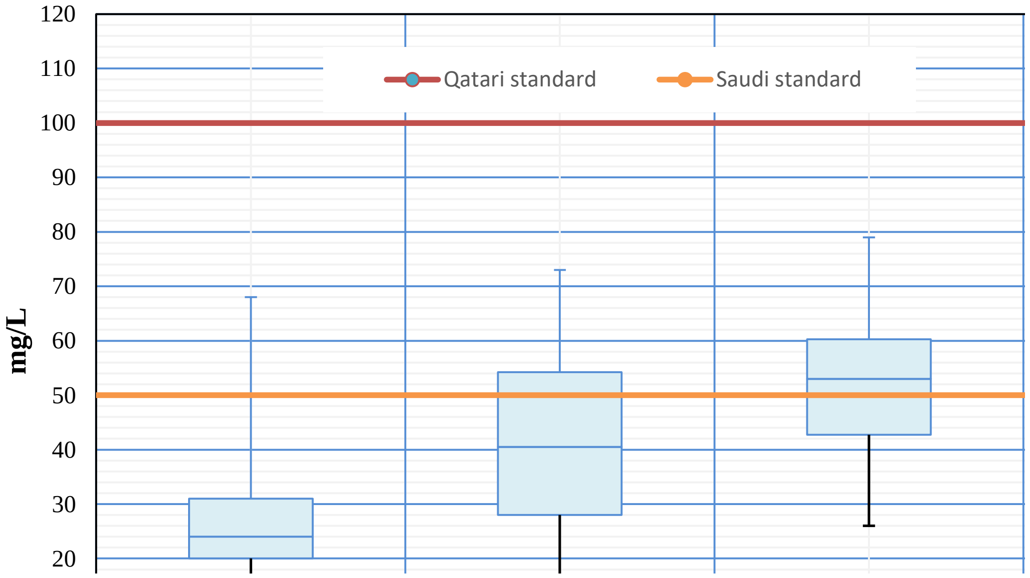
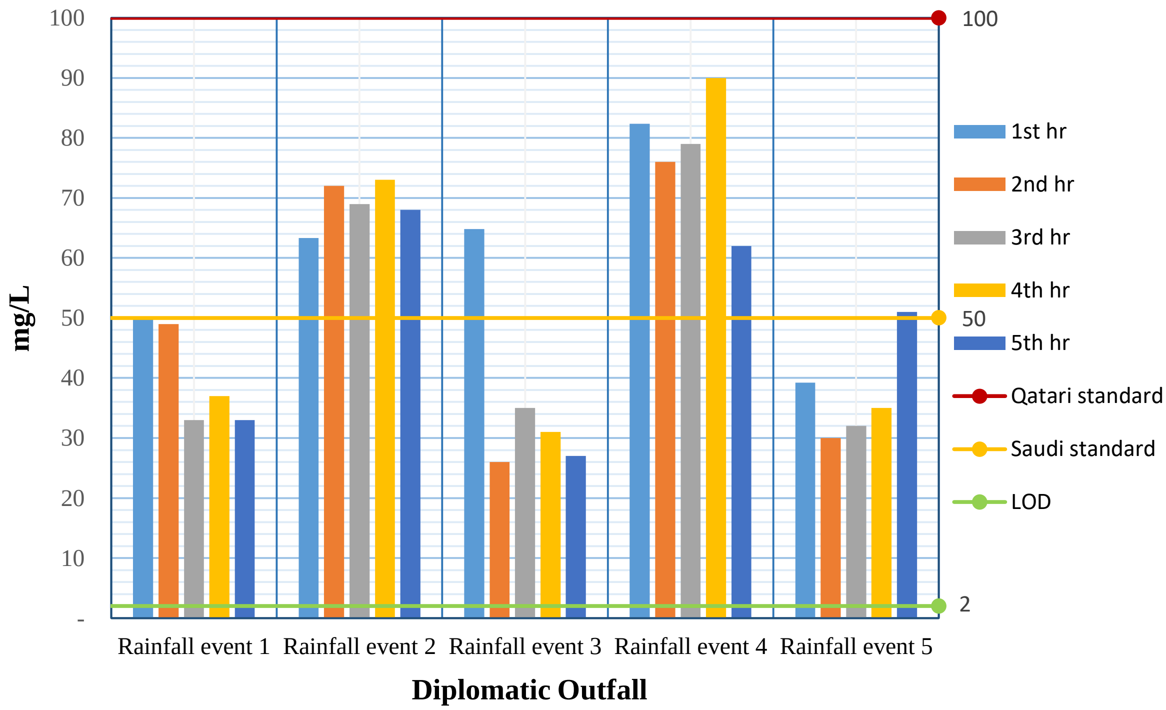


Figure 3. COD in Dry Weather Samples



#LOD – Limit of detection

Figure 4. COD in samples collected from Diplomatic Area outfall during rainfall events

The lowest and highest levels of TSS were found in samples collected from the Diplomatic Area outfall, while the average of TSS in samples collected during the 1st hour of sampling during rainfall event 5 from the mentioned outfall had the highest recorded levels. In all samples collected from the Diplomatic area outfall during rainfall event 1, the Faecal Coliform level was below the limit of detection, while Total Coliforms were below the standard limits. However, in general, the results showed that during rainfall events (Figure 5), the samples had more elevated levels of Coliforms when compared to dry weather conditions.

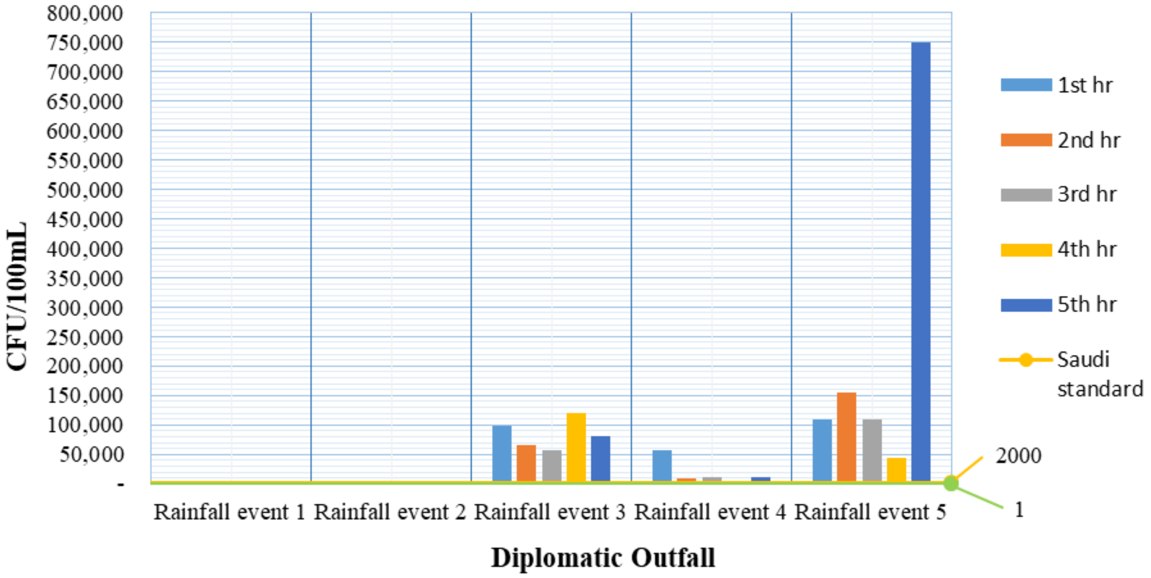


Figure 5. Total Coliforms in samples collected from Diplomatic Area outfall during rainfall events

Chromium and Iron were the common pollutants with levels above the standards limits in all four outfalls during rainfall events 4 and 5. Chromium and Lead levels were below the standards limits in all samples collected during dry weather. The observation of exceedance in metals, in samples collected during dry weather conditions was more than the rainfall events. Arsenic, Copper, Iron, Manganese, Mercury and Nickel showed exceedance in samples collected during dry weather. In samples collected during rainfall events, Chromium, Iron, Lead and Manganese showed exceedance.

In case of nutrients, one sample collected for TKN from the Diplomatic area outfall showed exceedance during dry weather conditions, while for the Total Phosphorus as P in the Tennis outfall showed exceedance during rainfall event 2 (Figure 6).

The main conclusions of this assessment include the following:

- COD, Total Coliforms and TSS are the common pollutants, which were found above the standards' limits in samples collected from the effluent discharges of all the four outfalls during both dry weather conditions and rainfall events;
- Chromium and Lead are most likely associated to stormwater runoff and not to the groundwater discharges;
- During first flush after the summer period, a higher number of parameters displayed more exceedances of their respective standards across all the sampled outfalls; and
- During dry weather condition, the samples showed more exceedances, especially for heavy metals, compared to the rainfall events in the Tennis and Diplomatic Area outfalls. Also, these two outfalls have more parameters with exceedances than the other two outfalls.

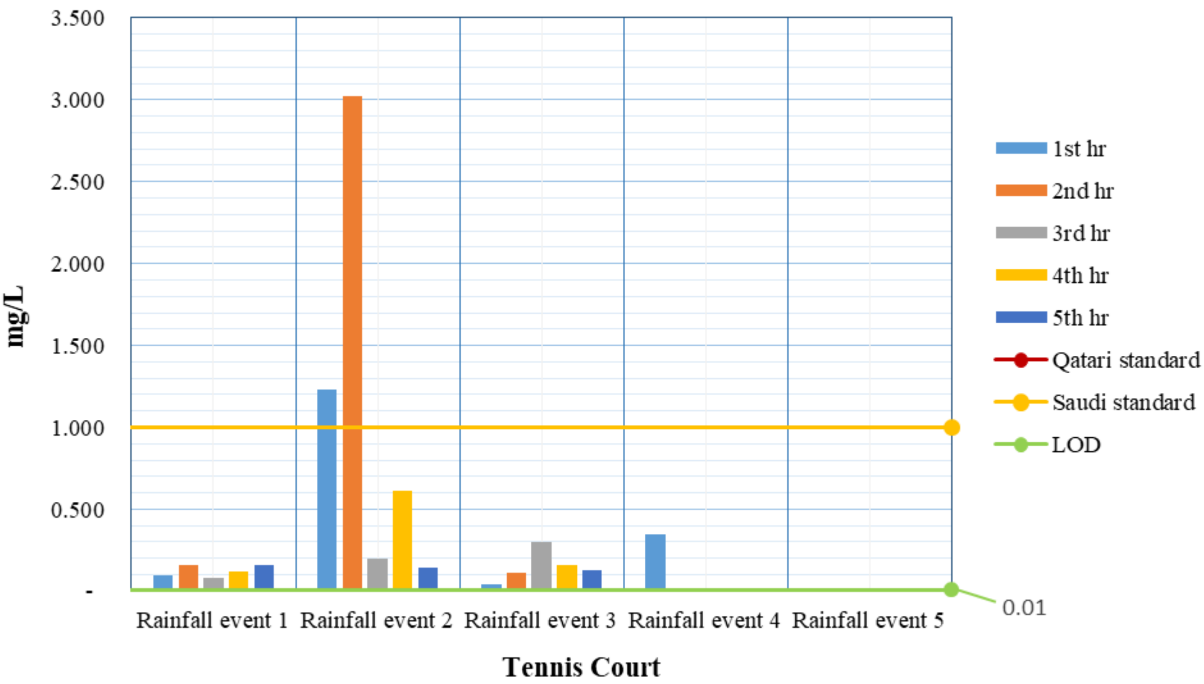


Figure 6. Total Phosphorus as P in samples collected from Tennis Court outfall during rainfall events

2.3 Evaluation of Pollution Loads

Among the pollutants COD, Arsenic, Lead, TSS and TPH pollutant loads showed a great variability. However, no trend was detected between pollutant loads during dry weather and during rainfall events. A summary of annual pollution loads for these parameters is shown in Table 2. Across all outfalls, dry weather COD load was calculated to be greater than the mean discharge value for the rainfall events.
The
A similar trend was observed for Arsenic concentration. At Souq Waqif and Rumailah outfalls, dry weather percentage of Lead discharge was found to be higher than the rainfall event percentage discharge. However, the opposite was observed at the Tennis Court and Diplomatic Area, whereby rainfall events had a larger percentage of discharge loads. Across all the outfalls, except the Souq Waqif, annual TSS load was observed to be higher due to rainfall events when compared to dry weather annual load. Overall, a general trend between loads could not be identified when dry weather and rainfall events conditions were compared.

Table 2. Annual pollutant load calculations for selected parameters

Parameters	Souq Waqif	Rumailah	Tennis Court	Diplomatic Area
	Estimated total annual pollutant discharge (kg/year)	Estimated total annual pollutant discharge (kg/year)	Estimated total annual pollutant discharge (kg/year)	Estimated total annual pollutant discharge (kg/year)
COD	1,016,963	376,430	228,850	34,615
Arsenic	29.10	6.23	4.19	0.70
Chromium	62.18	14.74	24.16	4.29
Lead	41.57	7.04	8.25	6.19
TSS	2,210,518	373,666	376,055	123,433
TPH	3,732	638.87	428.65	56.66

2.4 Risk assessment and recommendations

A risk assessment was carried out encompassing two methodologies, namely, qualitative and quantitative risk assessments. Qualitative risk assessment is subjective in nature and is designed to provide a high-level determination of the potential impacts that may be expected to occur. On the other hand, Quantitative assessment is based on quantitative data and quantitative outputs from computer dispersion modelling. The severity and risk have been evaluated for each modelled outfall, flow scenario and pollutant in the discharged water.

In line with the objectives of high-level Qatari national plans (GSDP, 2008), and the findings of regulatory framework gap analysis; institutional gaps and necessary recommendations for improvements for sustainable development and monitoring of stormwater outfalls, were identified. General recommendations were made for the improvement of institutions and their respective roles and responsibilities. Key recommendations are outlined in below Table 3.

Table 3. Recommendations based on sea outfall study in Qatar

Regulations	Recommendations
REGULATORY FRAMEWORK	Prepare unified Qatar Water Law aimed at developing integrated systems for water management by unifying regulations, identifying, and eliminating gaps in the legal framework.
	Embed the preparation of Strategic Environmental Assessment (SEA) in the regulatory framework
	Develop the legal framework for the Integrated Coastal Zone Management (ICZM) by adopting the ICZM guidelines
	Embed the application of mixing zone in the regulatory framework. Mixing zones are applied worldwide.
PLANNING AND APPROVAL FRAMEWORK	Develop a maritime spatial plan including a detailed updated map with ecological sensitive areas in Qatar. The maritime spatial plan would facilitate to avoid potential clashes between the planned sea outfall and other coastal / maritime use.
ENVIRONMRANTAL PERMITTING PROCEDURE	A stakeholder/public participation mechanism; and access to information by stakeholders/public
	Consider environmental "best practice" Principles for Assessment/Permitting of outfalls
OPERATION	Preparation of Operational Environmental Management Plan (OEMP), including an Emergency Response Plan
	Regular monitoring (based on a Monitoring Plan) and reporting to MME, including mixing zones management.

3. IDENTIFICATION OF CHALLENGES FOR COASTAL MANAGEMENT IN BANGLADESH

The ocean pollution in Bangladesh is caused mainly due to unrestricted discharge of wastewater (domestic and industrial) and other pollutants laden urban runoff into marine waters. There are number of pollution control regulations in Bangladesh for protecting its marine environment from pollution. These include National Environmental Policy (1992), National Water Policy, Environment Protection Rules (1997) and Coastal Zone Policy (2005). Despite having various regulatory measures, violation of standards by the polluters is not uncommon in Bangladesh. Bangladesh is lagged behind in strict enforcement of established standards and regulations (Karn and Harada, 2001).

The main challenges identified are as follows (Nazmul Islam; Karn and Harada, 2010; Williams, 1996):

- Noncompliance with standards;
- Failure to enforce existing regulations/standards;
- Poor coordination between key stakeholder/agencies;
- Inconsistency with policies;
- Lack of sectoral integration and approach to environmental management;
- Weak institutional structure and lack of manpower capabilities;
- Limitations of the environment acts and law;
- Outdated environmental laws as well as ignorance about these laws;
- Non-punitive approach of laws; and
- Politician- Polluter connection.

4. RECOMMENDATIONS FOR EEFECTIVE COASTAL MANAGEMENT IN BANGLADESH

Although some progresses have been made in recent years in developing governance structure and strategic planning for the future, the following recommendations are proposed for effective and sustainable management of marine environment in Bangladesh (Burt et al 2017; Williams 1996; Kinne 1984; MME 2017).

- Strict enforcement of existing laws and regulations;
- Effective and active engagement of all potentially affected stakeholders and relevant agencies within the government;
- Develop integrated eco-based management approach (EBM) instead of traditional single sector management;
- Conduct long-term marine and scientific research programs on all aspects of pollution including effects;
- Adequate interpretation and transposing of scientific knowledge into legislation and effective control measures;
- Formulation of new standards and guidelines based on the latest research;
- Improved communication between scientists and managers;
- Prepare unified Water Law by addressing policy gaps;
- Develop a spatial maritime spatial plan showing ecological sensitive areas;
- Public awareness campaigns and develop cooperation between general public and stakeholders;
- Changes in institutional, administrative and organizational arrangements;
- Strengthening the legal system;
- Develop monitoring and surveillance program to ensure standard water quality and evaluate the effectiveness of policy actions;
- Develop local, national, regional and international cooperation;
- Identify polluters within Bangladesh and its upstream neighbors and implement a polluter-pay principle for monitoring and rectifying the Bay of Bengal; and
- Joint research and monitoring programs among universities in Bangladesh and other countries and various donor agencies to benchmark the Bangladesh government studies.

5. CONCLUSIONS

Qatar's Ministry of Municipality and Environment (MME) has carried out a sea outfall assessment study to assess the coastal ecosystem in the vicinity of four major outfalls located in the Doha Bay. The recommendations and outcomes of this study provided the basis for development of national guidelines for sustainable coastal management in Qatar. As part of the above study, a regulatory framework has also been developed for planning, maintenance, and monitoring of sea outfalls in Qatar. Bangladesh is currently witnessing a rapid expansion in industrial and infrastructure development which is affecting its fragile coastal ecosystems. Hence, it is essential that all coastal discharges in Bangladesh are licensed, monitored and controlled for protection of marine environment and most importantly fisheries resources. It is anticipated that the recommendations of Qatar study could be utilized for developing integrated coastal management policy and effective regulatory framework for marine pollution control in Bangladesh.

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Recent Developments in GIS Capabilities in Water Sector in Bangladesh – CEGIS the Pioneer

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Abstract

Application of GIS technology introduced in Bangladesh in the early 90s while a special organization EGIS/CEGIS have been developed to provide expert support services to Water Sector and Natural Resource Sectors. CEGIS is a scientifically independent and technically sound center in Bangladesh that uses state-of-the-art technologies namely GIS and remote sensing (RS) for Natural Resources Management. It has developed many RS and GIS based databases, for example, GIS based digital Land Information System for BWDB, Computerized Land Management System, Integrated Coastal Resources Database, Integrated Haors and Wetlands Resources Database and Chittagong Hill Tracts Improved Natural Resources Management etc. It has been using GIS and RS technology in river morphology and erosion prediction, coastal morphology dynamics, flood monitoring, agriculture and fisheries, ecosystem and forestry and environmental impact assessment. CEGIS received National Digital Innovation Awards 2011 for the scientific research studies of Community based Flood Information System and SMS Gateway for Monitoring Avian Influenza (Bird Flu). With the advent of new sensors and free or very low cost availability of satellite images, CEGIS will explore more researches and applications of GIS and RS technology in monitoring SDGs activities, Bangladesh Delta Plan 2100, Climate Change Impact and adaptation, drought and land degradation and ecosystem heath monitoring. The knowledge developed from these research and applications will support better informed decisions, management of natural resources, and monitoring and forecasting environmental and economic issues.

Keywords: GIS, Remote Sensing, Satellite Image, Database, SDGs

1. INTRODUCTION

Applications of GIS and Remote Sensing (RS) technology initiated in Bangladesh in the early 1990s while Center for Environmental and Geographic Information Services (CEGIS) has started its journey as a pioneer to provide technical supports to Government and NGOs as a center of excellence. Recent developments of capabilities and experiences of using these tools has been extended beyond the country also. The CEGIS is a Center of Excellence in research, development and professional services. Following the disastrous floods of 1987 and 1988, the GoB developed a Flood Action Plan (FAP). In 1995, the project 'Environmental and Geographic Information System Support Project for Water Sector Planning (EGIS)' was launched by merging the two components of FAP i.e. FAP-16 and FAP-19, which ended in 2002. With a view to developing the national capacity of the country and continuing the successful efforts, CEGIS was established as a Public Trust on 16 May 2002 under the Trusts Act, 1882. Since then, it has been working as a self-financed, not-for-profit government-owned organization to fulfill its mission under the Ministry of Water Resources of the GoB. It is a scientifically independent and technically sound organization that uses state-of-the-art technologies namely GIS and remote sensing (RS) for Natural Resources Management. This paper briefly presents capabilities developed so far (within CEGIS) in application of GIS and RS in Water sector and Natural Resources sectors and future potentials for uses in supporting and improving Water and Natural Resource management in the country and abroad.

2. CEGIS'S DIVISIONS AND EXPERTISE

CEGIS is a very competent organization with fourteen divisions namely Water Resources Management, River, Delta and Coastal Morphology, Climate Change and Disaster Management, Socio-Economic and Institutional, Ecology, Forestry and Biodiversity, Agricultural and Fisheries, Power, Energy and Mineral Resources, Geographic Information System, Remote Sensing, Database, ICT and System Management, Research, Development and Training, Quality Management and Publication, Human Resource and Business Development and Administration, Finance, Accounts, Audits and Logistics. The highly dedicated multi-disciplinary qualified professionals enriched with updated tools and technologies of those divisions provide well informed and sound technical solutions.

3. MODELING, TOOLS AND TECHNIQUES

The important developed models, tools and techniques are Erosion Prediction and Dissemination, Drought Assessment, CEGIS Storm Surge Model, Community based Flood Information System, Analytical Framework for IWRM, Smart Project Monitoring and Management Information System, Tidal River Management and Urban Water logging removal.

4. INTERNATIONAL NETWORK

CEGIS is connected to many international organizations such World Bank, Asian Development Bank, JICA, USAID, FAO, ICIMOD, UNESCO-IHE, Deltares, University of Southampton, Wageningen University etc. Through these organizations, CEGIS's professional participate in international training programs, symposiums, conferences and collaborative projects. A number of professionals of CEGIS have been trained in Land Cover Classification System by FAO under the 'Deltas, Vulnerability and Climate Change: Migration and Adaptation (DECCMA)' funded by Canada's International Development Research Council (IDRC) and UK Department for International Development (DFID). Advance training programs on application of RS and GIS in water, forestry and disaster management organized by ICIMOD are participated to enhance capabilities in the relevant fields.

5. SATELLITE IMAGES, SOFTWAR AND EQUIPMENT

High resolution (0.3m-4m) optical satellite images such as WorldView-3, QuickBird, GeoEye, IKONOS and Cartosat-2 are used for mapping of detail infrastructure, land use and land cover. Moderate resolution (5m – 30m) optical satellite images, RapidEye and Landsat 8, are used for natural recourses mapping and erosion-accretion mapping. The RADAR images (6.5m – 100m) are used for flood monitoring. ERDAS IMAGINE and eCognition software are used for image processing and object-oriented classification respectively. The ESRI ArcGIS software is used for creation, editing, updating, visualization, analysis and mapping of geo-spatial data. The RTK DGPS system, Handheld GPS and Total Station is used for geospatial survey. The touch table, touch-enabled screen, is used to support stakeholder during design, analysis and negotiation through common visualization and spatial information handling.

6. GIS AND RS SERVICES

GIS and RS service such as mauza database creation, topographic survey, geospatial data analysis and 3D mapping, GIS based customized software and MIS development, GPS and total station survey, satellite imagery interpretation and classification, land use ad land cover classification and change analysis, natural resources database update, forest and agricultural mapping detail infrastructure database development are provided.

7. MILESTONE CONTRIBUTIONS STUDIES

The successfully completed projects where GIS and RS technology were used extensively are Haor Mater Plan 2012, Bangladesh Delta Plan 2100, Mapping of Potential Greenbelt Zone in the Coastal Regions of Bangladesh, Khulna Jessore Drainage Rehabilitation Project (KJDRP), Gorai River Restoration Project (GRRP), Community based Flood Information System (CFIS), Agriculture Resource Information System (ARIS), Soil & Land Resource Information System (SOLARIS) etc.

8. APPLICATION OF GIS AND RS

8.1. Geospatial Database Development

CEGIS has developed a comprehensive Natural Resources Database which includes spatial data (147 shape files), and nonspatial data (46) for better planning and management of natural resources. National Water Resources Database (NWRD), Integrated Haors and Wetlands Resources Database (IHWRD) and Integrated Coastal Resources Database (ICRD) were prepared using extensive use of satellite images and GIS. A Computerized Land Management Information System (CLMS) was developed pilot basis for automating land related activities. Bangladesh Water Development Board (BWDB) engaged CEGIS to develop a GIS Based Land Information System to handle the mauza maps, gazette notifications, khatians, possession certificate interactively with the options of viewing, searching, querying and overlaying maps.

8.2. River and Costal Morphology and Erosion Assessment

A unique expertise has been developed in CEGIS in studying different morphological aspects of rives and coastal using RS and GIS technology. Empirical method has been developed for prediction and monitoring of morphological changes and erosion of the Ganges, the Jamuna, the Padma and the Meghna rivers. Predicting of bank erosion and morphological changes of the Jamuna and Padma rivers is being done on a regular basis for the last couple of years for various projects of BWDB. Using GIS technology and analyzing satellite imageries, it has estimated net erosion 1,620 sqkm and net accretion 578 sqkm between 1973 and 2018. Time series satellite images have been analyzed by studying different morphological aspects such as the erosion and accretion between 1973 and 2008. A net 598 sqkm of land was accreted in the Meghna Estuary during this period.

8.3. Flood Monitoring and Assessment

CEGIS and its predecessor projects have explored the potential of using radar images for mapping and monitoring monsoon flooding since 1993. CEGIS used radar images during the catastrophic floods of 1998 to map and monitor flood extent in the Near Real Time (NRT) mode throughout the monsoon. Satellite images were used as a major source of data to map crop and settlement damage during the devastating flood in the south west in 2000. During 2003 and 2004 monsoon, national level and local level (Nagarpur and Daulatpur upazila) flood extent maps were produced regularly. The flood extent map and crop damage map due to flash flood in the Haor region in 2017 were mapped using Sentinel-1 and Sentinel-2 Satellite Images

8.4. Agriculture and Fisheries Development

CEGIS has developed GIS based DRAS (Drought Assessment) model in collaboration with BARC for better understanding water stress situation through visualization of GIS maps. The Soil and Land Resource Information System (SOLARIS) was developed for managing geo-spatial data base developed by Soil Resource Development Institute (SRDI). GIS based Crop Suitability Assessment Model (CSAM) has been developed for BARC. CEGIS has experiences in mapping of boro, aman, aus, till, potato and pulses. Satellite image is an excellent source of information for fishery resources inventory, identification of fish habitat, dry season water body identification, pond inventory, mapping aquaculture farms, mapping fish migration routes, land use suitability analysis for aquaculture, etc.

8.5. Ecosystem ad Forestry

The Cyclone SIDR hit Coastal region on 15th November 2017 and the affected area 1,260 sqkm (21%) of the Sundarbans ecosystem was identified using MODIS satellite images. The Mapping of Potential Greenbelt Zone in the Coastal Regions of Bangladesh was prepared under the Climate Resilient Participatory Afforestation and Reforestation Project of Bangladesh using remote sensing and GIS technology. The National Land Cover Map was prepared for Forest Department of Bangladesh using SPOT satellite images of 2015. It was found that about 50 sqkm area within the Madhupur National Park was deforested between 1967 and 2007.

8.6. Environmental Impact Assessment

In EIA studies, remote sensing is used to assess baseline condition of land use and land cover and carry out environmental monitoring during and after project implementation. The Gorai River Restoration Project and Khulna Jessore Drainage Rehabilitation Project had based much of their analysis on remote sensing data.

9. GIS AND RS TRAINING

GIS, Remote Sensing and GPS training are provided frequently on Integrated Water Resources Management, River Morphology and Erosion Prediction, Forest Cover Mapping and Agricultural Crop Mapping. A number of professionals of different organizations such as Bangladesh Water Development Board, Bangladesh Forest Department, Department of Environment, Bangladesh Bureau of Statistics, Bangladesh Water Partnerships etc. were trained in GIS and RS. With collaboration of USFS, CEGIS provided basic, intermediate and advance training on GIS, RS and GPS to the employee of Forest Department of Bangladesh.

10. NATIONAL DIGITAL INNOVATION AWARDS

CEGIS received National Digital Innovation Awards 2011 for the scientific research studies: “Community based Flood Information System (CFIS)” and “SMS Gateway for Monitoring Avian Influenza (Bird Flu)”. CEGIS undertook the “Community based Flood Information System (CFIS)” for risk reduction by providing prediction information on flood to the community of Daulatpur and Nagarpur upazila. An operational SMS Gateway System for FAO was developed to ensure rapid reporting and archiving of suspected Highly Pathogenic Avian Influenza (HPAI) cases for the Department of Livestock Services. It is a simple system comprising a mobile phone and a computer fitted with a modem and can be easily established anywhere such as at Union Parishad Information Centers.

11. FUTURE POTENTIAL USE OF GIS AND RS

11.1. Monitoring SDGs of Bangladesh

The 2030 Agenda specifically calls for new data acquisition and exploitation of new data sources to support implementation of SDGs goals. In the last decade, satellite data has become available in increasing quantities and at no or very low cost. This makes Earth observation applications more attractive for addressing societal challenges. Space based technologies can make a contribution to both achieving the SDGs and to assess progress towards targets by monitoring indicators.

11.2. Bangladesh Delta Plan 2100

The Government of Bangladesh has prepared and approved Bangladesh Delta Plan 2100 (BDP 2100) which is a visionary plan with support from the Government of the Netherlands to achieve long term sustainable development. A lot of physical data required for Delta Plan can be extracted spatially and temporally from satellite images. Analyzing those data using GIS would offer possibilities of generating various alternative options, thereby optimizing the whole planning process.

11.3. Climate Change Impact and adaptation

The locations of sinks and sources of CO2 can be identified from satellite image and GIS on the other hand can be used in environmental monitoring and modelling and management of vast spatial climate datasets for a wide number of applications. Both technologies can be used to take appropriate actions ahead of climate change events and find out strategies for climate change adaptation.

11.4. Drought and Desertification

Drought has become a recurrent natural phenomenon of northwestern Bangladesh in recent decades. Barind Tract covers most parts of the greater Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, Joypurhat and Naogaon districts of Rajshahi division. Remote sensing and hydrologic modeling techniques, Satellite-based rainfall estimates and Normalized Difference Vegetation Index may be used to provide information about the onset, progression, extent, and intensity of drought conditions.

11.5. Ecosystem Health Monitoring

There are potentials of using RS and GIS for monitoring ecological health of the Sundarbans mangrove ecosystem, plain land shal forest and Chittagong hill forest for better understanding the quality of given services and taking necessary actions accordingly. Maintaining a healthy ecosystem is essential for maximizing sustainable ecological services. Research and applications may be developed using high resolution optical and radar images, improved algorithms and technologies for ecosystem health monitoring.

12. CONCLUSION

Capabilities of using GIS and RS in water sector and natural resources management has been well developed and being widely used in planning, implementation and management in Bangladesh and abroad as well. CEGIS has been providing GIS and RS related technical supports to Government organizations and NGOs over around three decades with specific emphasis on water sector and natural resources management. With the advent of new sensors and free availability of satellite images, CEGIS would consider pursuing more research and additional applications to address cross-cutting issues such as SDGs, climate impact and adaptation, water resources management, hydrologic and carbon cycle, and global warming. The knowledge developed from these research and applications will be disseminated to natural resources managers to support better informed decisions, management of natural resources, and monitoring and forecasting environmental and economic issues. This will facilitate to achieve SDG 2030 goals and vision of becoming a developed country by 2041.

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Geomorphological Changes Along Coastline of Bangladesh

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Abstract

This study aims to study the geomorphological changes taken place along the coastline of Bangladesh from analyzing Landsat time series data. Landsat images for the year 1989, 2004 and 2016 of the post-monsoon periods have been used to find out the dynamic nature of coastline of Bangladesh. The scenario of 2028 has also been predicted from the scenario of 2004 and 2016 using MOLUSCE Plugin of QGIS. Analysis revealed that deposition is the dominant morphological change that takes place mostly in the Meghna Estuary. Erosion also takes place simultaneously along the banks of Lower Meghna. About 76959.7 ha areas have been eroded and 216742 ha areas have been deposited between 1989 and 2016, which results in about 139782.3 ha areas of net deposition along the coastline of Bangladesh. Urir Char, Sandwip Island, and Kutubdia Island are the most affected by the geomorphological changes. The scenario of 2028 has depicted that deposition will also remain dominant then but about 28859.9 ha area will also experience erosion.

Keywords: Coastline, Deposition, Erosion, NDWI, MOLUSCE

1. INTRODUCTION

Coastal area is defined as the interface between land and sea and coastline is the boundary which differentiates between these two land types (Emran et al 2017; Vinayaraj et al 2011). Coastal areas are the most populated areas around the world and coastal dynamics have significant impacts on the life and livelihood of coastal people (Wang et al 2013). Coastal regions around the world are the most dynamic areas due to their continuous geomorphological changes and habitats of diversified ecosystems (Aedla et al 2015). Coastal region of Bangladesh is not any exception. The Bay of Bengal has a significant impact on Bangladesh and its coastline. Bangladesh is dominated by Ganges-Brahmaputra- Meghna river system, which carries millions of ton sediments from upstream and deposits it in the Bay of Bengal through Lower Meghna (Islam et al 1999). Dynamic interactions between rivers and sea make the coastline more susceptible to changes. Erosion and deposition both are occurring here significantly. So regular monitoring of the changes in coastline is one of the most important environmental issues in coastal management.

Coastal Bangladesh has experienced vast changes in terms of erosion and deposition, especially in the Meghna Estuary and the major islands (Brammer 2014; Emran et al 2017; Sarwar 2005). Hassan et al (2017) indicated the declined river current as the main reason of sediment deposition in the southern parts of Bhola, Noakhali, and Hatiya. The reverse flow of seawater and the strong tidal effect have caused the erosion of Sandwip, Urir Char and southeastern part of Noakhali (Emran et al 2015; Emran et al 2017; Hassan et al 2017). Islands of Meghna Estuary have experienced more accretion than erosion and Domar Char is experiencing an accretion rate of about 208 ha/year (Hossain et al 2016). For this dynamic coastline, regular monitoring is must as coastal Bangladesh is more diverse and dynamic that is generally expected. If it cannot be recognized accurately, it will result in serious

misconceptions about the potential impacts of a rising sea level on Bangladesh with global warming (Brammer 2014; Hossain et al 2016).
Remote sensing techniques have become very convenient and effective for change detection studies. On the other hand, Landsat time series data is very easily accessible and easy to handle. Application of remote sensing techniques in studying geomorphological changes along the coastline is an established fact (Behera et al 2012; Emran et al 2015). Normalized Difference Water Index (NDWI) has been proved to be very suitable to differentiate between land and water areas (McFeeters 1996). This study has focused on the geomorphological changes along the coastline of Bangladesh from Landsat images using the threshold value of NDWI to differentiate land and water, to identify coastline in precise. There are very few studies focused on the whole coastline of Bangladesh and none has focused on future prediction. This study also aims to predict future scenario of coastline in 2028 applying Cellular Automata Model in MOLUSCE Plugin of QGIS.

2. MATERIALS AND METHODS

To study the geomorphological changes along the coastline of Bangladesh, Landsat images have been used. Coastal Bangladesh is covered by a total of 7 scenes of Landsat sensors (Figure 1). Landsat images of the year 1989, 2004 and 2016 of the post-monsoon periods (October – December) of the scenes have been collected from the United States Geological Survey (USGS) website (Table 1).

Table 1. Detail about acquired satellite images for the study

Year	Sensor	Path/Row	Acquisition Date
1989	Landsat 5 Thematic Mapper (TM)	135/46	06-11-1989
		136/44	29-11-1989
		136/45	29-11-1989
		137/44	20-11-1989
		137/45	22-12-1989
		138/44	27-11-1989
		138/45	27-11-1989
2004	Landsat 5 Thematic Mapper (TM)	135/46	15-11-2004
		136/44	06-11-2004
		136/45	06-11-2004
		137/44	29-11-2004
		137/45	29-11-2004
		138/44	06-12-2004
		138/45	06-12-2004
2016	Landsat 8 Operational Land Imager (OLI)	135/46	16-11-2016
		136/44	22-10-2016
		136/45	22-10-2016
		137/44	14-11-2016
		137/45	14-11-2016
		138/44	21-11-2016
		138/45	21-11-2016

After collecting the images, they are mosaicked together, and the area of interest has been extracted from the mosaicked images (Figure 1). Normalized Difference Water Index (NDWI) has been calculated using the Green (Band 2 of TM and Band 3 of OLI) and Near Infra-Red (Band 4 of TM and Band 5 of OLI) bands of Landsat images to identify the water areas by putting threshold value (NDWI>0) (McFeeters, 1996). For this study, NDWI maps have been reclassified into only two classes, Land and Water (Figure 1). Areas with negative NDWI values are classified as Land. Reclassified maps have been compared together to find out the erosion and deposition scenario along the coastline between 1989 and 2016. Change maps between the study years have been prepared using

MOLUSCE Plugin of QGIS. MOLUSCE Plugin of QGIS employs cellular automata model to predict future scenario based on past scenarios (Rahman et al 2017). The scenario for 2028 has been predicted based on Logistic Regression using the Plugin, employing Digital Elevation Model (DEM) as Spatial Variable. DEM has been downloaded from SRTM 30-meter DEM collections. Figure 2 represents the flow chart of the methodology of the study.

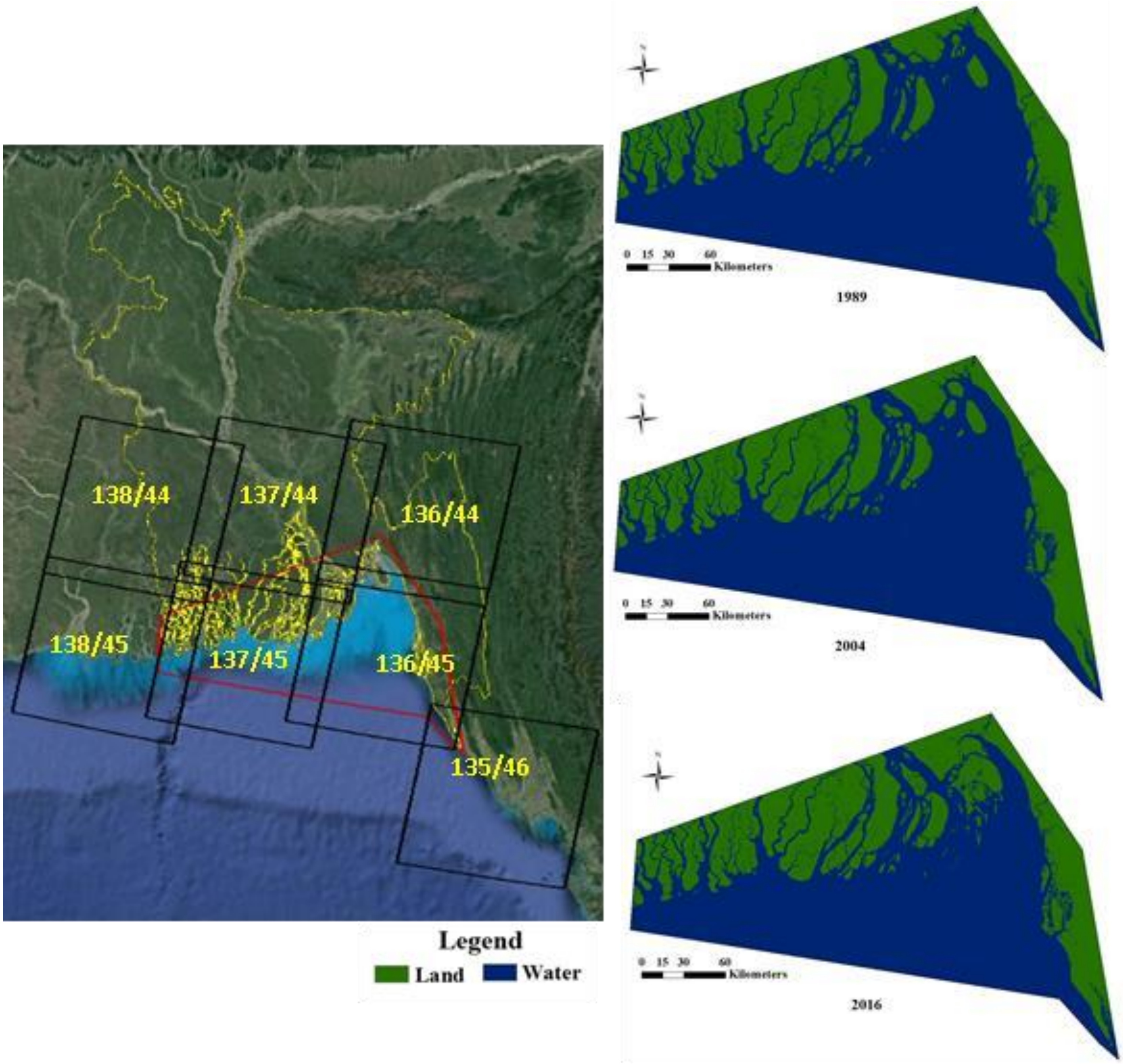

Figure 1. The Scenario of Coastline of Bangladesh between 1989 and 2016

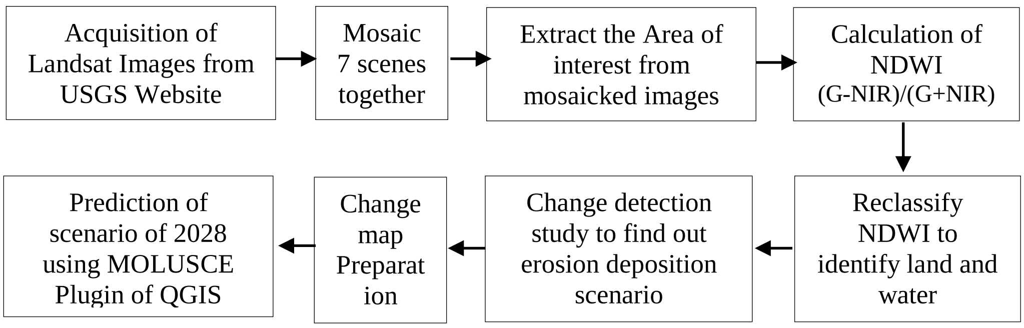

Figure 2. Methodological Flow Chart of the Study

3. RESULTS AND DISCUSSIONS

Analysis revealed that the coastline of Bangladesh is very much dynamic. It has faced both erosion and deposition in several hectares of lands between 1989 and 2016 (Table 2). Figure 3 represents the whole scenario of erosion and deposition along the coastline.

Table 2. Summary of geomorphological changes along the coastline of Bangladesh between 1989 and predicted 2028

Type	Area in Hectares			
	Between 1989 and 2004	Between 2004 and 2016	Between 1989 and 2016	Between 2016 and 2028
Erosion	57993.5	55340.9	76959.7	28859.9
Deposition	116315.3	136801.4	216742	31621.1
Net Change (Deposition)	58321.8	81460.5	139782.3	2761.2

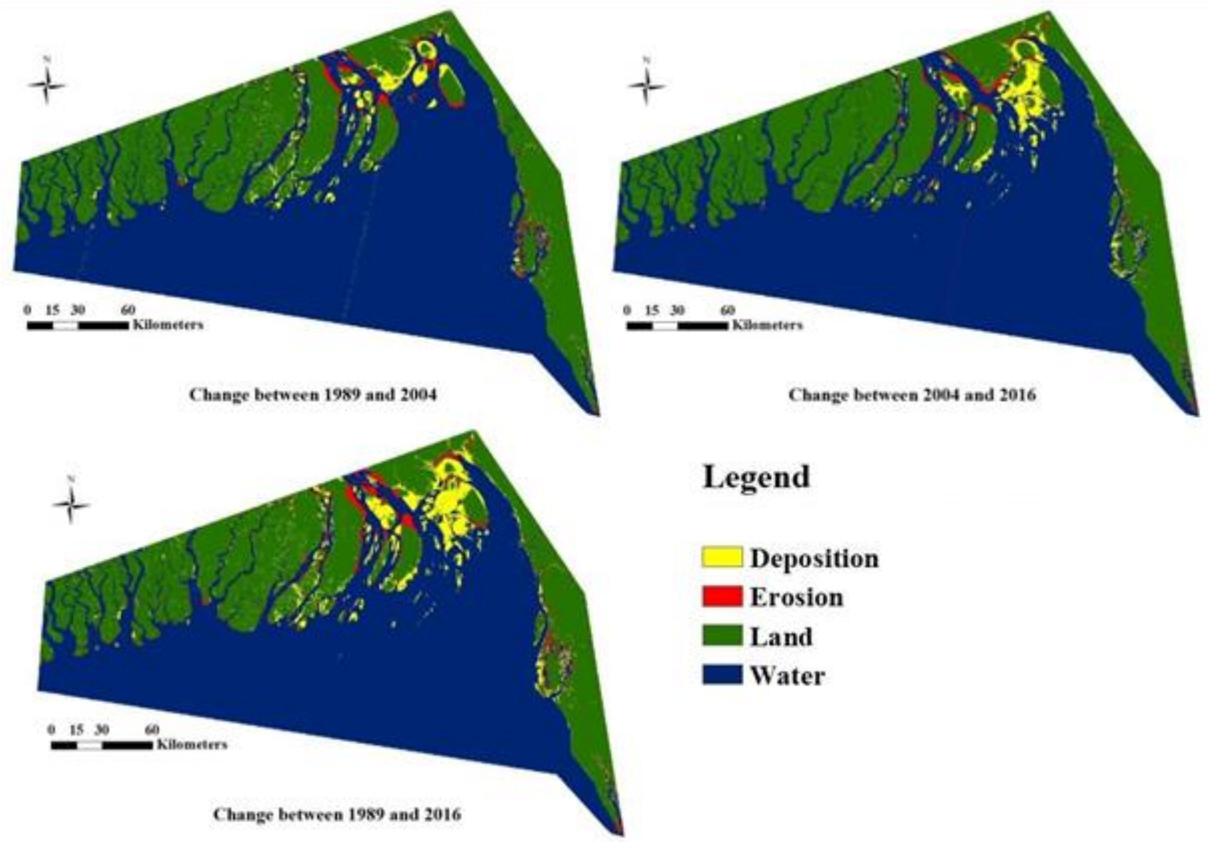

Figure 3. Geomorphological changes along the coastline of Bangladesh between 1989 and 2016

From the change maps, it is clear that Meghna Estuary is the most dynamic part of the coastline, where both erosion and deposition take place simultaneously. Urir Char and Sandwip Island have experienced a lot of changes from 1989 to 2016. Kutubdia Island has also gone through a morphological change between this period. About 216742 ha areas have been deposited along the coastline between 1989 to 2016 and 136801.4 ha has been deposited between 2004 and 2016. Depositions have been taken place around the islands mostly whereas erosion has taken place along the banks of Lower Meghna Channel (Figure 3). Around 76959.7 ha areas have been eroded between 1989 and 2016. Analysis depicted that coastline of Bangladesh can be characterized by dominant deposition nature. More areas have been accreted between 2004 and 2016 than between 1989 and 2004 (Table 2).

Sandwip island has been identified as one of the most dynamic islands by several studies (Emran et al 2015; Emran et al 2017). Emran et al (2015) found that this island has gained approximately 25 sq. km land areas between 1980 and 2014. Sandwip has also experienced erosion along the western, south-western and southern banks and deposition took place along the northern and north-eastern banks during these periods (Emran et al 2015). Hassan et al (2017) have found that about 4.6 sq. km areas have been eroded from Kutubdia island between 1973 and 2016. This study also found that erosion is dominant in Kutubdia island (Figure 3). Domar Char in Hatiya is another prominent island in Meghna estuary, which has also experienced significant morphological change between 1989 and 2016. Hassan et al (2017) found that about 340.9 sq. km areas have been deposited in Hatiya between 1973 and 2016. The accretion rate in Domar Char is about 208 ha/year whereas erosion rate is only about 160 ha/year between 1990 to 2015 (Hossain et al 2016).

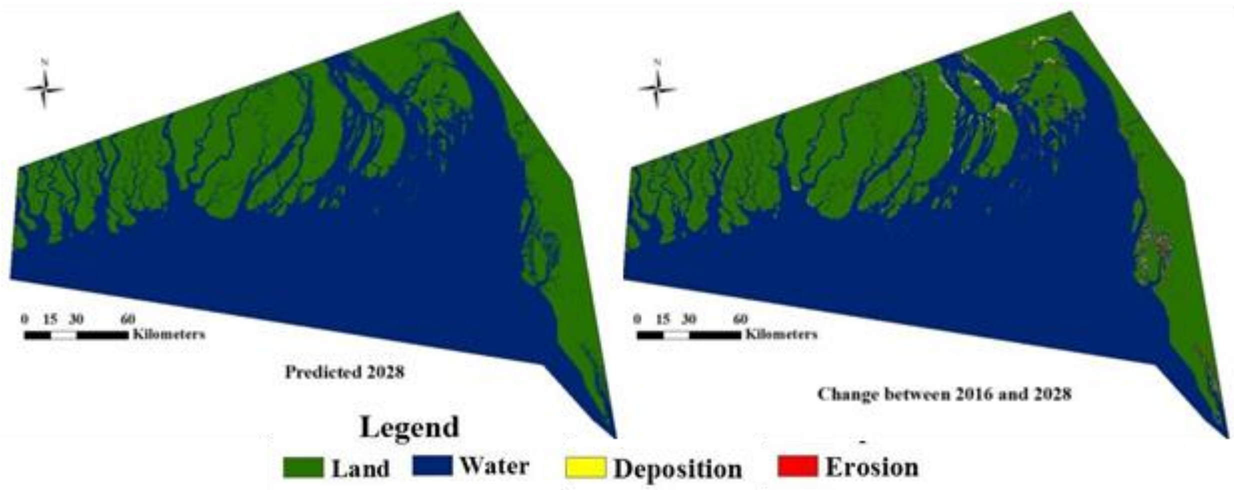

Figure 4. Geomorphological changes along coastline of Bangladesh between 2016 and 2028

MOLUSCE Plugin of QGIS predicts future scenario based on Cellular Automata Model and this study has used the Logistic Regression method of the model. Classified maps of the year 2004 and 2016 have been used to predict the scenario of 2028. Prediction revealed that the coastline of Bangladesh will continue to experience deposition more in 2028, though erosion will also take place in significant amount. Comparing the maps of 2016 and 2028, it can be said that around 28859.9 ha lands will be eroded, and 31621.1 ha lands will be deposited between 2016 and 2028 (Table 2). Analysis showed that more and more new lands have been deposited in the Lower Meghna Estuary, which has a significant impact on the tidal flooding (Figure 4). As the Lower Meghna becomes narrower, it cannot hold excess water and results in overbank flow. Geomorphological changes are one of the most important factors in the coastal area, which have also impact on coastal people’s living and livelihood.

4. CONCLUSIONS

Coastal Bangladesh is one of the most vulnerable coastal areas in the world. Due to the dynamic nature and actions of the Bay of Bengal, coastal Bangladesh have experienced significant changes. Erosion and deposition both take place here simultaneously but deposition is more dominant than erosion. About 580 km long this coastline has faced changes between 1989 and 2016, which is more concentrated in the Lower Meghna Estuary part. Sandwip, Hatiya, Kutubdia etc. have gone through a lot of changes between the study period. The Lower Meghna Estuary is gaining more and more lands, which might have caused disruption in the coastal morphology. Future prediction also shown more deposition in the estuary. As the coastal islands are habitat of millions of people, planned measures should be taken to reduce the vulnerability of islands from the actions of sea. Management plans should be formulated including their geomorphological characteristics and their potential to be changed in near future, predicted change in precise.

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Drinking Water Supply Challenges in Coastal Regions of Bangladesh under Increasing Salinity

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Abstract

Southern part of Bangladesh belongs to coastal region which is 710 km long along Bay of Bengal. Due to climatic change salinity intrusion is spreading also into noncoastal region. 19 districts out of 64 districts and 147 Upazilas (Sub district) are belongs to coastal region of Bangladesh. The coastal zone extends over 47150 sq. km area and has a population of 38.52 million. Around 24% of total population of Bangladesh are live in this area. People live in very remote areas even in off shore island expose to venerable natural calamities and disaster like cyclone. Due to the effect of climatic change intrusion of saline water is intensified during cyclonic storm surge flood and adversely affects drinking water and breakdown sanitation system. Main challenges for drinking water supply in coastal region are categorize as a) Adverse hydrogeology b) Less research on technology c) Community participation and awareness is ignored d) Less adoption initiatives climate change. Deep tube well, shallow tube well, shallow shrouded tube well and very shallow tube well based on ground water and protected pond, pond sand filter based on surface water along with rain water harvesting are the most potential means of portable drinking water practiced in coastal region. The people of coastal region of Bangladesh have got no option but to leave in and with salinity and natural disaster due to climatic change so adaption is very important. Many of the water points gone out of order early due to lack of awareness and ownership. So integration between technology and community participation are very much essential for sustainability. Awareness, motivation, training and empowerment of the local community to developed ownership are not less important than the technology itself.

Keywords: Salinity, adaptation, community, awareness, Technology.

1. INTRODUCTION

Southern part of Bangladesh belongs to Coastal region which is 710 km long along Bay of Bengal.19 districts out of 64 district and 147 Upazilas (Sub district) belongs to coastal region of Bangladesh. 13 districts are defined as the exposed and rest 6 districts are termed as interior coast (Figure 1). The coastal zone extends over 47150 square km area and has a population of 38.52 million (BBS 2011). Around 24% of total population of Bangladesh live in this area. Salinity of the sea directly enter into the main land through many rivers and their numerous tributaries due to the tidal effect every day. Intrusion of saline water is intensified during cyclonic storm surge flood and adversely affect Potable drinking water.

Access to a safe water supply which is basic right is one of the most important determinants of health and socioeconomic development. Main challenges for drinking water supply in coastal region are categorize as a) Adverse Hydrogeology b) Less research on Technology c) Community participation & awareness is ignored d) Less Adoption initiatives for natural calamities due to climate change. Hydrogeology of coastal belt is unpredictable even within few steps. Drinking water option in the coastal region is mainly addressed on urban and rural water supply. Coverage of water point (WP) in coastal area is shown in Table 1. In this paper we would focus on the challenges of rural water supply in coastal region.

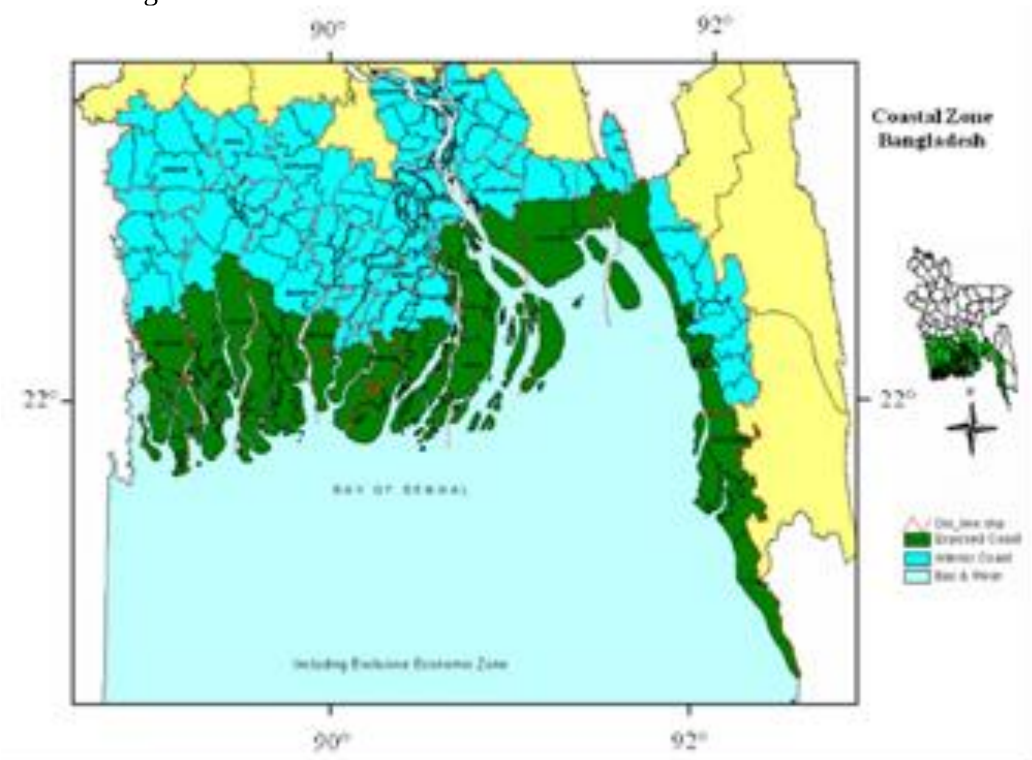

Figure1. Coastal zone of Bangladesh exposed and interior

Table 1. Coverage of water point (WP) in coastal area (DPHE)

District	projected Population	No of Running WP	coverage: No of user per WP	District	projected Population	No of Running WP	coverage: No of user per WP
Chittagong	4849371	57911	84	Patuakhali	1447449	23990	60
Cox's bazar	1943333	22285	86	Barguna	7556108	118677	64
Noakhali	2833526	32484	87	Khulna	1578154	23749	66
Feni	1240914	16151	77	Bagerhat	1389710	21388	65
Laxmipur	1590916	22327	68	Satkhira	1940473	29221	66
Chandpur	2148752	12477	172	Narail	661149	11381	58
Barisal	1958866	25198	78	Gopalganj	1192496	14296	79
Bhola	1663927	23597	71	Sariatpur	1111955	13266	84
Jhalakati	619211	10051	62	Jessore	2442481	32038	65
Pirojpur	1009792	18714	54				

2. PAST SCENARIO

In early 1976 there were many remote and isolated Upazillas and unions in coastal region of Satkhira with very adverse situation regarding drinking water as follows.

1. There were no deep or shallow tube well and people used to drink pond water which was not protected, and rain water collected by unhygienic way.
2. There were some union without tube well. (Gabura and Padma Pukur union of Satkhira)
3. Most of the pond dried up in summer.
4. Drinking water has been collected specially by the women from 5 or more km away.
5. A number of earthen pitchers were being placed in bottom of the Country boat and used to carry drinking water from distance places.
6. Drinking water are being loaded directly to the bottom of the country boat and unload and preserved in some big earthen pitchers called MOTKA and placed at courtyard bellow the earth to use in dry season.
7. In some stages cat fish and koi (Climbing Perch) fish has been dropped in the MOTKA to clean up the plankton and red worm.
8. People used to carry portable water from distance places for cows to avoid many diseases due to salinity.
9. People from north and sweet water zone do not like to get married and nor even like to work if got posted in coastal belt due to saline water.

3. PRESENT SCENARIO

Now-a-days situation has been gradually changed due to Government Planning and initiative supported by NGO and community participations. But due to frequent natural calamities and disaster due to climatic change, unfavourable hydrogeological conditions and salinity has adversely affect and facing a number of dimensional challenges for drinking water. Deep tube well, shallow tube well, shallow shrouded tube well and very shallow tube well based on Ground water and protected pond, pond sand filter based on surface water along with rain water harvesting are the most potential means of portable drinking water practiced in coastal region. Most dependable source of drinking water in coastal belt is groundwater.

1. Deep aquifer: DTW (Deep tube well)
2. Shallow aquifer: STW (Shallow tube well) / SST – Shallow shrouded tube well
3. Very shallow aquifer – Technology used VSST- very Shallow shrouded tube well

3.1 Ground water options:

3.1.1 Deep tube well and Shallow tube well

Water supply in coastal region is predominantly based on the ground water at deep and shallow aquifer in quality and quantity. Most of area of the coastal region are covered by deep tube well for drinking water varying depth from 75 m to 350m (Shallow tube well 20m-75m) using conventional hand tube well with #6 pump. Exploratory boring is to be done in deep aquifer to ensure the quality and quantities of water in the deep aquifer. There are 214334 deep and 196890 shallow tube wells in rural area of coastal Bangladesh (Status report DPHE June/2018). Many shallow tube wells in coastal region are with chlorides beyond acceptable limit are used for all other house hold purposes and they meet the demand of drinking water carrying by earthen pitcher mostly by women from nearby deep tube well.

3.1.2 VSST AND SST

Very Shallow (VSST) and Shallow Shrouded Tube well (SST), both technologies are functional on the same hydrogeological phenomenon depend on range of depth. In the most of the place of the coastal region there is no suitable aquifer in shallow depth but the ground water level is very high within around 2.5 m. VSST and SST cannot be installed in fine sand with #8 slot PVC filter. So Shrouding (artificial aquifer) with coarse sand and gravels are required for the purposes. Location of sweet water pocket at shallow depth in coastal region are to be identified by series of exploratory boring. Following hydrogeological condition is very much favourable for the purposes.

- 80% of sweet water pockets at very shallow level are identified near a pond.
- Old ponds with sandy bottom are much more potential than the new pond.
- Deep pond are with more possibility than shallow pond.
- Installation at the middle of the longer side of the pond is more potential.
- Perennial pond or water source may ensure uninterrupted supply from VSST and SST .
- Many tube wells of this type dried up in summer as ponds and surface water source are dried up.

3.2 Surface water option

3.2.1 Ponds

Pond is directly fed by rain and marked as a natural rain water collector. People use pond water in coastal region treated through Pond sand filter (PSF). In past water of the protected ponds in the village has been directly used traditionally for drinking purposes. In course of time pond water is contaminated due to washing, bathing, extensive fish culture, open defecation and for all other human activities. Protected pond has been popularised in coastal belt where potable water is not available even in deep or shallow aquifer. It is natural traditional water source in remote area and getting momentum recently in government policy (Figure 2). There are about 1,288,222 pounds in Bangladesh but about 17% of these ponds are probably dry up in the dry season (BBS 1997). The biological quality of water in these ponds is extremely poor due to unhygienic sanitary practices and absence of any sanitary protection. Many of these ponds are chemically and bio-chemically contaminated from fish culture. DPHE has started a project name “Water preservation and safe water supply project through re-excavation/maintenance of Ponds/Dighi/Ditches owned by zila Parishads” covering 42 districts in which 809 ponds re-excavation, and installation of 574 PSFs,225 solar PSFs,10 pond water filtration system are included. The Main objectives are as Development of sustainable, green and climate resilient environment through re-excavation of ponds/water bodies, Preservation of rainwater in rural areas, increasing use of surface water through reducing the trend of ground water use, increasing ground water table through protecting its depletion by recharge, increasing the rural water coverage and access to the safe drinking water. Finally, to address MGD for drinking water.

Figure 2. Pond re-excavation in Sonatala of Barguna

Figure 3. Improved pond sand Filter in coastal Region

3.2.2 Pond sand Filter:

Pond sand filter (Figure 3) is a slow sand filter installed by the side of a re-excavated and protected pond to purify pond water. Pond sand filter is a popular option for drinking water source in the coastal region since early 80's. But due to lack of proper maintenance, ownership and faulty design PSF has been abandoned gradually in some places. After monitoring and action research an engineering design has been modified to make it user friendly and more sustainable in the coastal area (Table 2).

Table 2: Design review of existing pond sand Filter:

sl no	Problems of existing PSF	Review design	Additional design
1	Not user friendly (Woman & Child) for height	Reduced Height for easy operation & maintenance by women	1.Concealed cover for sanitary concern 2. Early warning for cleaning 3. Intake management 4. Update disinfection System (Upon R&D). 5. Flow control over sand bed
2	Ineffective pre-treatment	With Pre-treatment	
3	Short filter run for having no pre-filtration	Addition of up flow roughing filtration unit	
4	Difficult washing system with sand replacement	Double bed for alternate cleaning Addition of Sedimentation zone for backwashing	
5	Bad water quality after Washing for single bed	Double bed for alternate cleaning	
6	No warning system for washing	Warning system for washing	
7	Inefficient Storage	Sufficient storage	
8	Improper Collection System of raw water	Primary cleaning of the raw water	

3.2.3 Solar operated PSF:

Plenty of direct sunlight is available along the coast line in Bangladesh almost throughout the year. So, Motor is driven by solar energy to lift raw water from pond for treatment.

3.2.4 Rainwater Harvesting:

Annual average rainfall of Bangladesh is 1600mm and more in coast line, so rain water is a potential source of drinking water in the coastal region if it can be preserved in hygienic way. Rain water also collected from corrugated roof sheet (Figure 4) and polyethylene funnel. To meet the rising demand of drinking water after devastating cyclone, when traditional water supply system is damage and epidemic breakout, rainwater is very much useful as drinking water. There are heavy rainfalls during the devastating cyclone, so roof of the cyclone shelter may be purposefully used as rain water collector.

Figure 4. Rain water harvesting from CI roof.

3.2.5 Desalination by Reverse Osmosis) Process

Direct Desalination by Reverse osmosis is a separation process used to reduce the dissolved salt content of saline water to make it acceptable level (Figure 5.) for domestic and other usages. When all the traditional water points are damaged by the cyclone in the coast purified water is arranging to supply on emergency by mobile unit of by Reverse Osmosis (Figure 6).

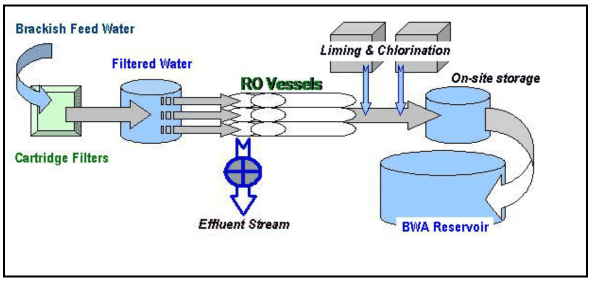

Figure 5. Flow diagram of Reverse Osmosis

Figure 6. Women are collecting portable water from RO

4. ADAPTATION

The people of coastal region of Bangladesh have no option but to leave in and with salinity and natural disaster due to climatic change. Bangladesh is considered as one of the most vulnerable countries in the world as the climate change and sea level rise concern (IPCC 2007). Cyclones and associated surges combined with sea level rise causes salinity intrusion in surface and ground water resources resulting acute drinking water problems (Rana et al 2001). They have no choice but to ready to adapt and all the infrastructures are to be built accordingly. The potential impact of climate change in coastal zone are minimized and reduced by adaptation (Adjustment to the climate change):

- All the tube wells are to be installed in a raised platform above highest flood level.
- Traditional tube well best to open off and kept in safe place and pipe is caped and refixed after cyclone.
- GI nipple pipes are to be used to raise the well as required.
- Embankment of the protected pond is to be made with sufficient height to protect salt water intrusion.
- Pond sand filter are to be installed above flood level.
- All agencies and local authorities are to be ready with moveable Reverse osmosis unit to meet the emergency water supply.
- Provision is to be made to collect rain water on roof of the cyclone shelter.
- Sufficient potable water and lifesaving commodities are to be preserved safely in cyclone shelter.
- Community of the coast have to be trained for disaster management.

5. CHALLENGES

Some challenges, which might need to tackle are:

a. Adverse hydrogeology

- Extensive exploratory test borings are required under planned R&D to identify more sweet Water pocket in coastal region.

b. Less research on technology:

- Research and development by the university may help to produce a user friendly and affordable new technology through master's and doctoral programme.

- New R&D programme for DPHE.

c. Community participation & awareness is ignored:

- In course of time many water points gone out of order due to lack of proper maintenance and technical knowledge of the community.
- Government and NGOs installed water points and handed over to the user group to use with proper maintenance. The community has a mindset that government is responsible for maintenance and repair, so they did not take any initiatives for even minor repair. As a result, water points gone out of order early. Community participation are to be enhanced by social mobilization and training.

d. Less Adoption initiatives.

- Adaptation is to be enhanced. Infrastructure made for adaptation are not properly maintained by authorities and communities in normal time, so it does not work during natural calamities. Action plan for Awareness and training is essential.

6. CONCLUSIONS

Extensive program to Excavate and re-excavate of ponds/water bodies in coastal area are very important for sustainable, green and climate resilience, Preservation of rain water, recharge ground water, increase the water coverage and access to the safe drinking water in coastal region. Integration between technology and community participation are very much essential for sustainability. Awareness, motivation, training and empowerment, behavioural change of the local community to developed ownership are not less important than the Technology itself.

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Rainwater Harvesting in Australia Using an Australia-Wide Model: A Preliminary Analysis

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Abstract

As the world's population is increasing, so the demand for fresh water is augmenting simultaneously. Groundwater resources are being utilized faster than they can be recharged, and surface water is becoming limited due to higher water use. Rainwater harvesting (RWH) is recognised as a sustainable means to overcome water scarcity and cope with the climate change and variability. RWH can be an important supplementary source of water in parts of the world like Australia where water demand is very high compared to many developing countries. Furthermore, Australia is one of driest continents and has the most variable rainfall with long periods of intense droughts and occasional devastating floods. Due to the higher water demand and environmental awareness, RWH systems have become popular in Australia in recent years. This study explores how rainwater can be harvested across Australia. In this study, daily rainfall stations covering three study periods, such as 30 years (1986-2015), 50 years (1966-2015), and 70 years (1946-2015) are used. Spatial analysis is carried out to demonstrate rainfall variability and the potential of rainwater harvesting in Australia. The ongoing study is aimed to develop a model to design an optimum RWH system at any arbitrary location in Australia.

Keywords: Rainwater harvesting, spatial rainfall, water savings, Australia, rainfall

1. INTRODUCTION

Australia is the driest inhabited continents, and one of the highest drinking water consumers in the world Preston (2009), Apostolidis et al (2011) and Haque et al (2013). The scarcity of fresh water has led to the need to identify and make use of alternative fresh water sources that can meet the growing demand for water Buraihi et al (2015) and Haque et al (2016). Rainwater harvesting (RWH) has become increasingly important due to the increasing urban population, frequent droughts caused by climate variability and change and the depletion of traditional fresh water sources Chubaka (2018), Ryan et al (2009) and Eroksuz et al (2010).

RWH is defined as a method of inducing, collecting, storing, and conserving local surface runoff for later beneficial utilization. The RWH system collects rainwater from impervious surfaces (e.g., rooftops, terraces, courtyards and road surfaces) or natural land surface and collected rainwater is stored in a storage system such as tanks, ponds, cisterns and underground storages of groundwater Rahman (2018) and Campisano et al (2017). Harvested rainwater is not only used in areas where the supply of water is limited by climate or infrastructure but also recently in well-developed watershed regions. It is driven by an increasing demand for water and an increased awareness of the negative environmental effects of urban runoff such as soil erosion and higher pollutant wash off. Onsite harvesting of rainwater also helps to reduce urban flooding and increase the water availability, with minimal costs for storage Friedler et al (2017). Harvested rainwater can also be used to meet the construction of water requirements as noted by Rahman et al (2018).

This paper presents how rainwater can be best harvested in Australia, which has a high spatial variability with respect to rainfall, evaporation and water use. The ultimate objective of this ongoing study is to develop a model that can optimize rainwater harvesting across Australia considering local rainfall, loss and water demand characteristics.

2. RWH STUDIES AROUND THE WORLD

Studies and experiments have been done to establish the usefulness of rainwater harvesting around the world. RWH has several benefits, e.g. rainwater is clean and a free source of fresh water (the only cost for collection and use), it can reduce clean water supply cost, it can minimize urban flooding problem at smaller return periods and topsoil loss, recharge groundwater, and use simple technologies which are cheap and easy to operate (Choudhury et al 2010; Julius et al 2013).

It has been reported that rainwater harvesting can be promoted the significant water saving in residences Ghisi et al (2007). For example, Cheng et al (2009) in a study on regional rainfall level zoning for RWH systems in northern Taiwan stated that RWH had been widely accepted as solutions to alleviate the problems of water shortages. Kahinda et al (2008) defined RWH as the collection, storage and use of rainwater for small scale productive purposes in South Africa.

Kenya has successfully implemented rainwater collection systems. The Kenya Rainwater Association uses low-cost technical options to build community-based organization systems. A combination of improved health awareness, clean and safe water and the resulting income from the sale of surplus agricultural products increase people's willingness to pay for improved housing and water supplies (Mbugua et al 1996).

A study conducted by Mutekwa and Kusangaya (2006) elucidates that RWH technologies have been successfully adopted in Zimbabwe, which has helped to alleviate the problems faced by resource poor farmers. The benefits of RWH technologies include an increase in agricultural productivity, improving food security for households and raising of incomes.

Since 1996, small and medium-sized residential and commercial buildings in the USA have shown an increasing interest in rainwater harvesting. Cities and countries around the world adopt different rainwater harvesting rules, in particular in the United States (Choudhury et al 2003).

In Australia, RWH has been quite popular and there have been numerous researches recently performed (e.g. Amos et al (2016, 2018a, 2018b); Coombes and Kuczera (2003); Hajani and Rahman (2014a, 2014b); Haque et al (2016); Imteaz et al (2011a, 2011b, 2012); Rahman et al (2012a, 2012b, 2013, 2016, 2017); Rahman and Eslamian (2016); Van der Sterren et al (2012a, 2012b, 2013, 2014). However, none of the studies considered the whole continent of Australia and hence this study is designed to overcome this limitation.

3. SELECTION OF STUDY AREA AND DATA PREPARATION

Australia is the focus of this study, which is an island and a continent. It is situated between the Indian Ocean and the South Pacific Ocean in Oceania. Australia located approximately between 10 degrees 41 minutes (10°41´) south (Cape York, Queensland) and 43°38´ south (South East Cape, Tasmania), and between longitudes 113°09´ east (Steep Point, Western Australia) and 153°38´ east (Cape Byron, New South Wales). It is the sixth largest country in the world, comprises of a land area of about 7.69 million km^2. About 20 percent of the land mass in Australia is classified as a desert. In addition to low annual average rainfall, rainfall throughout Australia is also highly variable. The rainfall pattern is concentric around the continent's vast arid core, with high rainfall intensity in tropics and some coastal areas.

Rain gauges located across Australia with longest records and no gaps are considered for this study. Initially 17,773 rainfall stations from Australia are considered as shown in Figure 1, but only 2904 stations have complete rainfall data without any gaps. Hence, these 2904 stations, as shown in Figure 2, are used in this study. The daily rainfall data of each of these locations are obtained from the Australian Bureau of Meteorology.

We use three study periods, 30 years (1986-2015), 50 years (1966-2015), and 70 years (1946-2015). Spatial locations of the selected 2904 rainfall stations can be seen in Figure 2. It can be seen that the density of the stations in the interior of Australia (arid region) is quite low. The density of rain gauges approximately matches the population density in Australia, i.e., the east coast has the highest population and also the highest number of rain gauges. The daily rainfall data were checked in a number of ways like missing data, consistency, and visual inspections on excel plots. The daily rainfall values were categorized into four intensity groups as follows: light rainy days, heavy rainy days, moderate rainy days and extreme rainy days. All data analyses were done using the FORTRAN program and graphs are plotted in Microsoft excel.

Figure 1. Location of the 17,773 daily rainfall stations in Australia

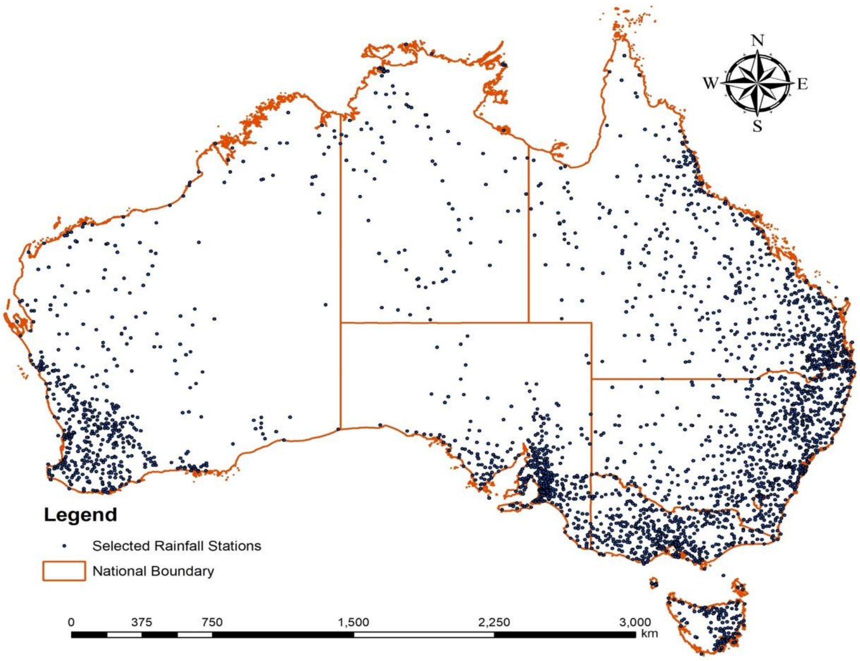

Figure 2. Location of the selected 2904 daily rainfall stations used in this study

4. RESULTS AND DISCUSSION

Figure 3 shows the average monthly rainfall of all the selected daily rainfall stations for three study periods: 30 years (1986-2015), 50 years (1966-2015) and 70 years (1946- 2015). Daily rainfall data have been processed to produce the average rainfall for each month by a FORTRAN program. As shown in Figure 3, most of the winter months (August to October) have smaller rainfall, while summer time (December to May) show higher rainfall. This means that the rainfall during the winter is less, so we need to harvest more rainwater using larger tanks to satisfy given water demand. But the water demand in the winter is generally smaller, which should discount the tank size.

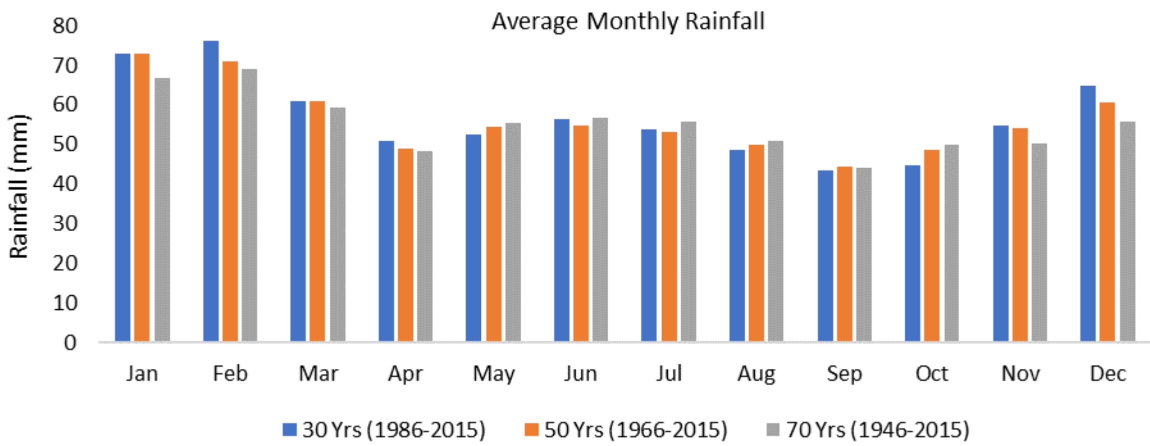

Figure 3. Average monthly rainfall for 30, 50 and 70 years

The number of rainy days is important in RWH as on rainy days the irrigation demand is reduced or become zero. A day is considered rainy when rainfall is greater than 1 mm. The annual average rainy days for the Australia are presented in Figure 4. For the purpose of this study, rainy days are divided into four groups: light rainy days, moderate rainy days, heavy rainy days, and extreme rainy days. The following rainfall (R) intervals were used to classify rainy days: light rainfall, $R < 10$ mm; moderate rainfall, $10 \leq R < 25$ mm; heavy rainfall, $25 \leq R < 50$ mm; and extreme rainfall, $R > 50$ mm following the criteria suggested by Hajani and Rahman (2018). From the preliminary analysis, it has been found that on average, less than 5% of the days are moderate, heavy and extreme rainfall days in a year. In these days, irrigation from rainwater tanks may not be necessary, but for other days, irrigation will be needed and hence if the tank is to be used for gardening/irrigation, a bigger tank will be needed to satisfy a given demand on these days.

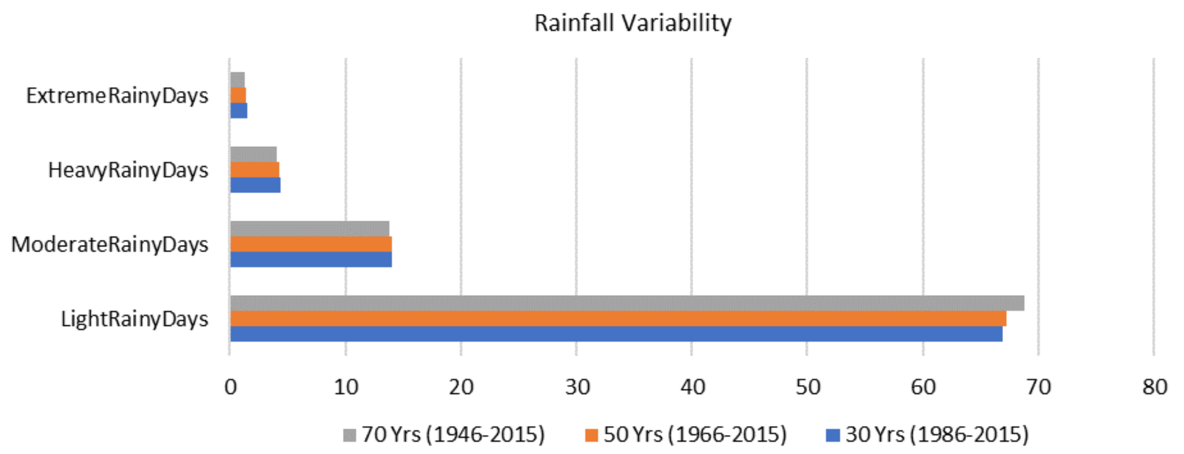

Figure 4. Average rainy days for 30, 50 and 70 years

Table 1. Minimum and maximum daily rainfall values across Australia (5 stations with the lowest and 5 stations with the highest daily rainfall)

Station Number	Minimum Daily Rainfall (mm)	Station Number	Maximum Daily Rainfall (mm)	Difference between minimum & maximum rainfall (%)
300000	74.93	31141	8670.14	11470.99
17037	140.86	31140	4723.3	6115.62
16027	148.55	31144	4672.54	6037.62
16059	154.16	31167	4472.47	5763.12
17076	155.39	31004	4364.79	5617.78

Table 2. Important rainfall statistics

Data Series	Mean Annual Rainfall (mm)	Mean Annual Rainy Days (day)
30 Years (1986-2015)	679.68 ± 440.79	86.86 ± 39.84
50 Years (1966-2015)	674.11 ± 399.43	87.05 ± 37.95
70 Years (1946-2015)	662.06 ± 401.50	87.96 ± 37.09

(Figures 5, 6 and 7) exhibit how rainfall varies across Australia for the 30, 50 and 70 years data lengths. The highest annual rainfall is found to be occurred in the Queensland, which is 8670 mm and the lowest rainfall is found in the arid region, which is quite low (75 mm). These figures guide us where more rainfall can be harvested and/or where a bigger rainwater tank will be needed to meet given water demand. A common tank size across Australia is not appropriate as it has a highly variable spatial rainfall distribution. The proposed rainwater tank model (which is under development) will incorporate the spatial rainfall variability across Australia.

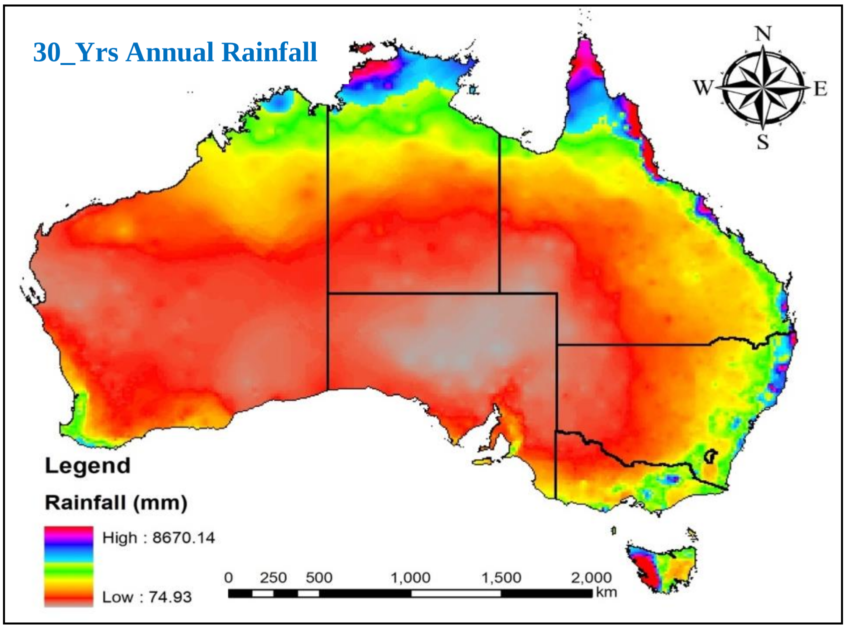

Figure 5. Spatial distribution of 30 years mean annual rainfall across Australia

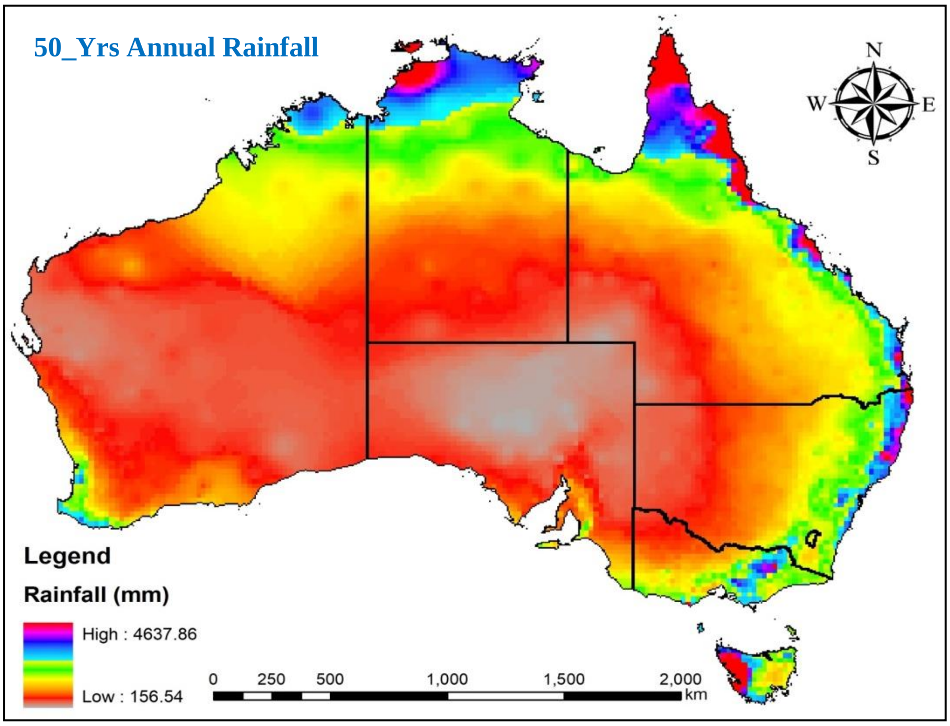

Figure 6. Spatial distribution of 50 years mean annual rainfall across Australia

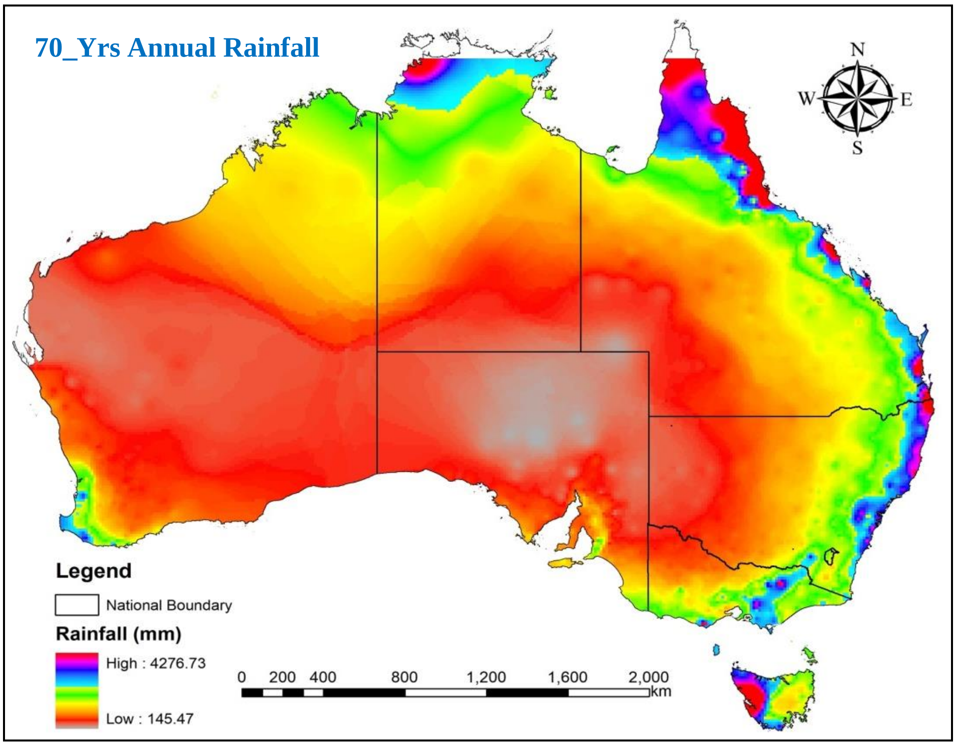

Figure 7. Spatial distribution of 70 years mean annual rainfall across Australia

5. PROPOSED RAINWATER TANK MODEL

The proposed Australia-wide RWH model will be based upon the followings:

i. Due to sharp rainfall variability across Australia, a single rainwater tank size may not provide the best possible water savings outcome throughout. Therefore, total 11 tank sizes will be available to test and select at any arbitrary location of Australia. These are 1 kL, 3 kL, 5 kL, 7.5 kL, 10 kL, 15 kL, 20 kL, 30 kL, 40 kL, 50 kL and 100 kL.

ii. A total of five water uses will be considered: (a) toilet flushing; (b) toilet flushing and laundry; (c) irrigation and outdoor washing; (d) drinking; and (e) all of these demands.

iii. It is assumed that that the average annual water savings from rainwater tanks will be correlated with average annual rainfall. Therefore, the local rainfall data will be used to optimize the tank size for a given catchment. Roof catchment and parking lots will be used as two possible catchments to harvest rainwater.

iv. A financial and environmental analysis will be part of the proposed model. It will include the rainwater tank cost, concrete base, pump, first flush, leaf- eater, pump- to- tank connection kit, electrical supplies, plumbing supplies and labor costs required.

6. CONCLUSION

There have been numerous studies on RWH in Australia; however, there is no nation-wide study to regionalize RWH, and hence this study aims to regionalize RWH in Australia using a nation-wide rainfall database. As a part of this ongoing study, we have prepared rainfall data from 2904 stations across Australia. The dataset is divided into three groups: 30 years (1986-2015), 50 years (1966-

2015), and 70 years (1946-2015). From the preliminary analysis, it is found that rainfall in Australia is highly variable. The yearly rainfall as high as 8670 mm is noted in Queensland and as low as 75 mm is found in the arid part of Australia. It is found that central part of South Australia has minimum annual rainfall (140 to 200 mm), while maximum rainfall values are found in Queensland (4000 to 8000 mm). There is a sharp rainfall variability across Australia, and hence in this study eleven different tank sizes will be considered to develop nationwide RWH model for Australia. It is expected that this study will make a significant contribution to the science and practice of RWH in Australia.

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A Case Study on Urban Flood Modelling in Sydney using DRAINS and HEC-RAS

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Abstract

Flood mapping is a crucial element of flood risk management in both rural and urban development projects. In small and ungauged basins, empirical and regionalisation approaches are often adopted to estimate design flood hydrographs that represent input data into a hydraulic model. The limitations of observed runoff data in urban catchments in Australia present a major challenge with respect to direct model calibration and verification. This paper presents a case study on flood risk assessment in a small urban development project in Sydney, Australia. For this purpose, DRAINS and HEC-RAS models are adopted. It is noted that in Australia a more holistic approach of flood modelling (e.g. Monte Carlo simulation) is advocated in the recent edition of Australian Rainfall and Runoff (ARR), the national guide. However, there is limited data availability in applying such holistic approaches, Outcomes provided from the HEC-RAS modelling of this case study will provide the estimated level of flood or flood height for that particular site according to the proposed plans. Flood level has been based on the 1:100-year ARI storm events. A minimum Finished Floor Level for the proposed development is reached with the addition of the minimum freeboard provided from this local council.

Keywords: HEC-RAS, DRAINS, floods, Monte Carlo simulation.

1. INTRODUCTION

Flood destruction causes massive economic cost with major social disruptions associated with emotional disturbance, relocation, counselling, loss of important private and personal articles and in some cases loss of human life. For many urban development projects, flood risk assessment is needed to ensure unnecessary flooding of the property. The Statistical Rational method is the most common method, both in Australia and overseas for urban flood calculation. Although the hydrograph methods were not well known in 1960s, they still derived hydrographs using the Rational method. They produced triangular and trapezoidal hydrographs using the peak discharge from the Rational method and the time of concentration from other methods.

As reported in Aitken (1975), there had been many attempts to use overseas computer models directly or to modify overseas models to suit Australian urban catchments. Two problems were found in selecting overseas computer models for use in Australia. The first problem was the single systems used for urban stormwater and sewage water collection as opposed to a two separate system in Australia. The second problem was the soil types with high differences in infiltration in urban areas in different locations of Australia compared to the overseas models. Over the years, these minor problems were modelled to work around these two problems and suiting Australian conditions. An example of this is the ILSAX (O'Loughlin 1993) model. Several well-known urban drainage computer models are widely used in Australia and overseas with another popular model, HEC-RAS. HEC-RAS (Hydrologic Engineering Centre 2000) is recognised as a successful urban drainage computer model for design and analysis.

The Rational Formula method is simply a mathematical rainfall-peak runoff model using two ways, deterministic and statistical. Aitken (1975) found that the Rational Formula method as deterministic model was of almost no use in the urban situations. Statistical Rational Method/Model had some advantage needing personal judgement on selection of runoff coefficient. The ARR87 recommends the Statistical Rational Method with several major assumptions made, which are:

I. The design storm is uniform in intensity over the catchment in both time and space,
II. The rainfall duration is equal to the time of concentration of the catchment,
III. The peak runoff is a fraction of the average rainfall rather than the residual after abstraction of losses,
IV. The return period of the peak discharge is equal to that of the rainfall intensity, and
V. Rainfall runoff response is linear.

Statistical Rational Method is given by:

$$Q_{\mathrm{peak}} = C_y I A / 360 \quad (1)$$

Where,
Q_{peak} is the peak discharge (m^3/s),
C_y is the runoff coefficient corresponding to return period y,
A is the catchment area (ha), and
I is the average rainfall intensity (mm/h) of a storm with return period y and storm duration t_c (hours).

For single land-use catchments, losses are assumed to be the same for the whole catchment, making the runoff coefficient is a function of return period and fraction of imperviousness. If the catchment consists with different land-uses having different losses, then the area-weighted runoff coefficient should be computed (Argue, 1986). The time of concentration in urban catchments can be calculated by interpolating the collected rainfall intensity for the site from Australian Bureau of Meteorology against the information collected from the contoured catchment plan map/s, such as the distance water will travel, the roughness of the ground and the slope of the site. The main shortfalls of this Statistical Rational method are:

- The subjectivity of the catchment runoff coefficient (although there are guidelines given in ARR87 based on limited data),
- Uniformly distributed storms are rarely experienced over the catchment,
- Storms are not uniform in intensity,
- The return period of runoff and rainfall would rarely agree,
- The catchment time of concentration may be unknown or at best variable,
- It is applicable only to small catchments, and
- Only peak discharge can be estimated.

In ARR1987, the Probabilistic Rational Method (PRM) was recommended for use in south-eastern Australia. The runoff coefficient is an important component of the PRM, which can be estimated from the contour map in ARR87 volume 2. French (2002) noted that the isopleths of runoff coefficient in ARR1987 ignore watercourses. Pirozzi et al (2009) and Rahman and Hollerbach (2003) evaluated the PRM and linked the runoff coefficient with catchment characteristics, but they achieved limited success. Rahman et al (2011) noted that there is a lack of independent evaluation of the PRM and designers have poor knowledge about the uncertainty in design flood estimates obtained by PRM. The ARR RFFE model recommended in ARR2016 has no urban application module, i.e. it is applicable to natural catchments only (Rahman et al 2016).
ILSAX and DRAINS are widely used by the local government authorities and consultants in Australia to design and analyse urban drainage systems. There are inadequate guidelines available to develop models for both gauged and ungauged urban catchments. The DRAINS manual (O'Loughlin 1998)

provides the information on how to assemble data to construct a model and some guidelines how to interpret results.

2. FLOOD ESTIMATION METHODS

Flooding is one of the most manageable of natural disasters, if flood prone areas are identified and suitable flood mitigation strategies are implemented. The most practical way of identifying flood prone areas and the effectiveness of flood mitigation strategies is by the application of mathematical models, which considers complex hydrological and hydraulic processes of these areas. The hydrologic models compute peak flows and/or flood hydrographs to minimise flood damage. Errors in peak flow estimation cause either undersized or oversized infrastructure. For an efficient and economic urban drainage system design, it is important to estimate the design flows and/or flood hydrographs accurately. In dealing with urban drainage design, some cases, full flood hydrograph is not required. Simple peak flow design methods particularly Statistical Rational method are sufficient to design inlets, pipes, gutters and channels in locations where rainfall variability and/or storage effects can be neglected for small urban catchments.

In these design methods, it is assumed that the calculated peak discharge has the same average recurrence interval (ARI) as the design rainfall in the design methods (ARI neutrality concept). These peak flow design methods are simple mathematical models. In most cases, the design of urban drainage systems involves consideration of flood storage, permanent storage, off-channel storage, inter-drainage diversions and pumping installations and silting of drains. Knowledge is required for flood hydrographs instead of just flood peak. A full hydrograph can be obtained from the rainfall-runoff models such as ILSAX (O'Loughlin 1993). It should be noted that ARI neutrality concept has been widely criticised (e.g. Rahman et al, 2002a; Loveridge and Rahman, 2018) and the ARR2016 has recommended Monte Carlo Simulation technique for design flood estimation (Weinmann et al 2002); however, its application has not been widely adopted in practice. In this regard, regional Monte Carlo simulation technique can be useful such as the method proposed by Caballero and Rahman (2014).

It is necessary to estimate the model parameters and land-use parameters for rainfall runoff modelling in the urban catchments. The parameters include infiltration and depression storage and the characteristics of the catchment (impervious area, supplementary area and pervious area). The ideal method to determine model parameters is to calibrate the models using observed rainfall and runoff data but there is large cost associated with monitoring of these catchments and hence little observed data is available.

3. COMPARISONS OF HYDROLOGIC AND HYDRAULIC MODELS

Most urban catchment models use hydrologic and hydraulic computations based on loss modelling, overland flow routing and pipe routing in simulating the runoff response. Table 1 describes the different methods used in urban catchment models. In the loss modelling, storm loss for an event is defined as the amount of precipitation that does not appear as direct runoff. The storm loss includes moisture obstructed by vegetation, soil infiltration or retained by surface storage (depression). It can occur from both impervious and pervious surfaces. These losses can be modelled by four different loss components: (1) impervious area depression storage (impervious area initial loss); (2) pervious area depression storage (pervious area initial loss); (3) pervious area continuous loss, and (4) evaporation loss from both impervious and pervious surfaces. It can be assumed that in storm events hydrograph modelling, evaporation from pervious and impervious areas can be neglected, compared to other loss. The use of probability distributed loss modelling as proposed by Rahman et al (2002b) has not been applied in urban applications; however, ARR2016 recommends considering stochastic nature of losses (e.g. Loveridge and Rahman 2014).

Depression storage is a volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas and can be considered as an initial loss. It represents a loss caused by interception and surface ponding. In storm event modelling, evaporation loss is insignificant and therefore the impervious area depression storage is assumed to be a constant in most urban drainage models. Typical values would be 0 to 2 mm for impervious area depression storage.

The pervious area depression storage is subject to infiltration and evaporation, though it is small losses. Therefore, the pervious area depression storage is also assumed to be constant in most urban drainage models. Typical values would be 2 to 10 mm for pervious area depression storage

Table 1. Modelling Methods Used in Different Models in Australia (Dayaratne 2000)

Model	**Continuous or Event Model**	**Impervious and Pervious area Lumped or Seperated**	**Loss Model**	**Overland Flow Routing Method**	**Pipe Routing Method**	**Can Water Quality Parameters be Simulated?**	**Output**
ILSAX/ DRAINS	Event	Separate	Horton	Time-area	Manning's equation	No	Hydrographs at each pit can be modelled
HEC-RAS	Not applicable	-Manning's equation -Gradually varied flow	No	Can be generated water surface profile	Manning's equation	No	
CIVILCAD	Event	Separate	Horton	Time-area	Manning's equation	No	Hydrographs at each pit can be modelled
SWMM	-Event or -Continuous	Separate	-Horton -Green-Ampt	Nonlinear reservoir	Kinematic wave	Yes	Hydrograph at each pit

Numerous equations have been developed for modelling the process of water entry into soil from the surface at one point. Some are based on empirical equations to infiltration data; others use numerical solutions to complex equations. Other types of infiltration loss models are topographical lumped (different ground material) models, which are constant loss rate, initial loss-continuing loss, proportional loss, antecedent precipitation index and SCS curve procedure (Nandakumar et al 1994). From these methods, initial loss-continuing loss, constant loss rate (i.e. runoff coefficient) and SCS methods have been used in urban drainage computer models. The model parameters of these types are estimated using the total catchment runoff. This method was found to be widely used due to its simplicity and ability to approximate catchment runoff behaviour (Nandakumar et al 1994). The ILSAX model uses initial loss-continuing loss model with its continuing loss model by the Horton equation, which considers average conditions over the entire catchment.

4. CASE STUDY

The case study location is Auburn, New South Wales, Australia. A flood study was requested by the client's local Council to provide the required Finished Floor for the proposed development. IM Engineering & Accredited Certifier was instructed to carry out these services. The site is located at

No.45 North Street, Auburn, NSW as shown in Figure 1. The proposal is for a suspended single storey outbuilding/granny flat. The existing dwelling at the front of the property remains.

Figure 1. Topographical view of case study site, 45 North Street, Auburn, NSW

The purpose of the study was to establish the 100-year flood level for the proposed outbuilding development, set floor levels, check pre-development and post-development depth of flows and study the velocity-depth product effects. Stormwater requirements were obtained from Cumberland Council (Auburn City Council) and the NSW Government Department of Planning's 'Floodplain Development Manual'and identified as below:

- A stormwater study is necessary to determine the 100-year ARI water surface level.
- The impact of the development on 100-year ARI inundation levels on adjoining properties.
- The required floodway width for conveyance of the 100-year ARI overland flow through site with a maximum allowable velocity-depth product of $0.4m^2/s$.
- Minimum floors levels to be at least 500mm above the determined 100-year water surface level. Garage floor levels or driveway crests are to be 150mm above the determined level of inundation.

The hydrological analysis of the catchment was carried out using the DRAINS program. The 5, 10, 20, 30, 60 and 120 minute storm durations were used in the analysis. The catchment area is approximately 40.7 Ha as shown in Figure 2. This catchment area was assumed with a 50% blockage factor for a more realistic result. The 100-year peak overland flow along the front, inside and to the rear of the site is found to be 21.934 m^3/s as determined by DRAINS, as shown in Figure 3. This value was then implemented in HEC-RAS.

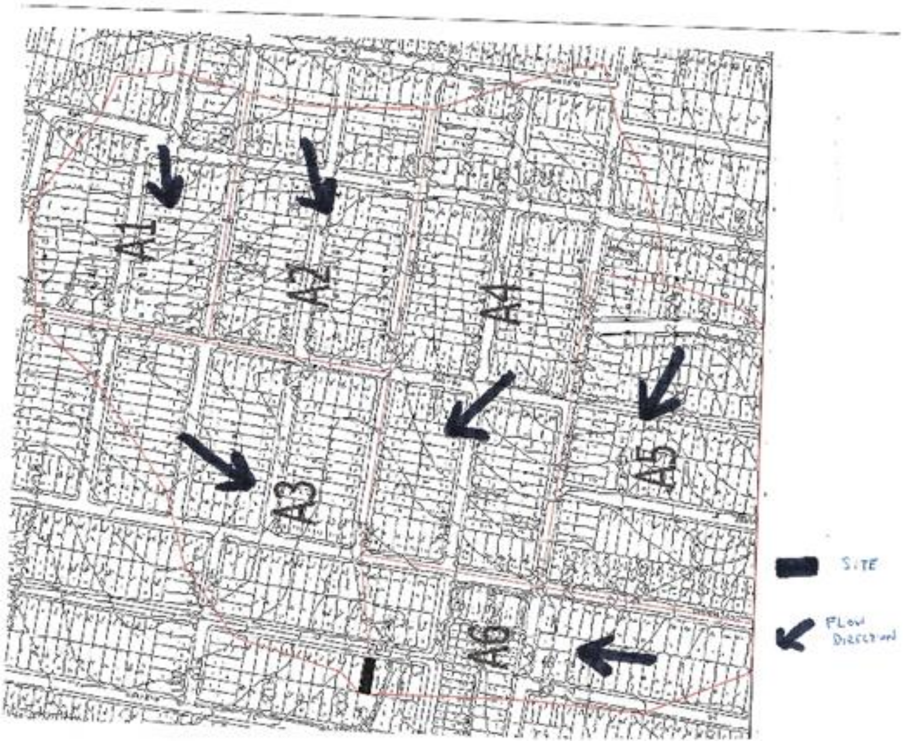


Figure 2. Catchment plan with sub-catchments to site for DRAINS modeling (Auburn Council 2016)

The HEC-RAS model was used to analyse the pre-development and post-development status at 100-year flood levels. The pre-development analysis was based on existing levels across these properties. The post-development analysis was further based on the new finished levels proposed for the suspended granny flat. For each scenario (i.e. Pre-development and Post-development), an arrays of cross-sections were developed in modelling the area of interest. Additionally, obstructions and ineffective flows were also considered and included in each scenario modeled.

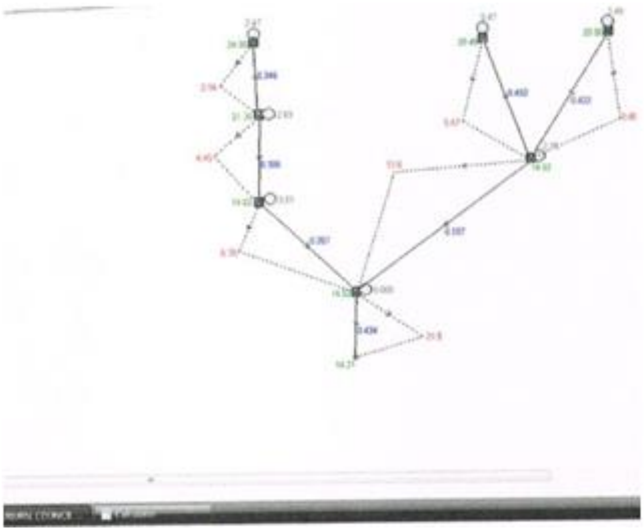
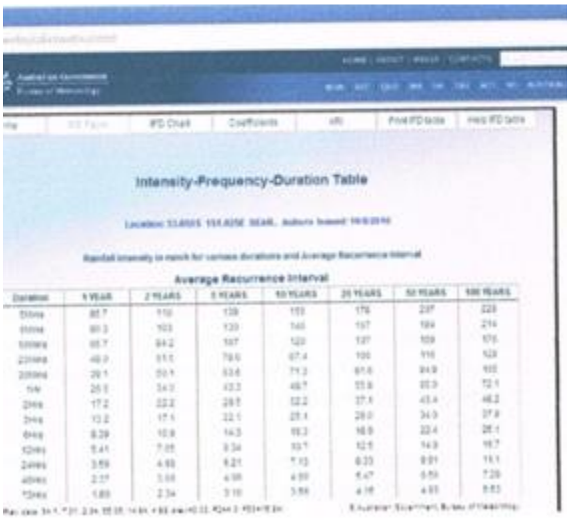


Figure 3. DRAINS model (version 2015.12) of sub-catchments for the site

Table 2. Rainfall intensity data for this site



4.1 Scenario 1: Existing conditions i.e. pre-development

The computed maximum water depth from North Street shows that overland flows and/or any back flow was apparent. The highest maximum Water Surface Level (W.S.L.) achieved for the site is 16.11m A.H.D (Cross section 3), as shown in Figure 4. With the existing development having a FFL of 15.49m, this indicates that the existing development will be flooded in the 100-year ARI flood event of a flood height of 0.62m to the top of water level.

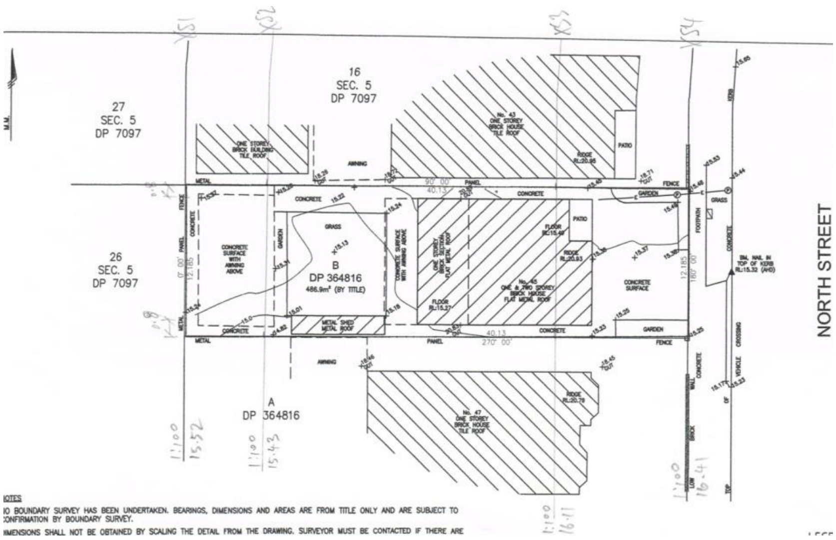


Figure 4: Existing site conditions (RGM Property Surveys,2016)

4.2 Scenario 2: Proposed conditions i.e. post-development

The post-developed scenario shows that if the proposed Granny Flat (Cross section 2) was filled under the ground floor to support the proposed ground floor slab, the water level will rise from 15.43m AHD (Existing flood level) to 15.72m AHD, as shown in Figure 5. This flood height will be 0.87m to the top of water level. By suspending the proposed ground slab to sit on a water-proofed and galvanised square hollow section posts sitting on concrete piers, this will make the flood levels at 'No Change' from the pre-developed stage. Cross-section 2 had a 100-year ARI flood level of 15.43m as the existing pre-developed stage shows the maximum height at the lowest point is 0.58m to the top of water level.

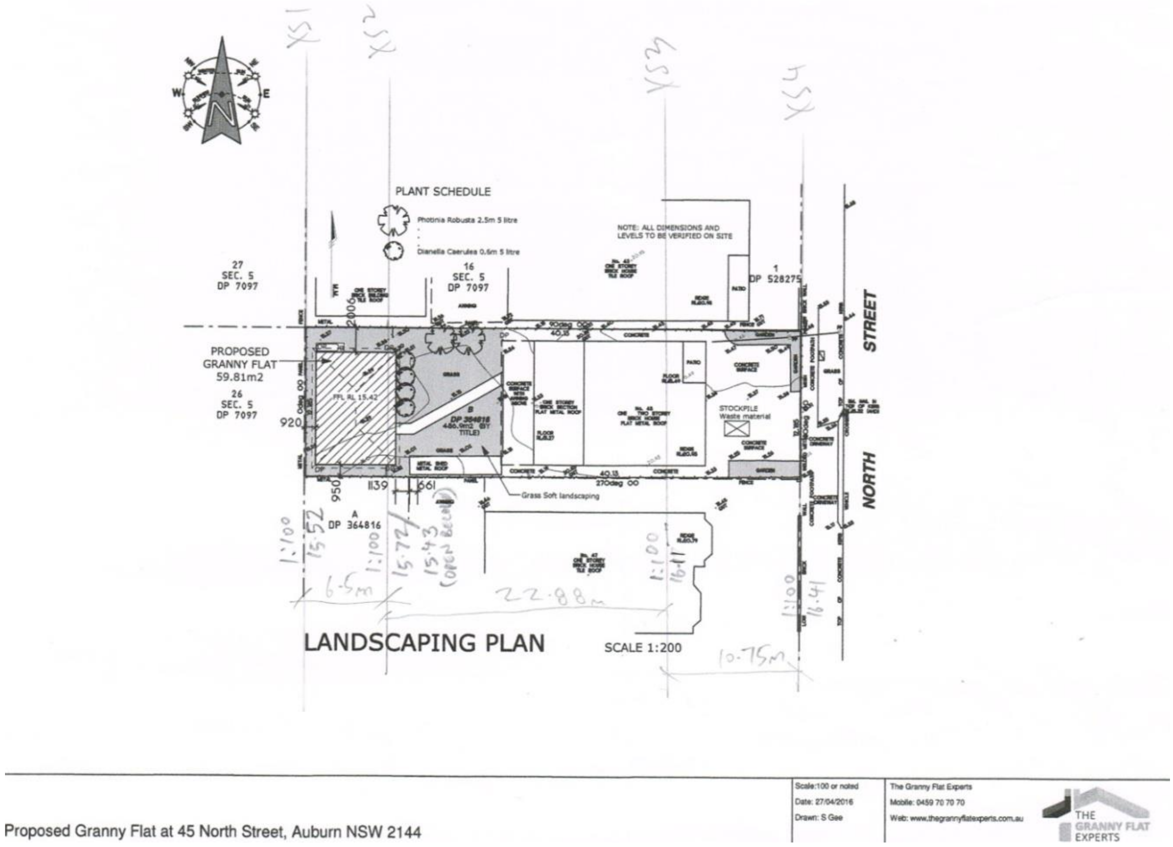


Figure 5. Proposed site conditions (The Granny Flat Experts 2016)

From the above results, it can be concluded that the proposed solution will have no effect on the existing neighbouring residences and on the future planning for this proposed development.

There was no change of impact on the proposed granny flat for the 100-year flood levels when analysed. It can be seen from the HEC-RAS results and sections modelled, that the proposed addition had no impact on the 100-year post-development flood levels even to the adjoining properties. The resulting 100-year flood levels are a conservative estimation and will actually be lower if the modelled flow width was extended as shown in Figure 6. The 100-year water surface levels are as follows as described in Table 3.

It is recommended that the floor level of the future building shall be a minimum of 500mm above the top of water level in order to maintain Council’s 300mm freeboard requirement, plus an additional 200mm for any inaccurate assumptions made in the model.

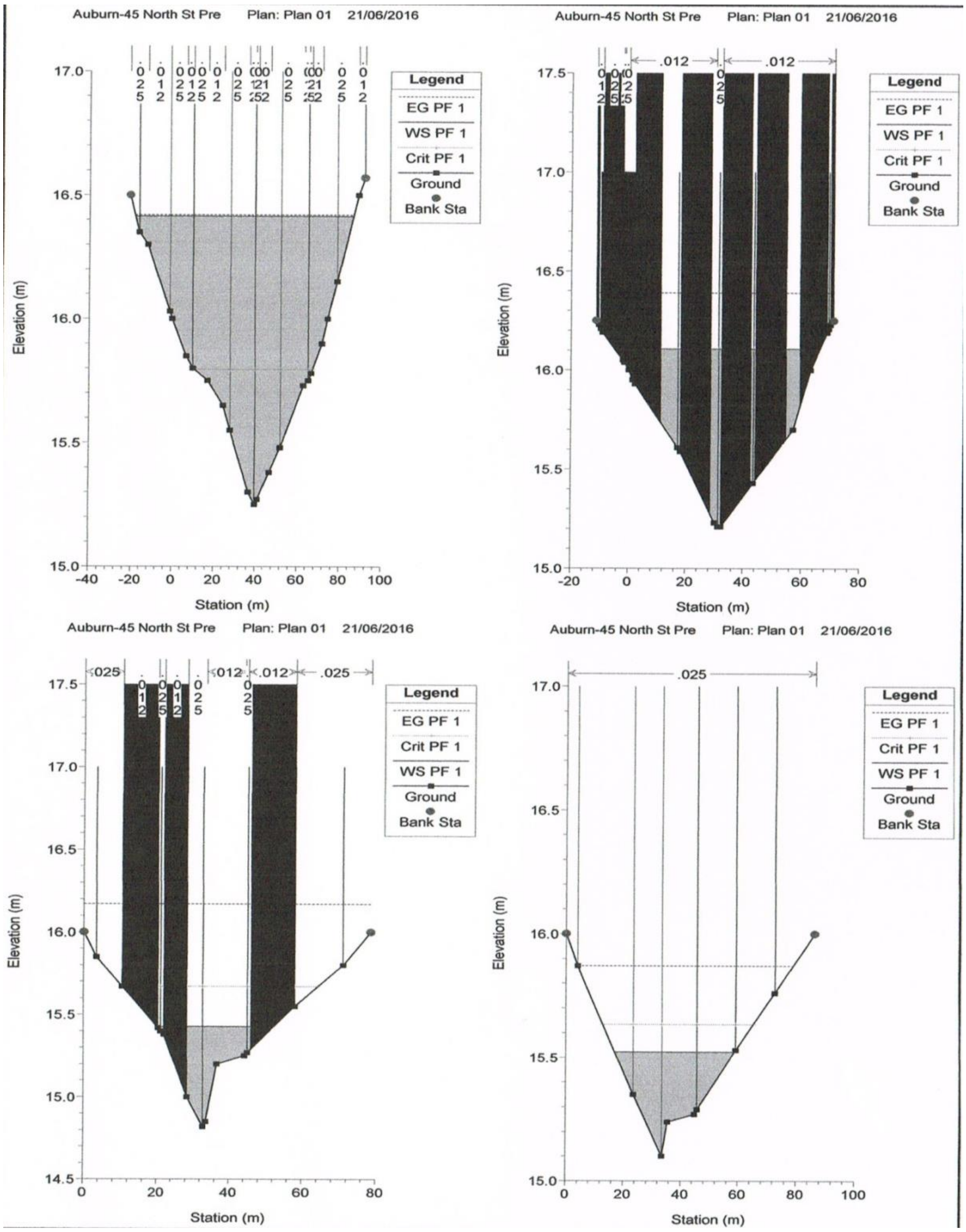


Figure 5. HEC-RAS 4.1.0 cross-sectional outcomes for PRE-DEVELOPED stage (www.hec.usace.army.mil/software/hec-ras, 2016)

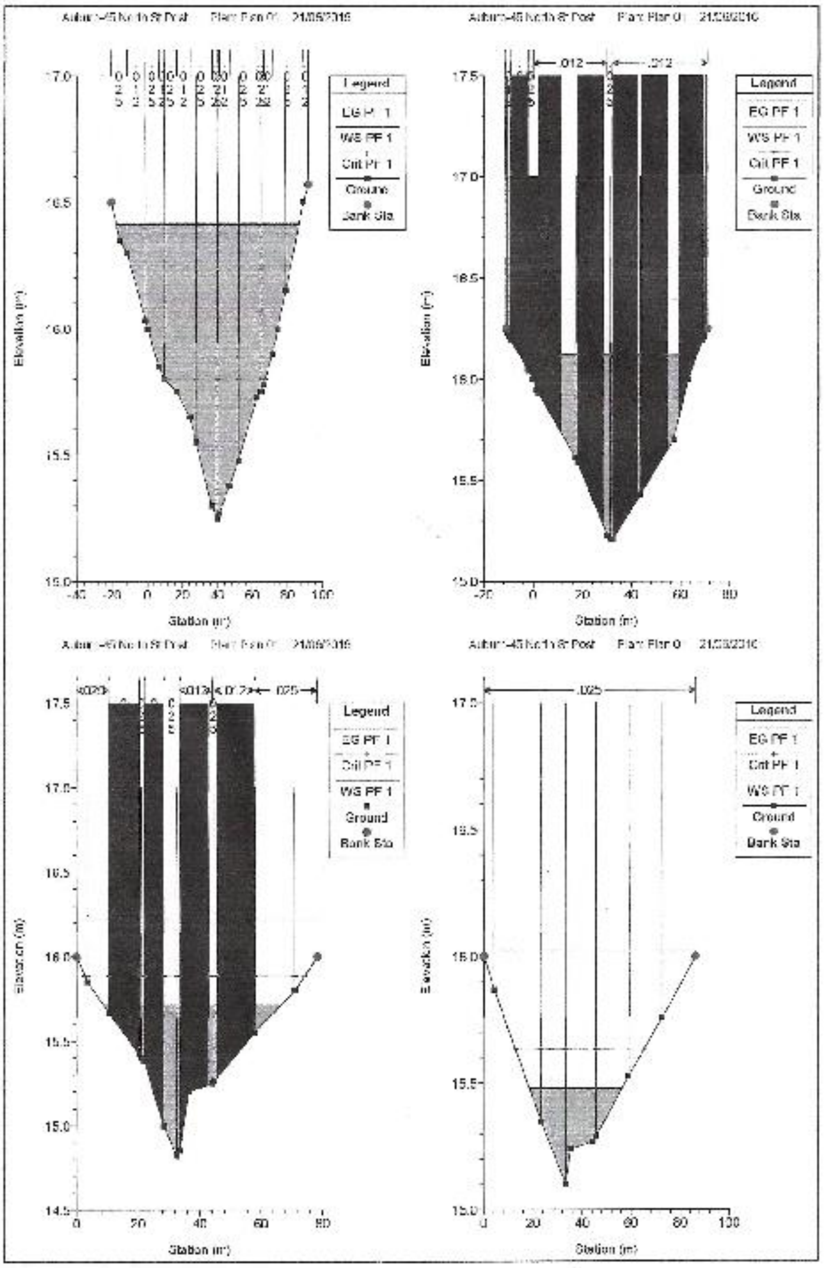


Figure 6. HEC-RAS 4.1.0 cross-sectional outcomes for POST-DEVELOPED stage (www.hec.usace.army.mil/software/hec-ras, 2016)

Table 3. HEC-RAS results with minimum required finished floor levels

PRE-DEVELOPMENT

River Station	Flood Level (m)	Minimum Required Floor Level (m)
4	16.41	-
3	16.11	16.61
2	15.43	-
1	15.52	-

POST-DEVELOPMENT:

River Station	Flood Level (m)	Minimum Required Floor Level (m)
4	16.41	-
3	16.11	16.61
2	15.43	15.93
1	15.52	-

5. CONCLUSION

The main aspects of an urban drainage system consist of property drainage, street drainage, trunk drainage and major water receiving bodies. In most drainage systems, retention and detention basins are also used for flood control and water quality improvement. Several urban drainage models have been developed to simulate the rainfall-runoff process of urban drainage systems. The major components of these models include the modelling of rainfall excess, overland flow routing and pipe routing. Different models use different methods to model these components. Most drainage models calculate rainfall excess using hydrologic methods and this rainfall excess is then routed through the pipe system and other system components using hydraulic methods. However, there are other models where hydrology and hydraulics of the system are lumped together in computing flood hydrographs and/or peak discharges. The choice between the two types of models depends on the type of the catchment to be modelled, the availability of catchment data, the level of complexity and sophistication required in the simulation of the catchment runoff response and time available for the analysis. There has been little advancement with respect to modelling method, although application of GIS has enhanced model visualization aspects. ARR2016 advocates application of Monte Carlo simulation approach for flood hydrograph modelling, which, however, is not practiced as yet in urban flood modelling. Hence, the uncertainty in flood level prediction is not fully assessed with the current deterministic approach.

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Regional Flood Frequency Analysis: Investigation of GEV distribution with L-moments for South East Australia

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Abstract

Identification of an appropriate statistical distribution is a fundamental step in Regional Flood Frequency Analysis (RFFA) that finds the most appropriate distribution to the observed annual maximum flood data and lead to accurate quantile at a single site. Parameter regression technique (PRT) is a regression technique that relates the parameters of a probability distribution (i.e. location, scale and shape to the mean, standard deviation and skewness of the flood data) to catchment characteristics. The Generalised extreme value (GEV) and Log Pearson type III (LP3) distributions have been identified by several studies as the top best-fit distributions in RFFA. However, in Australia, PRT-GEV method has not been tested for RFFA. In this paper, GEV distribution has been investigated and its parameters have been estimated using L-moments for 176 catchments from New South Wales (NSW), 186 catchments from Victoria and 196 catchments from Queensland (QLD). Goodness of fit tests and L-moment ratio diagram were used to examine how GEV can fit the maximum flow data. It has been found that most of the catchments are dominated by negative shape parameters. GEV with L-moments seemed to be good candidate distribution to fit annual maximum flood data for NSW, QLD and VIC.

Keywords: *GEV, Goodness of fit tests, L-moment ratio diagram.*

1. INTRODUCTION

Flood is one of the worst catastrophic natural events that cause deaths of human beings and animals and bring disruptions to services and damages to infrastructure, agricultural lands and properties. Thus, it results in severe economic downturn, e.g. floods in 2010-11 in Australia caused over $30 billion damage to Australian economy (Garrett 2011). Flooding is one of Australia's costliest natural disasters, for example, in Australia, about 1.3 million homes have a flood risk rating and the estimated average annual flood damage is worth over $314 million (Australian Bureau of Statistics 2008).

To reduce flood damage, the planners need to know flood risk at a given location. Design flood estimation is often used for this purpose, which is a flood having a specified exceedance probability. At-site flood frequency analysis is the best method of design flood estimation which needs a long period of recorded flood data to generate meaningful outcomes. However, Australia is a large continent where many catchments have poor/no streamflow data. In such cases, Regional Flood Frequency Analysis (RFFA) is adopted, which is a data-driven procedure that allows estimating design floods at sites with short or no recorded flood data by transferring flood information from gauged to ungauged catchments on the basis of regional homogeneity (Cunnane 1989). In RFFA, flood characteristics information is transferred from gauged to ungauged catchments. RFFA uses data from nearby sites in a defined homogeneous region to analyse flood frequency estimation at ungauged sites of interest and estimate flood quantiles at any site within this region.

Over the years, a large number of RFFA techniques have been developed around the world, with different assumptions, data requirements, and limitations. Currently, there is no universal RFFA approach that has been adopted across the world and most of them are associated with a high degree of error (Haddad and Rahman 2012a; Haddad et al 2012b). Therefore, the development of new and more accurate RFFA approaches are desirable to design more flood-safe infrastructures that will reduce flood damage by allowing passage of flood water safely.

An RFFA method consists of three major steps: (1) data preparation; (2) identification of homogeneous regions; and (3) regional estimation of flood quantiles at the site of interest. Many RFFA procedures have been used and tested in different countries in the world (e.g. Cunnane 1988; Rahman et al 1999; Micevski and Kuczera 2009; Haddad et al 2011a, b; Rahman et al 2011). Some of the most commonly adopted RFFA methods in practice include the Index Flood Method (IFM) (Dalrymple 1960; Hosking and Wallis 1993; Rahman et al 1999; Ishak et al 2011 and Zaman et al 2012b) which assumes that the flood frequency distribution at sites within a homogeneous region is identical except for the scale factor. Recent studies have shown more accurate quantile estimates when combining IFM with probability weighted moments (PWMs) or L-moments. Another method, the Probabilistic Rational Method (PRM) (Mulvaney 1851; I.E. Aust. 1987; Rahman et al 2008; Pirozzi et al 2009) was recommended in south-east Australia for design flood estimation in small to medium-sized ungauged catchments in ARR 1987. Researchers have criticised the PRM because of the assumption of geographical contiguity, the mapping and application of the runoff coefficients.

Recently, several regression-based methods have been adopted for example, Quantile regression technique (QRT) (Rahman 2005; Haddad et al 2006, 2008, 2009) and parameter regression technique (PRT) (Hackelbusch et al 2009; Haddad et al 2012; Micevski et al 2015; Rahman et al 2015a). The QRT is a regression technique that relates flood quantiles to catchment characteristics. However, the PRT is another regression technique that relates the parameters of a probability distribution (i.e. location, scale and shape to the mean, standard deviation and skewness of the flood data) to catchment characteristics assuming linearity. The advantages of both the QRT and PRT are that they neglect the assumptions made by PRM and IFM. Also, there have been few studies comparing the PRT with the QRT in RFFA (Haddad and Rahman 2012; Haddad et al 2012; Haddad et al 2015a and Ahn and Palmer 2016). The advantages of PRT over the QRT are that by using PRT, flood quantiles increase with ARIs, any at-site information can be accounted for regional estimates method and flood quantiles can be estimated for any given ARI. At present, the IFM and the regression-based methods are the most commonly used RFFA techniques.

Recently, Rahman et al (2015) upgraded the Regional Flood Frequency Estimation (RFFE) method in Australian Rainfall and Runoff (ARR) (the national guide) as a part of ARR Project 5 Regional Flood Methods. In Australia, PRT-GEV method has not be tested in RFFA. Therefore, this paper aims to investigate the appropriateness of the one most commonly adopted distribution in Australia, the Generalised Extreme Value (GEV) for South East Australia and compare its results with the Log Pearson type III (LP3) in intention to propose additional recommendations to enhance the accuracy of RFFE in Australia

2. STUDY AREA AND DATA

A total of 176 catchments have been selected from New South Wales (NSW), 186 catchments from

Victoria and 196 catchments from Queensland (QLD) from Australian Rainfall and Runoff (Project 5). The geographical distribution of the selected 196 catchments is shown in Figure 1. The record lengths of annual maximum flood series of these 558 stations range from 20 to 102 years. The catchment areas of the selected catchments range from 1 km^2 to 1,036 km^2.

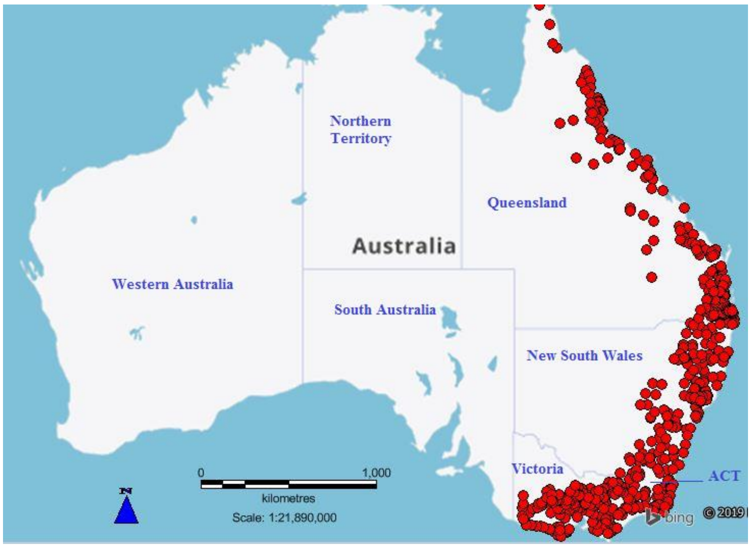

Figure 1. Geographical distributions of the selected catchments in Queensland, Victoria and NSW, Australia

3. METHODOLOGY

3.1. Selection of Flood Frequency Distributions

The selection of best fit flood frequency distribution and associated parameter estimation method is a principal step in at-site and RFFA. There have been a number of studies comparing several probability distributions. In Australia, the GEV and LP3 distribution have been identified in several studies as the top best-fit distributions in RFFA (Haddad et al 2008; Rahman et al 2013; Ahn and Palmer 2016). Goodness of fit tests and L-moment ratio diagram are frequently used to examine how candidate distributions fit the maximum flow data. For the parameter estimation techniques, MLE and L moments have been considered as robust methods and preferable in most studies.

3.1.1 Log Person type III (LP3) distribution

The LP3 distribution is one of the most frequently used distributions for frequency analysis of hydrologic extremes. Its PDF and CDF can be expressed as below:

PDF: $$f(x) = \frac{1}{\alpha x \Gamma(\kappa)} \left\{ \frac{\ln(x) - \mu}{\alpha} \right\}^{\kappa - 1} \exp\left\{ -\frac{\ln(x) - \mu}{\alpha} \right\} \quad (1)$$

CDF: $$F(x) = \frac{1}{\Gamma(\kappa)} \int_0^{\frac{\ln(x)-\mu}{\alpha}} \exp\left\{ -\frac{\ln(x) - \mu}{\alpha} \right\} d\left(\frac{\ln(x) - \mu}{\alpha}\right) \quad (2)$$

where *Γ*= the gamma function; *μ* is the location parameter; *α* the scale parameter; and *κ* the shape parameter which are based respectively on the mean, variance and skewness of the data.

3.1.2 Generalised Extreme Value (GEV) distribution

GEV distribution is a continuous probability distribution introduced by Jenkinson (1955) and widely used for flood frequency analysis. GEV has 3 parameters: location, scale and shape. The Probability Density Function (PDF) and Cumulative Density Functions (CDF) are defined in Hosking (1990) as:

PDF : $$f(x) = \frac{1}{\alpha}\left[1 - \frac{\kappa(x-\mu)}{\alpha}\right]^{\frac{1-\kappa}{\kappa}} \exp\left\{-\left[1 - \frac{\kappa(x-\mu)}{\alpha}\right]^{1/\kappa}\right\} \quad (3)$$

$$1 - \frac{\kappa(x-\mu)}{\alpha} > 0+$$

CDF: $$F(x) = \exp\left\{-\left[1 - \frac{\kappa(x-\mu)}{\alpha}\right]^{1/\kappa}\right\} \quad (4)$$

where μ is the location parameter, α the scale parameter, and κ the shape parameter which are based respectively on the mean, variance and skewness of the data.

3.2. Parameter Estimation Techniques

The parameter regression technique regionalises the first three moments of the GEV distribution. The selection of parameter estimation method is an important step to fit the probability distribution to the selected annual maximum flood data. A number of methods can be used for parameter estimation (such as Method of Moments (MOM); Maximum Likelihood Estimates (MLE) and L-moments). These methods have been the subject of many research studies: MOM (Haddad and Rahman 2011; Rahman et al 2013; Haddad et al 2015a); MLE (Martins and Stedinger 2000; Katz et al 2002; Haddad and Rahman 2011; Rahman et al 2013); L-moments (Hosking and Wallis 1993; Saf 2009; Rahman et al 2013; Haddad et al 2015b). L-moments and MLE method are the best among the three methods. Therefore, L-moments is used in this proposed research as parameter estimation techniques for GEV distribution for RFFA.

3.2.1 Probability Weighted Moments (PWMs) Equations

PWMs are required for the calculation of L-Moments. After arranging the data in ascending order, following equations can be applied (Cunnane 1989).

$$M_{100} = \text{sample mean} = \frac{1}{N}\sum_{i=1}^{N} Q_i \quad (5)$$

$$M_{110} = \frac{1}{N}\sum_{i=1}^{N} \frac{(i-1)}{(N-1)} Q_i \quad (6)$$

$$M_{120} = \frac{1}{N}\sum_{i=1}^{N} \frac{(i-1)(i-2)}{(N-1)(N-2)} Q_i \quad (7)$$

$$M_{120} = \frac{1}{N}\sum_{i=1}^{N} \frac{(i-1)(i-2)(i-3)}{(N-1)(N-2)(N-3)} Q_i \quad (8)$$

in which *N* is the sample size, *Q* is the annual maximum flood data value and *i* is the rank of the value in ascending order.

3.2.2 Method of L-Moments:

The following L-Moments equations are defined from Cunnane (1989):

$\lambda_1 = L_1 = M_{100}$ (9)

$\lambda_2 = L_2 = 2M_{110} - M_{100}$ (10)

$\lambda_3 = L_3 = 6M_{120} - 6M_{110} + M_{100}$ (11)

$\lambda_4 = L_4 = 20M_{130} - 30M_{120} + 12M_{110} - M_{100}$ (12)

The 4 L-Moments (λ_1, λ_2, λ_3, λ_4) are all derived using the 4 PWMs.

The L-moment ratios are *L-CV* (τ_2), L-Skewness (τ_3) and L-Kurtosis (τ_4)

L-CV is similar to the normal coefficient of variation (*CV*). The standard equation for $CV = \frac{standard\ deviation}{mean}$, and shows how the data set varies. The larger the *CV* value, the larger the variation of the data set from the mean.

The L-moment ratios equations defined by Hosking (1990) are as follows:

$$L-CV = \tau_2 = \lambda_2 / \lambda_1 \quad (13)$$

$$L-Skewness = \tau_3 = \lambda_3 / \lambda_2 \quad (14)$$

$$L-Kurtosis = \tau_4 = \lambda_4 / \lambda_2 \quad (15)$$

PRT-GEV

As stated, the GEV distribution uses three parameters: μ is the location parameter, α is the scale parameter and κ is the shape parameter. The parameters are defined from Hosking (1997) as:

$\kappa = 7.8590c + 2.9554c^2$ (16)

in which $c = \frac{2}{3+\tau_3} - \frac{ln2}{ln3}$ (17)

$\alpha = \frac{\lambda_2 \kappa}{(1-2^{-\kappa})\Gamma(1+k)}$ (18)

$\mu = \lambda_1 - \alpha[1-\Gamma(1+\kappa)]/\kappa$ (19)

in which Γ = the gamma function

Once all parameters have been estimated, calculation of the *T*-year flood quantile (Q_t) can be done using:

$Q_t = \mu + (\frac{\alpha}{\kappa})[1 - (-log\left(\frac{T-1}{T}\right))^{\kappa}]$ (20)

in which *T* is the desired return period in years.

3.3. Goodness of fit Tests

A total of three goodness of fit tests has been adopted to evaluate the appropriateness of the GEV probability distributions.

3.3.1 Chi-Squared Test

The Chi-Squared (CS) test is used to determine if a sample comes from a specific distribution. The CS statistic is defined as:

$$\chi^2 = \sum_{i_C=1}^{k_C} \frac{(O_i - E_i)^2}{E_i} \tag{21}$$

Where, O_i is the observed frequency; N= sample size;

$$k = 1 + log_2 N \tag{22}$$

E_i is the expected frequency calculated by: $E_i = F(x_1)\text{-}F(x_2)$ (23)
Where F is the CDF for the distribution being tested; x_1 and x_2 are the limits for the class interval i.

3.3.2 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov (KS) test statistic is based on the greatest vertical distance difference between the empirical and theoretical CDFs. Similar to the AD test statistic, the hypothesis regarding the distributional form is rejected if the test statistic is greater than the critical value at a chosen significance level.

The test statistic ($D_{\max}$) is defined as:

$$D_{\max} = \max_{1\le i\le N}\left(F(x_i) - \frac{i-1}{N}, \frac{i}{N} - F(x_i) \right) \tag{24}$$

Where N is the number of observations; $x_1, x_2, \ldots, x_n$ are the observations; and $F(x)$ is the CDF.

3.3.3 Anderson-Darling (AD) Test

The Anderson-Darling is a general test that compare an observed cumulative distribution function (CDF) to an expected CDF.

The AD statistic is defined as (A^2). If A^2 is greater than a given critical value at a given significance level (α), then the hypothesis regarding the distribution level is rejected. The critical values for a significance level α =0.05 is 2.492 and for α =0.01 is 3.857

$$A^2 = -n - \frac{1}{n} \sum_{n=1}^{n} (2i - 1)[lnF\,(x_i) + \ln(1 - F(x_{n-i+1}))] \tag{25}$$

Where n is the number of observations; $x_1, x_2, \ldots, x_n$ are the observations in ascending order; and $F(x)$ is the empirical CDF.

4. RESULTS AND DISCUSSION

We applied GEV distribution on the 558 catchments of NSW, QLD and VIC using L-moment parameter estimation. Tables 1, 2 and 3 show the results of the three parameters (location, scale, shape) of the GEV distribution estimated for 10 sample stations in NSW, QLD and VIC. Then the quantiles for ARIs of 2, 5, 10, 20, 50, 100, 200 and 500 years are estimated (Tables 4, 5 and 6).

Table 1. Estimated parameters of GEV (NSW)

Station	Shape	Scale	Location
201001	-0.11032	285.0401	276.8188
201005	0.122392	246.5891	325.809
202001	-0.09143	62.38325	57.97
203002	0.160862	136.1038	155.9788
203005	-0.30117	313.4997	254.0551
203010	-0.0789	226.0066	189.462
203012	-0.16758	66.35656	75.35104
203014	-0.06752	107.9913	117.0828
204008	-0.35594	17.8011	19.63872

Table 2. Estimated parameters of GEV (QLD)

Station	Shape	Scale	Location
102101	-0.11469	498.6207	653.655
104001	-0.11355	263.7579	386.7883
105105	0.078249	153.7188	211.1932
105106	-0.31405	238.9422	268.514
107001	-0.31729	139.9561	182.0864
107002	0.439368	247.4927	632.8251
108002	-0.01566	533.1769	949.9638
108003	0.01483	339.9102	604.51
108008	-0.0099	55.34414	70.20483

Table 3. Estimated parameters of GEV (VIC)

Station	Shape	Scale	Location
221201	-0.2056	50.51003	40.02696
221207	-0.24835	26.42852	27.07371
221208	-0.30022	55.05186	37.75819
221209	-0.08873	40.99384	32.5162
221210	-0.16257	230.0129	182.7176
221211	-0.19108	31.93397	29.50137
221212	-0.32597	96.11347	85.72128
222202	-0.22749	90.05096	75.37519
222206	-0.31829	48.10473	45.36022

Table 4. Flood quantiles for different ARIs for example of sites in NSW

Station	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q500
201001	383.43	741.77	1004.90	1278.63	1666.79	1984.97	2327.32	2821.12
201005	414.19	663.71	810.86	939.87	1090.83	1193.19	1286.84	1398.79
202001	81.22	158.26	213.84	270.86	350.47	414.73	482.96	579.89
203002	204.42	337.36	412.95	477.36	550.40	598.38	641.12	690.66
203005	375.54	848.47	1263.17	1759.45	2584.30	3373.24	4342.86	5976.11
203010	273.51	549.33	746.00	945.92	1222.13	1442.84	1675.18	2001.87
203012	100.43	188.51	256.74	330.76	440.83	535.35	641.19	801.10
203014	157.16	287.55	379.54	472.26	599.18	699.65	804.59	950.79
204008	26.61	54.92	81.04	113.58	170.19	226.77	299.02	426.28

Table 5. Flood quantiles for different ARIs for example of sites in QLD

Station	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q500
102101	840.30	1469.74	1933.85	2418.18	3107.50	3674.55	4286.55	5172.40
104001	485.50	818.10	1063.07	1318.51	1681.72	1980.22	2302.13	2767.65
105105	266.73	428.75	528.37	618.59	728.08	805.04	877.66	967.61
105106	361.33	726.30	1050.17	1441.43	2098.77	2734.04	3521.85	4862.88
107001	236.48	450.93	641.79	872.92	1262.29	1639.56	2108.48	2908.80
107002	716.61	904.70	986.55	1043.37	1094.68	1121.48	1141.14	1159.38
108002	1145.94	1759.16	2171.19	2571.00	3095.25	3493.14	3893.93	4429.41
108003	728.75	1108.73	1356.81	1592.20	1893.17	2116.00	2335.74	2622.19
108008	90.53	153.84	196.15	237.03	290.38	330.68	371.12	424.89

Table 6. Flood quantiles for different ARIs for example of sites in VIC

Station	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q500
221201	59.25	128.77	184.56	246.80	342.33	426.92	524.18	675.75
221207	37.21	75.11	106.75	143.17	201.11	254.21	317.11	418.61
221208	59.09	142.06	214.75	301.69	446.06	584.04	753.52	1038.76
221209	47.79	98.28	134.62	171.83	223.65	265.40	309.64	372.35
221210	269.58	573.42	807.70	1060.93	1435.95	1756.65	2114.51	2653.02
221211	41.63	84.97	119.29	157.17	214.62	264.89	322.12	410.25
221212	123.14	271.65	404.89	567.27	842.81	1111.67	1447.86	2025.73
222202	109.80	236.35	340.01	457.52	641.21	806.76	1000.04	1306.65
222206	64.06	137.84	203.57	283.22	417.51	547.74	709.71	986.38

Shape parameter has a critical significance for GEV distribution as it controls the behaviour of the upper tail of the distribution. The GEV distribution belongs to one of the three families of extreme value distribution (EV1 (Gumbel), EV2 (Fre´chet), or EV3 (Weibull) distribution, when the value of the shape parameter is equal to zero, has a negative value, or positive value respectively, Therefore, it is important to examine whether the value of the shape parameter is 0 or not. Figure 2 shows the results of the shape parameter of the GEV distribution for NSW, QLD and Victoria. As we can see most of the catchments are dominated by negative shape parameters.

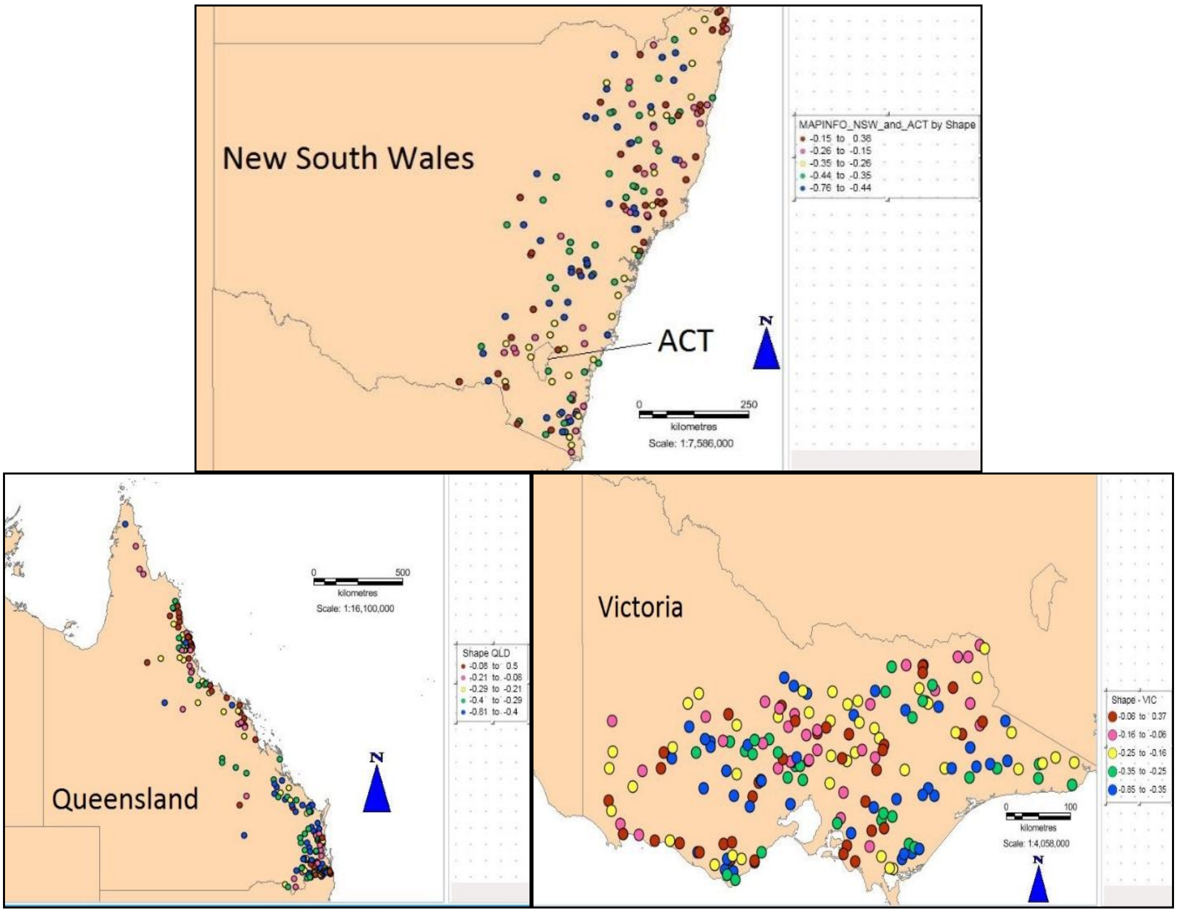

Figure 2. Results of the shape parameter of the GEV distribution for NSW, QLD and Victoria

4.1. Goodness of fit tests

Based on goodness-of-fit tests (i.e. Kolmogorov–Smirnov test, Anderson–Darling test and Chi-square test), Zaman et al (2012a) found that LP3 is the best-fit distribution for NSW, QLD and generalised pareto (GPA) is the best-fit distribution for VIC. Table 7 summarises the results from goodness of fit test of GEV distribution with L-moments for NSW, QLD and VIC. We can see the number of stations where the hypothesis regarding the distributional form is not rejected at the chosen significance level. Table 8 shows the results from goodness of fit test of GEV and LP3 distribution with Maximum likelihood estimation (ML) for VIC. Therefore, the application of different parameter estimation methods can affect the results of the goodness of fit test.

Table 7. Results of GOF for GEV with L-moments

GEV with L-moments			
	AD	**CS**	**KS**
NSW	26	52	63
QLD	63	141	120
VIC	73	169	147

Table 8. Results of GOF for LP3 and GEV with ML estimation

ML estimation						
VIC	**AD**		**CS**		**KS**	
	Rank 1	Rejected	Rank 1	Rejected	Rank 1	Rejected
LP3	108	2	86	23	99	2
GEV	78	-	100	-	87	-

4.2. L-Moment Ratio Diagram

L-moment ratio diagram is the method used to measure how candidate distributions fit the maximum flood data. It has been used for regional distribution identification and testing outlier stations in many recent studies (e.g. Rahman et al 2013; Mamoon, et al 2014; Ahn and Palmer 2016; Komi et al 2016). L-moment Ratio Diagram is a simple diagram plotting L-kurtosis (τ_4) versus L-skewness (τ_3) of the sample data and comparing these values against the theoretical curves of commonly used distributions such as log-normal 2 (LN), GEV, Pearson 3 (P3), generalised logistic (GLO) and generalised pareto (GPA) (Hosking and Wallis 1997).

Figures 3, 4 and 5 illustrate the L-moment ratio diagrams for the annual maximum flood data for the states of NSW, QLD and VIC respectively. As shown in the Figures, it is obvious that each annual maximum flood series have different parent distribution (for example the average point falls on GPA curve in case of NSW and on P3 curve in case of QLD and VIC). Therefore, a single distribution cannot be specified as the best-fit distribution for the studied Australian states. Also, GEV and P3 seem to be good candidate distributions to fit annual maximum flood data for NSW, QLD and VIC.

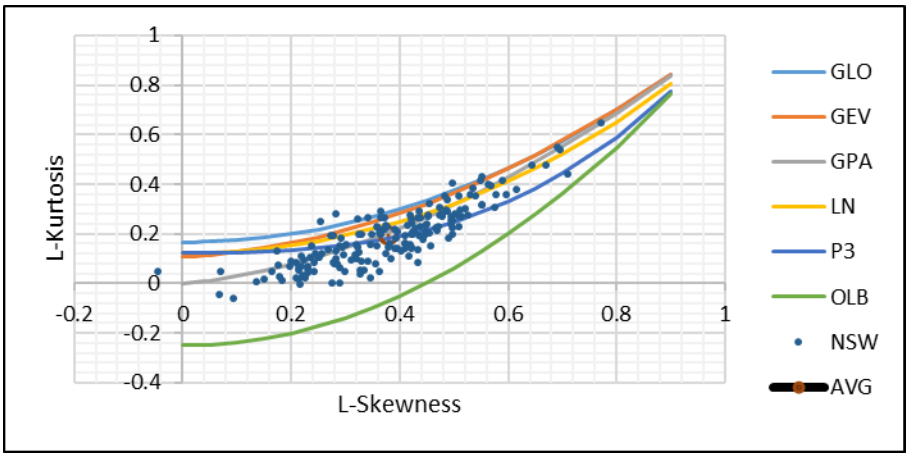

Figure 3. L-moment ratio diagram for NSW and ACT catchments

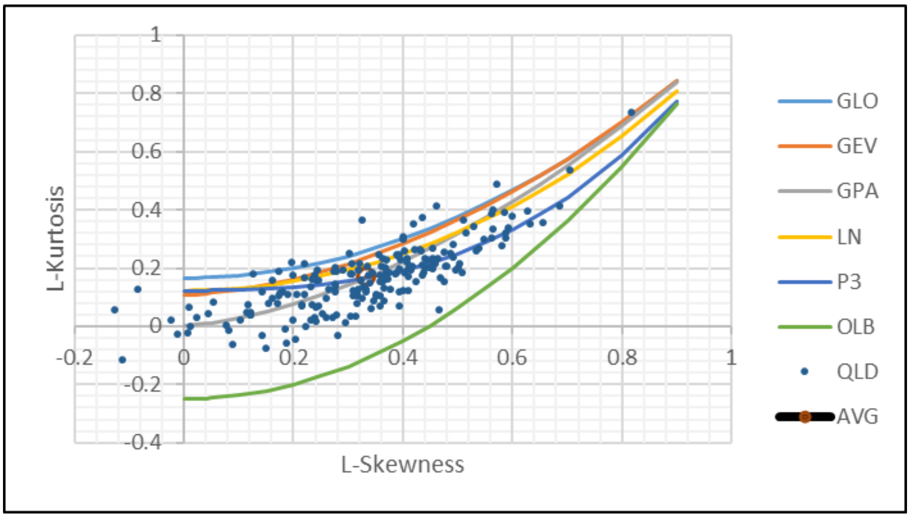

Figure 4. L-moment ratio diagram for QLD catchments

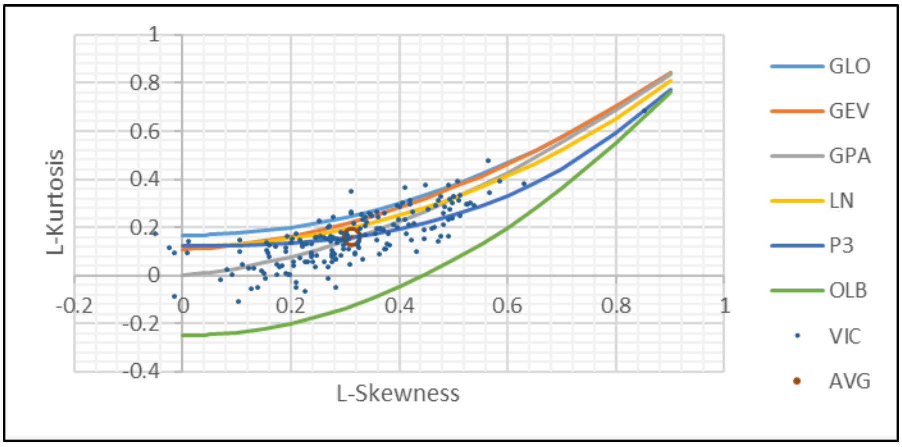

Figure 5. L-moment ratio diagram for VIC catchments

5. CONCLUSIONS

This paper investigates GEV distribution using L-moments. Shape parameter has negative values in most of the catchments. A total of three goodness-of-fit tests were adopted i.e. Anderson-Darling test (AD), Chi-Squared (CS) and Kolmogorov-Smirnov test (KS) to identify whether GEV can fit the maximum flow data.

The goodness-of-fit tests results indicate that the best fit distribution varies from station and to station, and no single distribution can be ranked constantly the best for all. Furthermore, results are also affected with the application of different parameter estimation methods. Furthermore, the L-moments ratio diagram is used to make a visual assessment. It has been found that a single distribution cannot be specified as the best-fit distribution for the studied Australian states. GEV with L-moments seem to be good candidate distribution to fit annual maximum flood data for NSW, QLD and VIC.

The methodology developed in this paper must continue for developing of regional prediction equations and validating of the regional model and also should examine the relationship of the shape parameter with catchments characteristics attributes.

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An Investigation of Small Scale Rainfall Induced Landslide Identification Using Remote Sensing and GIS Analysis- A Case Study of Bangladesh

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Abstract

Remote Sensing (RS) and Geographic Information System (GIS) methods can be employed for identifying and mapping landslides for quick and effective results avoiding time consuming physical studies. Currently, landslide identification mainly covers large scale mountainous landslides, while small scale shallow landslides in relatively plain lands are still overlooked. The processes and techniques involved in such studies are also developed based on large scale landslides. This necessitates carrying out similar studies based on small scale shallow landslides. This study focuses on rainfall induced shallow landslides that occurred in Cox's Bazar district of Bangladesh during 14-15 June 2010. The study adapts common techniques and methods involved in landside studies and apply them to small scale landslides. The identification was conducted using 2D visualization of high-resolution image and semi-automatic recognition of medium resolution images. A novel method of integrating manual interpretation and semi-automatic results was used to obtain a final landslide inventory. The validation of the model was conducted using actual landslide events of June 2010 where validation results revealed a high degree of landslide prediction represented by success rate curve and associated Area Under Curve (AUC) value of 0.8913. The validity of predictive model prove the efficiency of the method and justify their use for rainfall induced shallow landslides.

Keywords: Rainfall, small scale landslides, remote sensing, GIS, identification, Bangladesh.

1. INTRODUCTION

Landslides represent approximately 9% of all the natural disasters occurring worldwide over last few decades (Yilmaz 2009). Every year numerous landslides occur in various parts of the world causing thousands of deaths and material losses worth of billions of dollars (Brabb 1991 cited in Yilmaz 2009). There were 2,620 fatal landslides recorded worldwide during 2004-2010 resulting in 32,322 fatalities; this translates to 4,617 fatalities every year (Petley 2012). The hazardous effects of landslides necessitate a great deal of disaster management and response effort. The mitigation of landslide risk largely depends on landslide risk assessment and susceptibility mapping to decide appropriate control measures (Dai et al. 2002). The prime requirement of deciding appropriate control measures is landslide identification where landslide inventory is not available.

Traditionally, landslide inventories were created from physical surveys of the location is time consuming and often unmanageable due to the difficult terrain in they occur. Moreover, physical collection of landslide information from the ground requires a good budget and resources which are often not available. This necessitated the development of the concept of extracting landslide information from remote sensing data. Remote sensing (RS) and Geographic Information System (GIS) methods have been employed to study landslides for quick and effective results avoiding hassles of physical data collection efforts and time. Generally, landslide detection using RS data largely involved for large scale mountainous landslides where as small scale landslides occurred in relatively plain land is still overlooked. Recent studies (Petley 2012) have shown that loss of life due to landslides is concentrated in less developed countries where even small scale landslides can have catastrophic impacts on people and property. This study therefore, focuses on rainfall induced shallow landslides that occurred in Cox's Bazar district of Bangladesh during 14-15 June 2010.

Landslide extraction studies involve creating 'landslide inventory' through manual interpretation and semi-automatic/automatic detection process and thereafter, its validation through physical field surveys. The methods and techniques involved in large scale landside studies can be standardized and apply them to study small scale landslides. However, the trigger mechanism and the scale of landslides (large or small) will dictate the resolution and type of RS data to be used for a particular study. Therefore, high or medium resolution image is necessary to study small scale landslides.

This paper presents how to identify small scale landslides from high and medium resolution RS imagery. To minimise the scope of this research, the identification is limited to manual visual interpretation, image indices difference and post classification Image difference. The ultimate objective of the study is to develop a model for identifying small scale landslides combining manual and semi-automatic process of RS data.

2. LANDSLIDES DETECTION USING REMOTE SENSING – AN OVERVIEW

There have been many studies carried out on landslide extraction using RS and GIS analysis (Lin et al. 2002; Hervás et al. 2003; Cheng et al. 2004 ; Rosin and Hervás,2005; Weirich and Blesius, 2007; Chiang & Chang 2009; Yilmaz 2009; Martha et al. 2010; Tsai et al. 2010; Mondini et al. 2011). Keefer (2002, cited in Rathje, 2009, p.3) states that 'landslide mapping using aerial photography was probably first used after the 1948 magnitude 7.3 Fukri, Japan earthquake'.

Beside aerial photography, satellite images were solely used to identify and map landslides by several investigators (Lin et al. 2002; Hervás et al. 2003; Cheng et al. 2004 ; Rosin and Hervás, 2005; Metternicht et al. 2005; Barlow et al. 2006; Lee and Lee, 2006; Martha et al. 2010; Tsai et al. 2010). Joyce et al. (2009) demonstrated the feasibility of using only optical data. The study claims optical data provides the best results due to spatial resolution and look angle. Therefore, we find a wide variety of studies based on RS optical satellite imagery.

Several studies provide evidence that, earthquake induced landslides are more suitable for remote sensing study (Harp & Jibson 1996; Petley et al. 2002; Bajracharya & Bajracharya 2008; Rathje, 2009; Ren & Lin, 2010). However, Mondini et al.(2011) presented a method for recognition and mapping of rainfall induced shallow landslides. Rathje (2009, p.3) states that 'the study of earthquake-induced landslides typically involves the use of aerial photography, ground observations, and more recently, satellite imagery and GIS information'. Similar approaches can also be applied for studying small scale rainfall triggered landslides (Dai & Lee, 2003; Santacana et al. 2003; Mondini et al. 2011).

Traditionally, landslide detection using RS data largely involved manual visual interpretation which has been proven most successful for large scale landslides. Several automated processes involving image differencing based on band ratios, indices (Cheng, Wei, & Chang 2004; Rau et al. 2007; Mondini et al. 2011) and image classification based on supervised, unsupervised, object oriented classification (Nichol & Wong, 2005; Dymond et al. 2006; Joyce, Dellow, & Glassey 2008; Martha et al. 2012) have been also used for such study. All these processes involve semi-automatic or automatic change detection process to identify landslides. However, the trigger mechanism and the scale of landslides (large or small) will dictate the resolution and type of RS data to be used for a particular study (Corominas et al. 2013). Moreover, there is no well-established technique to study shallow landslides. Therefore, a study of shallow landslides may provide a suitable approach for identifying small scale landslide from remote sensing optical data.

3. STUDY AREA AND METHODOLOGY

The study area encompasses the Cox's Bazar Municipality area and its surroundings, which is a part of the Cox's Bazar Sadar Upazila (Admin Area) and bounded by northern latitude 21º23'- 21º28' and eastern longitudes 91º56'- 92º02'. The study area falls within Chittagong Hill Tracts (CHT) region of Bangladesh as shown in Figure 1. The study area has suffered numerous shallow landslides in the recent past, which are quite small in comparison to large scale mountainous landslides.

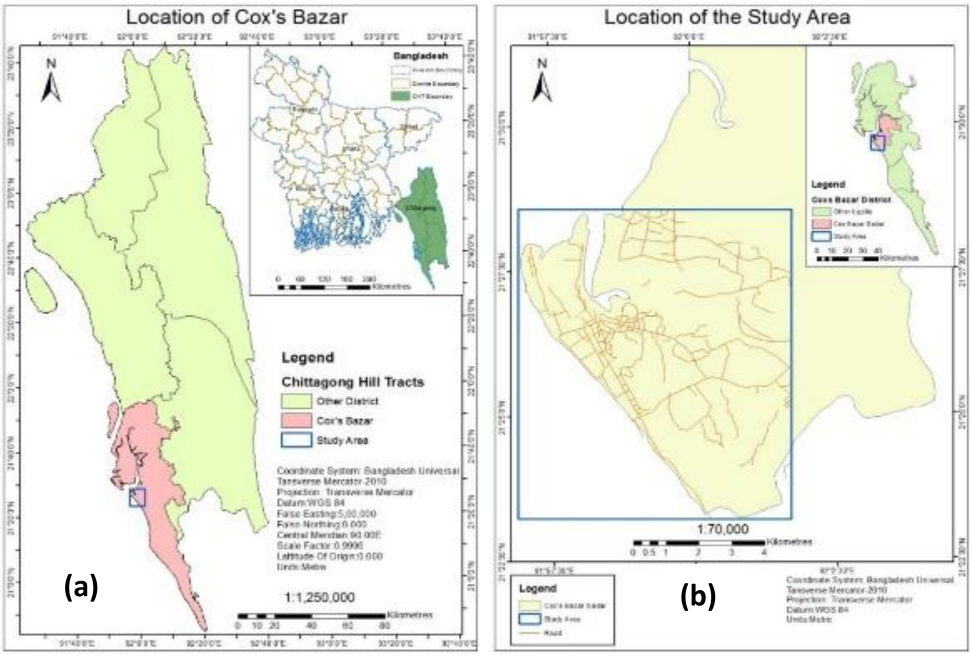

Figure 1. (a) Location of Cox's Bazar District in CHT region of Bangladesh (b) Location of the study area

The study of the geology, monthly rainfall data (Figure 2) and history of landslide occurrences suggests that, the landslides of the region has no relation with earthquake, rather with slope instability and rainfall intensity. This study is specifically based on the landslides which occurred during 2010 monsoon. The landslides were shallow in nature and covered very small areas ranging from 30-250m^2 which can be termed as rainfall induced shallow landslides.

This study aims to identify the rainfall induced shallow landslides from optical satellite images. This requires two sets of images before and after the event to identify the temporal change through manual interpretation or an automatic change detection process. Since, the landslides are shallow in nature and cover very small areas ranging from 30-250m^2; high resolution (HR) images are required to extract them. Accordingly, two sets of SPOT-5 image and one set post event HR World View-2 (WV-2) image were obtained. Since only post event WV-2 HR is available, it could not be used for semi-automatic change detection. Therefore, the WV-2 images were selected for manual visual interpretation and multi-temporal SPOT-5 images were selected for semi-automatic change detection.

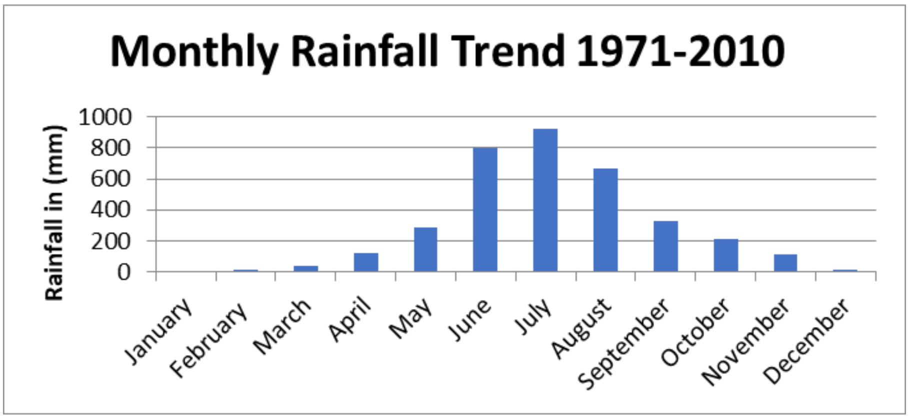

Figure 2: Monthly rainfall trends of Cox's Bazar district based on 1971-2010 data (Bangladesh Metrological Department, 2015)

The methodology of the identification involves both manual and semi-automatic processes. Manual process involves 2D visualization of WV-2 data and change detection with Google Earth to obtain a landslide inventory. On the other hand, semi-automatic processes involve SPOT-5 image processing which include various indices calculation and image differencing, unsupervised classification and post classification comparison and finally creating a combined changed map. A novel method of integration is used of combine manual and semi-automatic changed map to create a verified landslide inventory. The identified landslides are validated using a truth data of actual landslide inventory, which was obtained from ground survey. The methodology flow chart is given in Figure 3.

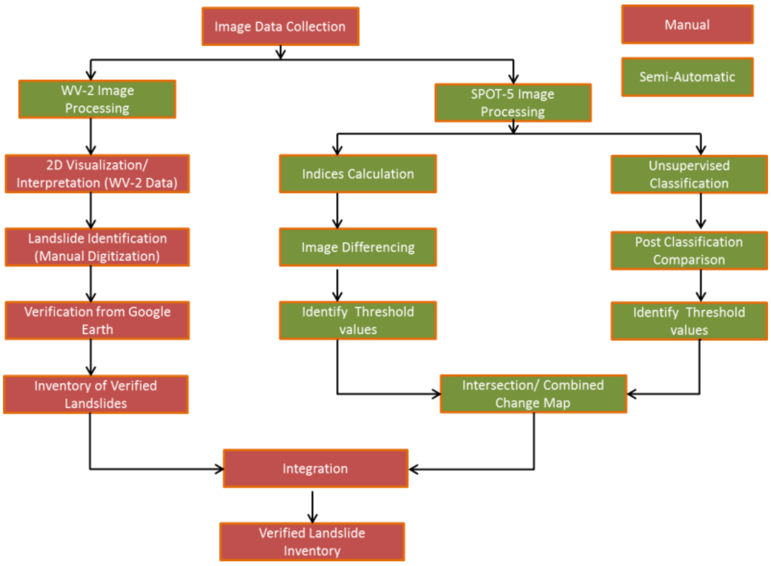

Figure 3. Flow diagram for landslide identification and inventory preparation.

4. RESULTS AND DISCUSSION

Manual identification of landslides was conducted using visual interpretation of WV-2 image. The identification tends to find out the areas having sign of vegetation removal and was digitized manually. The manually identified landslides were verified from pre-event Google Earth® image. The verified landslides were kept after removing the data not verified from Google Earth®. Thus a potential landslide inventory was obtained through manual 2D visualization, which is shown in Figure 4.

SPOT-5 image processing is conducted to calculate various indices as a part of semi-automatic process. Image algebra change detection was performed for two indices: NDVI and SAVI. The difference image showing only vegetation change was initially obtained. To predict the potential landslide locations, the difference image was further filtered using number of iterations and obtained the threshold image. The threshold values obtained for NDVI was -0.287 to -0.106 and for SAVI -0.4 to -0.25. The threshold value images for two indices are considered as the result of image algebra showing potential landslide locations as in Figure 5.

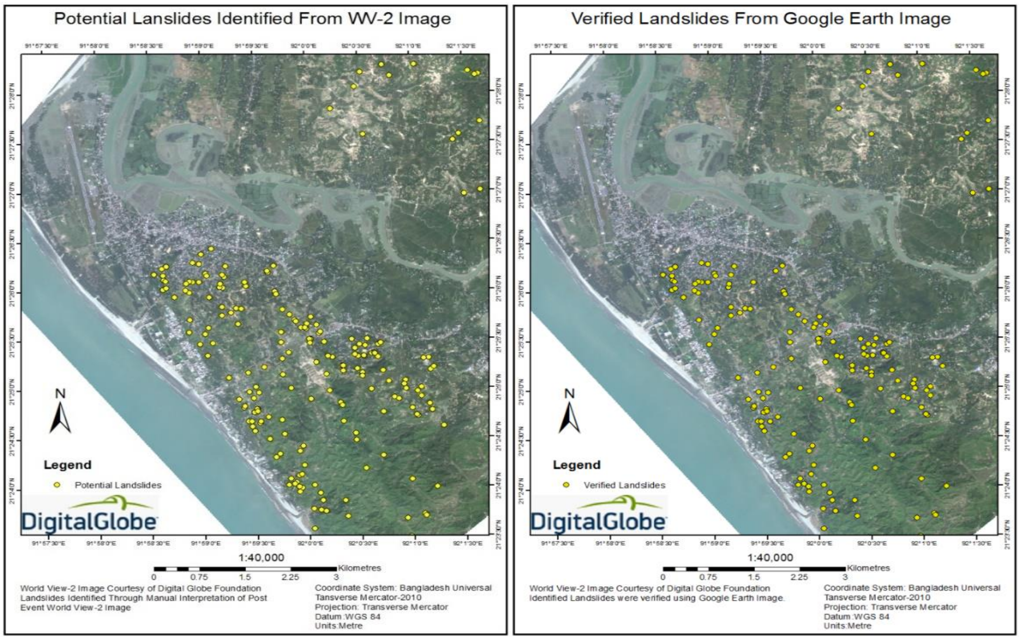

Figure 4. Potential landslides identified from WV-2 Image and Verified landslides from Google Earth Image.

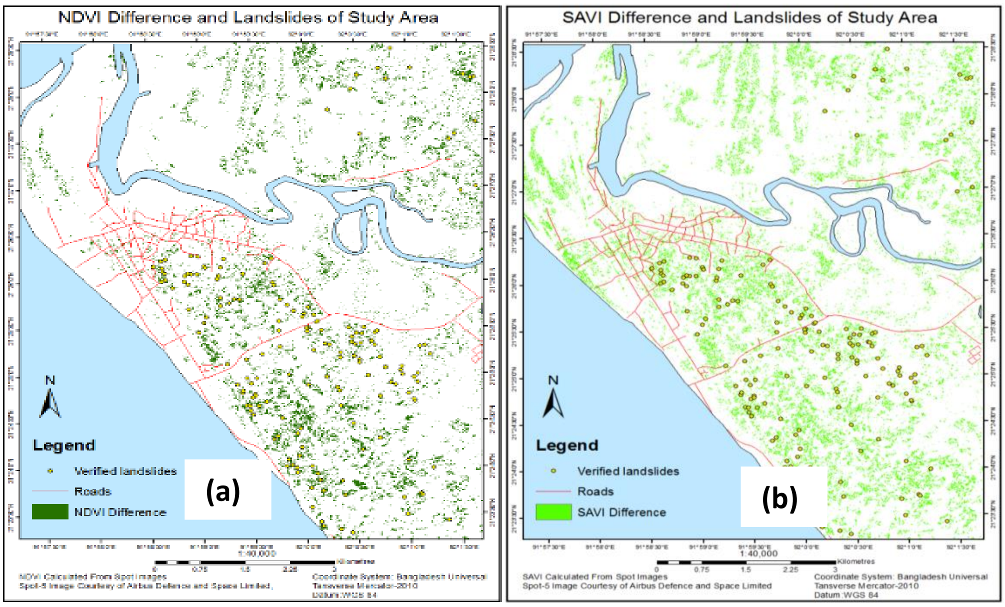

Figure 5: NDVI and SAVI Threshold value image and verified landslides.

Second phase of semiautomatic process involves post classification comparison based on unsupervised classification of SPOT-5 image sets. Results in obtaining a changed map showing change mainly in vegetation and suburban areas. The threshold value of this changed map is likely to provide potential location of landslides as shown in Figure 6 (a). The results obtained from three changed maps show likelihood of potential landside based on respective indices difference. Finally, a combined changed map (Figure 6b) was prepared using common areas of all three results. This result was considered as the outcome of semi-automated process which might be taken as more reliable potential landslide locations.

The final landslide inventory was created by integrating manual and semi-automated results. The landslides which are common in both manual and semi-automatic process are kept in the final inventory map as shown in Figure 7. The final landslide inventory contains total 143 landslides with minimum area of 27.64 m^2 to maximum area of 612 m^2.

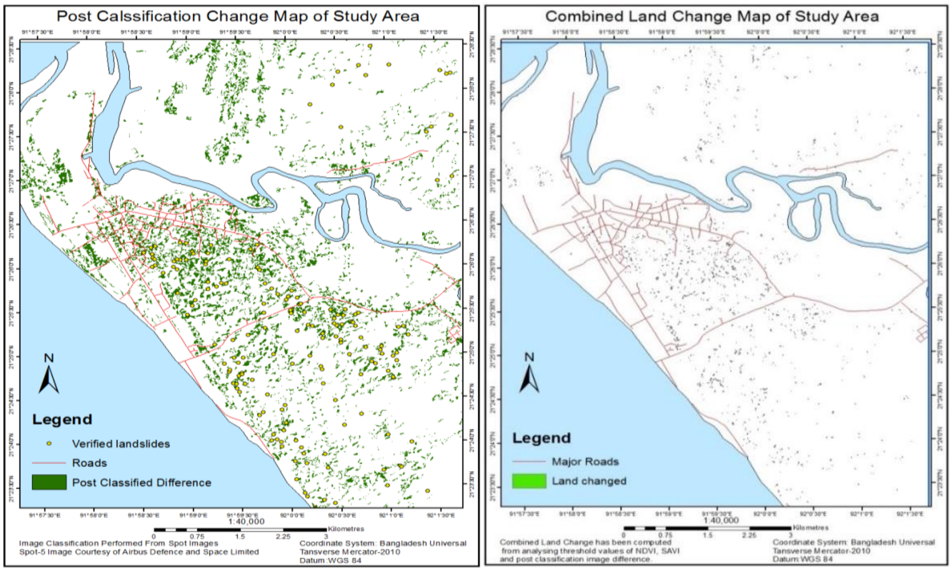

Figure 6. (a) Post Classification changed map and verified landslides (b) Combined changed map of the study area.

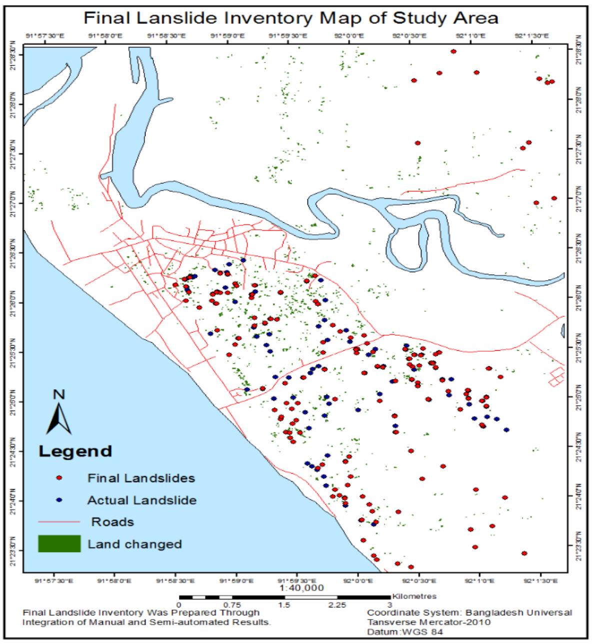

Figure 7. Final Landslide Inventory map of the study area.

The validation of remotely identified landslide inventory was conducted against the actual landside data with the help of success rate curve. The validation of the model reveals high degree landslide prediction represented by success rate curve and associated AUC value of 0.8913 as shown in Figure 8.

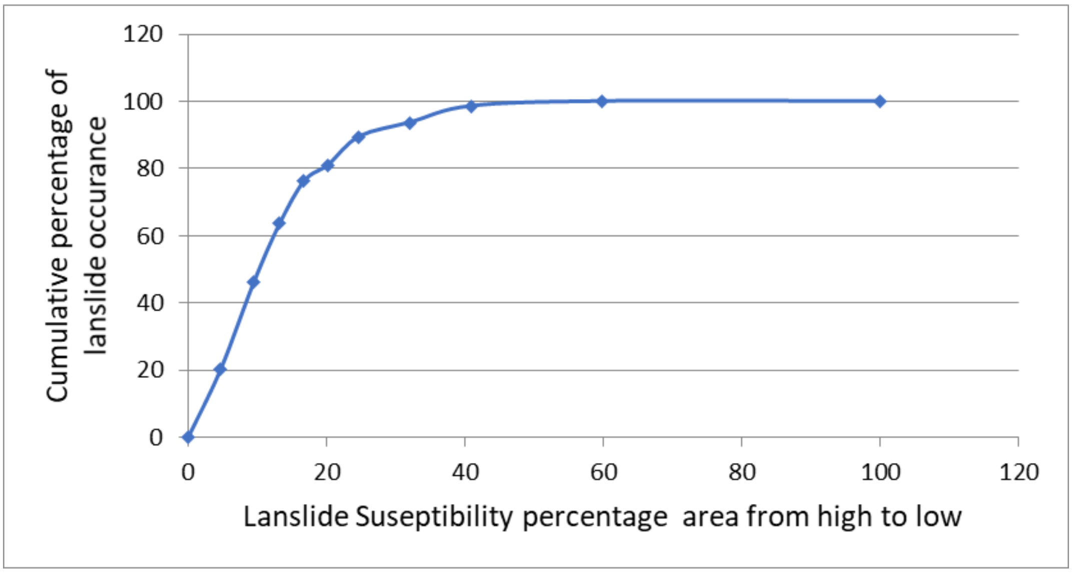

Figure 8. Success rate curve and AUC values using identified landslide data

5. KEY FINDINGS OF THE STUDY

Key findings and recommendations from this study are summarised below:

I. Manual visual interpretation of satellite images through 2D visualization can be successfully utilised for identifying small scale shallow landslides. However, 3D visualization of high resolution RS images is recommended in real world applications.

II. Open source web portals (i.e., Google Earth) can be utilised for manual interpretation in the absence of suitable high resolution images.

III. Image algebra and post classification change detection can be successfully utilised to avoid complex semi-automatic recognition processes for creating a landslide inventory for LSM.

IV. Integration of manually interpreted and semi-automated recognition results provides a better solution, even when they are derived from different data sets. However, using the same set of data for both semi-automated and manual interpretation is suggested where possible.

6. CONCLUSION

There have been numerous studies on identification of landslides through RS and GIS analysis. However, these are mainly based on large scale mountainous landslides and there is limited comprehensive study on identification of small scale shallow landslides through RS and hence this study aims to develop a suitable methodology to identify a particular small scale shallow landslides of Bangladesh using High Resolution (HR) and Medium Resolution (MR) optical satellite images. As a part of this study, manual 2D visual interpretation of HR image and semi-automatic change detection through indices, unsupervised classification of MR have been performed to obtain landslide inventory. A novel method of integration of manual results with semi-automatic process results is used to get a reliable landslide inventory. The landslide identification through RS and GIS is validated through truth data, which was surveyed on ground by a third party. Thus, the study successfully developed a methodology to identify small scale shallow landslides through RS and GIS analysis. It is expected that this study will make a significant contribution to the science and practice of studying landslide prediction and mitigation measures in Bangladesh and other similar countries

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Assessment of Particulate Matters Concentration in Air at Selected Locations in Chittagong City

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EXTENDED ABSTRACT

Particulate matter concentration levels remain dangerously high in many parts of the world. New data from WHO shows that 9 out of 10 people breathe air containing high level of pollutants. Updated estimations reveal an alarming death toll of 7 million people every year caused by ambient (outdoor) and household air pollution (Begum et al 2011). In Bangladesh, the Atomic Energy Centre, Dhaka (AECD) of Bangladesh Atomic Energy Commission (BAEC) has been monitoring $PM_{2.5}$ and PM_{10} as part of regional air pollution monitoring network of 15 countries in Southeast Asia and the Pacific under Regional Cooperative Agreement (RCA) with financial assistance from International Atomic Energy Agency (IAEA) (Hopke et al 2013). The purpose of this project is to improve air quality in the Asian region by applying advanced nuclear analytical techniques (NATs) to the assessment of airborne particulate matter (APM) pollution. The ambient air quality monitoring network Bangladesh consists of eleven (11) fixed Continuous Air Monitoring Stations (CAMS). In Chittagong, there are two stations one in Agrabad and another in TV Station area from which the instruments of TV Station is not working smoothly. It is not sufficient to monitor the whole city's air quality with the one station. That's why individual research should carry out to give the dwellers idea about current scenario of the city.

From several literature (Tanzir et al 2008; Randall et al 2014; Hoosen and Hoque 2018), it is found that in most of the cases the responsible pollutants for air pollution is Particulates matter ($PM_{2.5}$ and PM_{10}). That's why in this study we concentrate on the particulates matter's concentration. The paper adopted a methodology as suggested by Hasan et al (2016). Particulate matter sampling was performed by using the device "Handheld Air Quality Analyzer" to collect the data from eight different locations. The device was placed in the selected locations for collecting PM from morning to evening (9:00 a.m. to 5:00 p.m. local time). In our work, we have tried to find out the particulate matter (PM) having aerodynamic diameter of 2.5 and 10 µm and the vehicles passing through those points per 30 minutes to determine in which area the particulate matter is higher when the vehicle passing rate is high. Data collection was done in eight locations. Description of the sampling locations in Chittagong City, Bangladesh is given below in Table 1.

Table 1. Description of selected locations

Locations	Status of the Site
Agrabad – Badamtoli Circle	Commercial area with heavy traffic
Tigerpass Circle	Semi urban area with medium traffic
Lalkhan Bazar Circle	Commercial area with heavy traffic
GEC Intersection,	Commercial area with heavy traffic
Sholashohor 2 No Gate Circle	Commercial plus industrial area with heavy traffic
Muradpur Circle	Commercial area with heavy traffic
Bahaddarhat Circle	Commercial area with heavy traffic
Kalurghat Bus Stand	Industrial area with heavy traffic

The Particulate matter concentration of $PM_{2.5}$ and PM_{10} in the air of Chittagong City have been collected and compared with seasonal and daily basis variation. The higher concentrations of $PM_{2.5}$ & PM_{10} are found during winter season from November 2017 to January 2018 at Kalurghat, GEC, Lalkhan Bazar, Tigerpass, Bahaddarhat, 2No.Gate. The higher concentrations of $PM_{2.5}$ & PM_{10} are found during and after winter season at Muradpur in both working days & weekends which exceeds the ambient air quality standards in Bangladesh ECR'1997 (Table 2).

Table 2. Concentrations of selected parameters at several locations

Parameters	**During Winter**				**After Winter**			
	Working Days		Weekend		Working Days		Weekend	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
$PM_{2.5}$(μg/m^3)	178.25	36.25	148.15	78.23	175.3	81.6	177.8	49.2
PM_{10} (μg/m^3)	752.75	143.23	437.43	193.11	734.64	205	710.4	195.8

Overall, the atmospheric condition of Chittagong City specially in terms of particulate matter concentrations gradually getting unhealthy for survival. So, initiatives have to be taken to control the PM emission from brick kilns, motor transport which will give positive impact on the air quality of Chittagong City.

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Determining Deep Groundwater Security in the Bengal Delta, Bangladesh and Importance of Monitoring

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EXTENDED ABSTRACT

Groundwater is the major source of fresh and safe water in Bangladesh and about 97% of drinking water and 80% of dry season irrigation water has been provided by groundwater (Zahid et al. 2017). This huge stress on groundwater has already posed water quality and quantity problems in many areas of the country. Arsenic contamination in shallow groundwater has changed the scenario of its use. There is also high vulnerability to salinization in the coastal areas due to pumping-induced mixing of pre-existing fresh and saline groundwater and to vertical infiltration of saltwater from periodic storm surge flooding.

Providing sustainable fresh water for domestic and agriculture uses is one of the greatest challenges in the coastal belt of Bangladesh. In the coastal delta where the quality of water in the upper aquifers is a serious constraint, future development will likely be confined to the safe and fresh deep groundwater. Owing to the importance and pervasive use of the deep groundwater, the sustainability of water use has received extensive attention. However, excessive abstraction from the deep aquifer may pose a threat to the storage as well as on the quality of water due to high susceptibility to salinization and arsenic contamination from upper aquifers. Hence, the extension of aquifer units and characterization of aquifer sediments are very important in order to sustainable development and management of limited fresh groundwater resources. The study area extends over fifteen districts of the coastal region of Bangladesh. For assessment and monitoring of deep fresh groundwater potential in the study area, upto 72 hours constant-discharge aquifer pumping tests have been performed at eighteen locations (Figure-1). Different methods have been used to analyze drawdown and recovery data considering aquifers as confined or leaky confined.

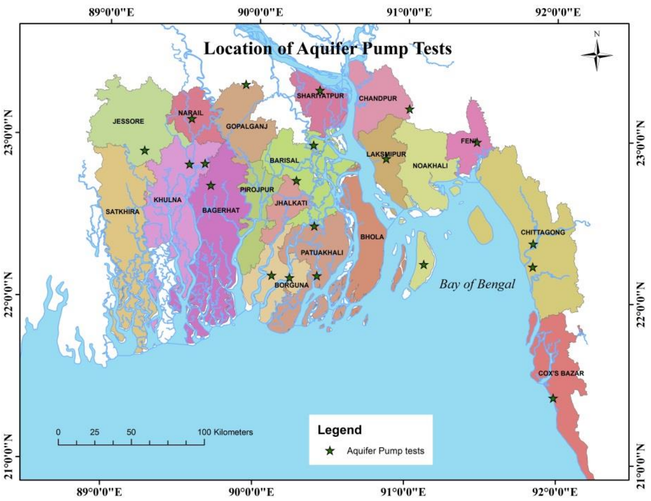

Figure 1. Location of the deep aquifer pumping test sites in the coastal regions of Bangladesh.

It reveals from this study that the distribution of aquifer sediments in the subsurface of the southeastern coast is very complex due to highly variable alternation of aquifer-aquitard even within a short distance. This high variable range of transmissivity (T) values indicate that the degree of sorting of sediments in the aquifers are variable which is consistent with the lithological data of the aquifer. Beyond the stage of early rapid drawdown, groundwater heads for different locations showed variable responses with the variable pumping rate (2.01-64.22 m^3/hour) and for different geological settings. Besides these, the duration of pumping rate, distance of the observation wells from the pumping well, lithologic condition, i.e. position and thickness of the overlying aquitards, aquifer type, source of recharged water etc. influenced the rate of drawdown. No drawdown of water heads was observed in the observation wells installed in upper aquifers above the clay or silty clay layers. This suggests that with limited and regulated abstraction of groundwater from the deep aquifers in the study area, does not allow saline water to reach to the deep fresh groundwater units except where there is no significant aquitard exists between pumping aquifer and upper contaminated aquifers.

For minimizing the well losses and partial penetration effect on T values, the Cooper-Jacob method is the best solution for the studied aquifers. Based on T values, Chittagong and Feni deep aquifers show low potential with T ranges between 123.67and 370.84m^2/day, while high potential aquifers with T ranges between 2095.23 and 3545.6m^2/day were estimated for Jhalokathi, Narail, Chandpur and Noakhali aquifers. Storage co-efficient values indicate that aquifers are confined to leaky confined in nature. Although large scale abstraction of deep groundwater for irrigation is not recommended, but maintaining proper well spacing, under moderate discharge rate i.e. up to 65 m^3/hour, few hours of pumping per day can be done for potable water supply.

Sustainable development and proper management of groundwater can be done with a clear understanding of the groundwater system, its geology, hydrogeology, the subsurface flow and the response of the system considering seasonal, tidal and pumping stresses. As such, investigation of the aquifer systems, understanding of formation behaviour, regular monitoring of groundwater storage and quality are important considering adoption of appropriate and sustainable strategy to ensure food security, healthy society and safe water supply and combat climate change impacts. Estimation of the availability of water and preparation of water budget and water allocation plans for different uses down to Upazila/Union Level need to be formulated. Strengthening appropriate monitoring organizations for tracking groundwater recharge, surface and groundwater interaction, and changes in water quality are important. Due to arsenic contamination in shallow groundwater and salinity at different depth levels, deep fresh water aquifers may serve as sustainable options for safe drinking water, however, irrigation use of deep groundwater should not be encouraged. More use of surface water mainly for irrigation and industrial use, wherever available and reduce misuse and over-use of water in irrigation and urban water supply may also reduce the stress on groundwater resources.

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Mapping Potentiality of Artificial Storage and Recovery (ASR) of Groundwater for the Bengal Basin, Bangladesh

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EXTENDED ABSTRACT

Artificial recharge i.e. the augmentation of infiltration into groundwater by different technologies like recharge basins, recharge wells, induced infiltration by injection wells etc. of treated safe and fresh surface water and harvested rain water are very much accepted worldwide for overstressed aquifers Bhalerao and Kelkar 2013). The artificial storage and recovery (ASR) is useful for aquifers subject to declining water levels, salinity encroachment etc. However, artificial recharge to groundwater does not pay adequate attention in developing countries like Bangladesh. In Bangladesh, groundwater means a lot for its livelihood and socio-economic development as groundwater has a very close link to fresh and safe water supply and agriculture. The shallow and main aquifers in the country can yield large quantities of water. But, is not completely suitable for development because of declining trend of water table and quality problems in many areas where arsenic contamination in shallow groundwater and saline water encroachment in the coastal belt makes the water unsuitable for human consumption. Over exploitation is usually the result of irrigation abstraction in rural areas and huge domestic and industrial usage in cities. Areas where groundwater is already over-exploited e.g. Dhaka city and Barind tract in north-western Bangladesh or saline prone areas, like in the coastal belt where high rates of pumping from the shallow aquifers may result in saltwater intrusion, recharge enhancement has potential to store excess runoff or rainwater and to reduce salinity.

Various studies showed that artificial recharge has several potential advantages. The recharge technologies are generally well understood, easy to operate and maintain and very few special tools are needed to install these technologies. Storage structures required are small and cost-effective. Not only storage of water but also the quality of the aquifer water can be improved by recharging with high-quality injected water. Recharge can significantly increase the sustainable yield of an aquifer. However, artificial recharge has some risks too that needs to consider carefully during implementation of technologies. There is a risk for contamination of the groundwater from injected surface water runoff, especially from agricultural fields and roads surfaces if, the injected water is not pre-treated. Recharge can degrade the aquifer unless quality control of the injected water is adequate. This document summarizes the method used to generate the maps of potentiality of artificial recharge technologies for Bangladesh.

The method consists of analysing various variables that contribute to the Physical Potential or the Demand Urgency for this system. The identified variables that define the Physical Potential are: Precipitation intensity and duration; Evaporation loss; Surface geology; Thickness of the aquitard; Groundwater depth below the surface in the middle of the Monsoon (June); Wells contaminated with Arsenic; Inundation land type. The variables that define the Demand Urgency are: Population density; Depth of the groundwater table below the surface at the driest month (April); Poverty; Absence of perennial rivers close by; Irrigation demand.

The different variables describing these two aspects are analysed and reclassified according to several criteria. Each class is then assigned a "suitability score" equal to 0, 0.5 or 1 depending on its correlation to the physical potential or urgency for demand. For example, areas with high precipitation

intensity and long duration of the precipitation are most suitable than areas with low precipitation as rainwater needs to be harvested for infiltration. The chosen criteria are: the precipitation is 100mm/month or more during less than 4 months = suitability 0, while the precipitation is 100mm/month or more during 4 to 7 months = suitability 0.5 and the precipitation is 100mm/month or more during at least 7 months = suitability 1. Again, if the thickness of the aquitard is less than 5 meters, Infiltration Wells are less suitable as water can infiltrate directly. If the aquitard has a thickness of more than 35 meters, drilling a well might require more sophisticated machinery. The chosen criteria are: if thickness of the aquitard is less than 3 meters = suitability 0, while if thickness of the aquitard is between 3 and 5 meters or more than 35 meters = suitability 0.5 and if thickness of the aquitard is between 5 and 35 meters = suitability 1. Once the score is ready, the scores for the variables related to the Physical Potential are combined and so are the ones defining the Demand Urgency.

The final total potentiality has been calculated by first normalizing the Total Physical Potential and the Total Demand Urgency, and then adding them up. The infiltration well is the most common aquifer storage and recovery technique used in Bangladesh. It is mostly meant for domestic water supply. There are several studies researching the potential of this system and monitoring its benefits, however there is no concluding study yet on its impact. There are other techniques, most of them still in experimental phase, which could also enhance the rainwater harvesting during the wet season to make water available during the dry season. Some of them might be more interesting for irrigation purposes and other for domestic water supply.

In this study the potential of other aquifer storage and recovery techniques have been mapped using the method described above. The three systems where defined by experts of Bangladesh:

- Infiltration pond: this system consists of building a pond in a sandy area where water can infiltrate easily. The pond has a permeable bottom to allow water to infiltrate and recharge the aquifer. This system has been applied in several countries and have proofed to work.
- Recharge basin connected to the aquifer: this system consists of creating an artificial pond by digging out the surface impermeable material and replacing it by sandy material in order to bring the new sand in contact with the aquifer and enhance the recharge of it. This system is at the moment conceptual and its potential still needs to be tested.
- Artificial reservoir disconnected from the aquifer: similar to the previous system, this one consists also of digging out some clay and fill it with sand. In this case the clay thickness us such that the new sand does not come in contact with the aquifer. This technique might be useful to create shallow surface water lenses disconnected from a deeper aquifer that might be contaminated by saline water or arsenic rich water.

For these systems, the suitability maps of the precipitation, the geology, the thickness of the aquitard, and the groundwater depth have been adapted due to the different characteristics of these system in comparison with the infiltration well. The urgency of demand remains the same for all the systems as it is independent of the characteristics of the system. The infiltration well and the artificial reservoir seem to be the techniques with more areas with a high physical potential. This is mostly due to the geology of the area and the thickness of the first aquitard.

Authorization for artificially recharging the aquifer should be granted only if the hydro-geological situation, environmental condition and the recharge-water quality permit injection, percolation or infiltration of water by artificial means into aquifers for storage and retrieval. Artificial recharge of ground water should be licensed and controlled by competent authorities according to specific requirements laid down in an appropriate permit system, taking into account all relevant aspects, including ecological ones.

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Determination of Drinking Water Quality Index of Some Selected Points in Gazipur.

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Abstract

Drinking water quality index is a simple, flexible, stable and reliable index and can be used as an effective tool to characterize drinking source water quality. It helps to explain the overall water quality using a sing number. The index consists of water quality variables: color, turbidity, pH, EC, total alkalinity, total hardness, calcium, magnesium, chloride, iron etc. In this study, the main objective was to assess the drinking water quality of supply water of some selected points in Gazipur using Drinking water quality index. The index was constructed on the basis of both WHO guideline and ECR 97 guideline. The results of this study can be used to assess the present situation and will help to improve the present water quality of the supply water.

Keywords: Drinking water quality index, WHO guideline, ECR 97 guideline, turbidity

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Evaluation of Carbon Sequestration in the Lake Environment of Dhaka City

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Abstract

Urban parks play significant roles in the carbon sequestration process as the cities own larger share in the global carbon emission. Two of the major urban parks of Dhaka City, Dhanmondi Lake and Ramna Park were selected in this study for the assessment of carbon sequestration by the living and non-living reservoirs for the very first time. Total tree biomass of Dhanmondi Lake for 35 different tree species consisting of 2553 trees were estimated at 46.08 ton whereas total tree biomass of Ramna Park for 137 different tree species comprising 4592 trees amounted to 45.84 ton. Total carbon stock by tree species of Dhanmondi Lake and Ramna Park were evaluated to be 23.04 ton/ha and 32.24 ton/ha respectively. Total topsoil carbon stock for Dhanmondi Lake and Ramna Park were obtained at 19.13 ton/ha and 98.93 ton/ha respectively. Total sediment carbon stock for Dhanmondi Lake and Ramna Park were respectively 31.98 ton/ha and 3.31 ton/ha. The average amount of CO_2 in water bodies of Dhanmondi Lake and Ramna Park were estimated to be 6.53 ppm and 0.86 ppm respectively. Evaluation of the variation of carbon storage capacity by each species of trees in the Dhanmondi lake area suggested that the species Albizia Procera, Michelia Champaca, Polyalthia Longifolia, Swietenia Mahagoni and Ficus Benghalensis are able to sequester the maximum amount of carbon from the environment (ranging ~100-200 tons/hectare) and thus should be grown with priority. Whereas, evaluation of the variation of carbon storage by each species of trees in Ramna park area recommended that the species Colroupita Guianesis, Anthocephalus Cadamba and Bougainvillea spp are able to sequester the maximum amount of carbon from the environment of the total zone (ranging~ 113-236 tons/ha). Both the lakes were finally divided into three zones for the digitization of carbon storage distribution through GIS mapping according to the existence of total tree species.

Keywords: carbon, sequestration, park, lake, storage

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The Quality of Public Open Space in Urban Waterfront: The Case of Jail Khal, Barisal

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Abstract

Sustainable management of public open space (POS) through urban design of urban waterfront particularly in developing cities is a fiery one. Emerging climate change and environmental degradation make development issues even more complicated in developing cities. Conventional urban design literature heavily focuses on development framework mostly related to place making for developed cities with little reference to urban waterfront in order to investigate measures to enhance POS in developing cities. The research aims to identify the factors to ensure the quality of POS of urban waterfront of Jail khal area, Barisal. This research uses case study based approach and involve stakeholder participation through focused group discussion and key informant interviews. The anticipated outcome of this study is to provide an integrated framework that will confirm planning and development process of a city. It will also highlight context-based urban design guidelines for local actor, planner, and policy makers while conserving ecological balance and preserving urban water front to ensure sustainable development.

Keywords: Public open space; Urban waterfront; Urban design, Jail Khal Barisal

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A Field Evaluation of Catch Basin Insert for Treating Gross Pollutants from Urban Stormwater

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Abstract

Urban stormwater runoff contains wash-off solid waste (known as gross pollutants) and also dissolvable pollutants such as nutrients, heavy metals or hydrocarbons. Among them, stormwater gross pollutants (GPs) is more critical as it can clog the stormwater drainage system and seal the infiltration capacity of side entry pit and resulting urban flooding. The GPs may include vegetation (plant-based debris), litter (paper, plastic, cans and others) and sediments of different sizes. Many best management practices (BMPs) have been introduced to manage urban stormwater including oil and grit separators, grassed swales, vegetated filter strips, retention ponds, constructed wetland, gross pollutant traps (GPT) and catch basin inserts (CBI). The GPT and CBI are mainly used for capturing GPs in urban stormwater. The GPT is mainly used to collect GPs from the outlets of piped storm drainage system but difficult to clean periodically which is also not effective to remove sediments less than 5mm. On the other hand, CBI can be typically mounted within a catch basin (e.g. side entry pit) and thus clean stormwater at source by removing GPs down to 150µm. The CBI also has the flexibility for easy maintenance. In this study, two CBIs were selected from each of four different land used areas in Western Australia. These are located in four different suburban areas which include (i) Subiaco- purely residential area (ii) Gosnells: mixed-land used area (iii) Hillarys: commercial-cum-recreational area and (iv) Mandurah: a construction site. The GPs were collected from these CBIs during the rainy seasons of 2014-2016 and the collected samples were categorised into different components based on the material types as well as the sediment sizes. The results revealed that the vegetation was found the highest component (>90%) with respect to others. The stormwater sediment distribution results show significant variation in different land use patterns. The finest sediment was found in the residential area while the coarsest sediment was found in the construction area. The hierarchy of sediment distribution follows: residential area<mixed-land used area<commercial-cum-recreational area<construction site. The finer sediment is more prone to have heavy metals content because of traffic emission and tyre and brake pad wear of vehicles. However, this research is limited to evaluating the stormwater gross pollutants only and further research is needed to explore the stormwater sediments as heavy metal carriers.

Keywords: Stormwater, Gross pollutants, Catch basin insert, Treatment, Water quality

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Stormwater Drainage Network Analysis of BUET

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Abstract

Water logging is a very common problem for Dhaka city. A moderate of heavy rainfall is causing water logging now a days. The situation is seriously provoked during the monsoon. BUET is not exceptional in this case. The main reason behind the water logging in BUET is the lacking of organized drainage network and capacity of it. There is no valid data on how much water BUET area does carry to the outlet of Education Board area, Bakshi Bazar, Dhaka. This study mainly focuses on determining the total outfall at the outlet of that area. A study area of 73.12 acres of BUET is chosen for the study. The study area has been divided into three parts. West Palashi campus is not included in this study, as the outlet of that campus is different. The water logging problem is severe in the main campus and the Southern side of the campus. After assessing the drainage network, it was found that some network is mixed with the sewer system. Also, some new network is not modified in the main drawing. As the study area is small, DEM was not used, rather the area was extracted from the Google Earth. A stream network was given later. After that the model was simulated using GeoSWMM. As the Southern part of BUET is lower than the Eastern side, a lot of stormwater comes outside of the catchment area and goes through BUET main WASA line of stormwater. That's why an extra flow is assumed in this study at the first junction point. Peak discharge at two outlets have been determined considering 50 years rainfall data for 5 year and 10-year return period.

Keywords: Stormwater, Drainage Network, GeoSWMM.

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Stormwater Management Practices in Dhaka and Sydney – A Comparative Review

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Abstract

With the rapid and unplanned urbanization in Dhaka city, most of the drainage canals have been illegally occupied and this has resulted reduced carrying capacity of stormwater. Two separate drainage systems are operating in Dhaka City: one is for managing stormwater and the other one is for domestic and industrial wastewater. There are also few water storage facilities such as lakes, ponds and wetlands etc. to aid the management of stormwater in Dhaka. The stormwater runoff usually discharged to the surrounding rivers. The water levels of these rivers remain high during monsoon and the drainage systems get an impact of backwater effect from surrounding rivers though canals and lakes provide retention spaces for stormwater during the monsoon period. But the existing drainage system has failed to reduce frequent flooding in Dhaka and the use of stormwater as a resource has been ignored. By the growing frequency and severity of stormwater surcharge and flooding, the necessity to deal with both the quantity and quality of runoff has been recognised in recent years in Sydney. The hard engineering strategy where majority of the stormwater is transported through drainage system (e.g. pits and pipe systems) to receiving waterways without any treatment is being modified by the application of Water Sensitive Urban Design (WSUD). Most Australian cities including Sydney promoting the adoption of Water sensitive urban design (WSUD). This strategy focuses on decentralised stormwater management system where the runoff and pollutants are managed locally within urban housing, commercial and industrial areas. WSUD involves the utilisation of natural process, storage and reuse principles to reduce local and regional flooding and improves the quality of stormwater discharging from the site. This paper presents a comparison of stormwater management in Dhaka and Sydney and suggests possible improvements for Dhaka.

Keywords: urbanization, drainage system, Water sensitive urban design, managing stormwater

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Effects on Water Quality of Buriganga and Dhaleshwari Rivers Due to Relocation of Tannery Industries from Hazaribagh to Savar

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Abstract

Bangladesh is a low-lying riverine country located in South Asia. Buriganga and Dhaleshwari are two of the major rivers for Dhaka, the capital of Bangladesh. Buriganga has become a dying river due to the indiscriminate disposal of effluent from various industries, especially tannery industries situated at Hazaribagh, close to the Buriganga. To improve the water quality of Buriganga the tannery industries were relocated to Savar in 2016, on the bank of Dhaleshwari River. A Common Effluent Treatment Plant (CETP) has been established there to treat the wastewater of tannery industries before discharging into the river, so that Dhaleshwari does not become another Buriganga. The main objective of this study is to assess the impacts on the water quality of river Buriganga and Dhaleshwari due to the relocation of tannery industry from Hazaribagh to Savar. This research also examines the seasonal and spatial variation of water quality parameters for both the rivers, the pollutant load from the CETP to the Dhaleshwari and the performance of the CETP. To achieve these goals, field survey was carried out in the Hazaribag and Buriganga river area and Savar Tannery Estate area and water sampling locations were selected for both the rivers. For Buriganga river, Rayerbazar, Chadnighat and Bangladesh China Friendship Bridge (B.C.F.B) were selected as the sampling points. For Dhaleshwari, three points namely upstream, downstream and mixing point were selected as river water sampling locations and inlet and outlet samples were also collected from the CETP. Another sample was taken from a sewage pipe which is located close to the outlet point of CETP and directly discharging wastewater to the river. Samples were collected for ten months from October, 2017 to July, 2018 for both the rivers. The samples were analyzed in the laboratory and the characterization of the collected samples was performed. After analyzing the results, it is evident that for River Buriganga, water quality parameters have been improved in Rayerbazar location (where tannery industries used to discharge the wastewater previously), especially Chloride concentration has decreased from 800 to 55.6 mg/L. But the parameters have not improved significantly in the downstream direction such as Chadnighat and B.C.F.B. Thus it can be said that the water quality close to the location of previous tannery industry (Rayerbazar, Hazaribagh) has improved but in the downstream of the Buriganga River, the effects of shifting tannery industries is insignificant. The reason is the presence of other industries on the bank of Buriganga River that are polluting the river on a regular basis. For Dhaleshwari River, present study result shows overall degradation of water quality in comparison with the previous data, especially DO has reduced to 2.72 from 6.1 mg/L. The increased amount of Chloride and presence of Chromium in Dhaleshwari River also indicates that treated effluent from CETP of Savar tannery estate has started polluting the river Dhaleshwari. The data of wet season was better than the dry season for both the rivers as expected. Regarding the performance of CETP, the treated effluent of CETP does not comply with the standard limit set by DoE (ECR, 1997). However, the removal efficiency of BOD, COD and Chromium was observed improving gradually throughout the study period, but there is no improvement in TDS and Chloride removal. This is due to the absence of any Chloride reducing unit in the treatment process. The test results also show that the discharge from the sewage pipe (close to CETP outlet) contains high concentration of COD (1960 - 8620 mg/L) and Cr (22.6 - 107.0 mg/L) which indicates that the discharged wastewater through the sewage pipe is carrying industrial wastewater, not only the domestic sewage.

Keywords: Surface Water quality, River health, Tannery effluent, Tannery Relocation, CETP

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Carbon Footprint of Drinking Water Bottle in Saudi Arabia

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Abstract

Due to lack of safe and reliable drinking water supply network in Saudi Arabia, many residents rely mainly on bottled water supply for drinking purpose. The drinking water bottle made of Polyethylene Terephthalate (PET), is a polyester based thermoplastic polymer, which has potential hazards on environment. Previous studies show that bottled water consumption in Saudi Arabia has increased from 77 L/capita/year in 1999 to 99 L/capita/year in 2009. Because of rapid industrialization, high population growth and fast urbanization in Saudi Arabia, level of solid waste generation is increasing. Among Gulf Cooperation Council (GCC) countries, Saudi Arabia produces 64% of the total municipal solid waste, where by composition plastic material comprises 5% of the total waste. Significant amount of fossil fuels is used to produce PET resin, which ultimately produces greenhouse gas such as CO_2*. An estimation shows that a 500 mL plastic drinking water bottle has a total carbon footprint of equal to 82.8 g of* CO_2*. In this paper, we study the carbon footprint of bottled drinking water in the context of Saudi Arabia. Calculation procedure of carbon footprint for bottled water will be reviewed and strategies to reduce carbon footprint of bottled drinking water will be investigated.*

Keywords: Bottled water, Greenhouse gas, Polyethylene Terephthalate (PET)

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Water Quality Scenario in Peripheral Rivers of Dhaka City during Dry Season

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Abstract

Dhaka city is blessed with six rivers, namely the Buriganga, Turag, Dhaleswari, Tongi, Balu and Lakhya rivers around its periphery. At present, Pagla Sewage Treatment Plant (STP) is the sole treatment plant with a capacity of 120 MLD. But only 30-40% of its capacity is being used, which is less than 10% of total generated sewage of Dhaka city. Though sewerage network for Old Dhaka has been built in British period, now it is in a dysfunctional state. Other parts of Dhaka have no separate sewerage system. As a result, untreated sewage of Dhaka city is going into the peripheral rivers through drainage system of Dhaka city. There are industrial hubs in Narayanganj, Shyampur, Gazipur, Savar which includes dyeing, tannery, pharmaceuticals etc. industries. Most of these industries have no functional Effluent Treatment Plant (ETP); consequently, discharging their untreated wastewater into these rivers. To observe the peripheral river water quality an extensive field visit was undertaken in the months of February and March of 2017. The survey was conducted in more than 170 km stretch of these six rivers. The water quality parameters i.e. Dissolved Oxygen (DO), Electric Conductivity (EC), temperature and pH levels were measured using sophisticated equipment. DO level was less than 1 mg/l for all the peripheral rivers except the upstream (upstream of Murapara Ferry Ghat) of Lakhya River. The Buriganga was found as the most highly polluted river among these six, where the DO level was less than 0.5 mg/l. The main reason for this high level of water pollution is untreated sewage load, industrial load, oil and grease from water vessels and indiscriminate solid waste dumping along the bank of these rivers. In this article, implementable recommendations will be made to improve the overall water quality of these peripheral rivers.

Keywords: Water Quality, Industrial Waste, Sewage Treatment Plant, Dhaka City.

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Rainwater Harvesting for Toilet Flushing

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Abstract

Since Rainwater Harvesting is unfamiliar in relation to domestic water supply and extra space required for storage, so the common people of Bangladesh are reluctant to use it. Also, due to the paved surface in urban areas, rainwater cannot be infiltrated through the surface to the underground. That is why water logging is occurred in the urban areas with great sufferings. One way of getting out of this problem is to collect and use of the rainwater eventually dropping the water logging of urban areas. For this purpose, a project is undertaken to develop an arrangement in the academic building of DUET campus, which will exploit the harvested rain water in the toilet flushing in an automatic way. The rain water from the roof will be collected and stored in a tank kept on the toilet slab under the roof slab of each floor. These tanks will be connected with the existing flushing system by an automation system, which will guide the underground water consumption after exhaustion of rain water stored in the tank. If there is no rain water, existing water supply will meet the flushing demand. If this system could be successfully developed and multiplied in other buildings of the campus then the water logging of the DUET campus would be eradicated.

Keywords: Water logging, Rainwater, Paved surface, Sufferings, Automatic way

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Efficiency of Urban Parks in Reducing Urban Heat Island in the City of Melbourne

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Abstract

Increasing urbanization converts naturally vegetated areas into built-up and impervious areas. Higher conductivity construction materials in urban areas absorb and store a higher amount of solar heat during the day as compared to rural areas, and consequently, lead higher temperature in urban areas. The phenomenon of higher temperature in urban areas as compared to surrounding rural areas is commonly referred to as Urban Heat Island (UHI). Introducing green spaces such as urban parks is one of the sustainable and effective ways in mitigating the UHI. The aim of this study is to evaluate the efficiency of urban parks in reducing the UHI for the city of Melbourne during an extreme heat condition. Numerical simulations are conducted by using the Weather Research and Forecasting (WRF) model coupled with the Single Layer Urban Canopy Model (SLUCM). The fractions of urban parks are increased by 20 %, 30 %, 40 % and 50 % using mosaic method of the WRF model. Results show that urban parks can reduce the UHI from 0.6 to 3.7 °C by increasing their fractions from 20 % to 50 % during the night in which lower storage heat was the main driver. Urban parks provide shading and partition a major portion of net radiation into latent heat flux via evapotranspiration, and as a result, reduce the storage heat in urban areas during the day. Therefore, less heat is stored by urban surfaces to release during the night, which results in the reductions of UHI during the night.

Keywords: UHI, WRF, Urban Parks, Melbourne

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Present Scenario of Domestic Solid Waste Management in Dhaka City

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Abstract

Dhaka is one of the rapidly growing megacities. Everyday a huge amount of domestic solid waste is generated by the city dwellers, managing of which is an arduous job. Domestic solid waste from households of Dhaka city is managed by the two city corporations. The management of domestic solid waste is under waste management division of city corporations and in some areas through outsourcing by private contractors. These two city corporations have constructed Secondary Transfer Stations (STS) for better management of domestic solid waste. A detailed study was conducted on the domestic solid waste management system of Dhaka city in October 2017. Solid waste from households are transported to STS by vans and pickups and then transported to sanitary landfill sites (Aminbazar for DNCC and Matuail for DSCC) by compactors, container trucks, dumpers and open trucks. In addition, roadside open containers are placed at many places of Dhaka city. Solid waste from these containers are also transported to landfill sites by container carriers. Some small-scale informal recycling factories were found during site visit which are based on plastics, paper, glass, bones, tyres etc. materials. Formal recycling facilities were not found at the two landfill sites. In case of DNCC, the amount of dumped solid waste in Aminbazar landfill site is the joint contribution from STSs (90%) and roadside containers (10%). In case of DSCC, the amount of dumped solid waste in Matuail landfill site is the sole contribution from roadside containers, because the newly built STSs are in in operation yet. In the newly added wards of both city corporations, there is no formal solid waste management system by the city corporations yet. Finally, in this paper recommendations will be given on making the solid waste management system more efficient.

Keywords: Domestic Solid Waste Management, Secondary Transfer Station (STS), Sanitary Landfill Sites, Recycling

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Treatment of Textile Effluent by using Dolichos Lablab and Bucket Filter

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Abstract

A textile industry is one of the largest industries in the world. This industry generates huge quantities of complex chemical substances in the form of wastewater. The textile industry effluents are treated with a series of physical and chemical treatment methods such as coagulation, flocculation and biological treatment. A bucket filter is fabricated to treat the effluent of textile industry. Dolichos lablab is then used to determine the removal efficiency. The parameters tested include TS, TDS, TSS, COD and pH. The average removal efficiencies of Dolichos lablab are 4.62, 3.79, 15.5, 20.47 and 2.23% for TS, TDS, TSS, COD and pH, respectively. The average removal efficiencies of bucket filter are 4.9, 1.81 and 32.71% and of Dolichos lablab are 3.74, 2.08 and 28.74% for TS, TDS and TSS, respectively. The average combined removal efficiencies of bucket filter and Dolichos lablab are 8.43, 3.85and 53.49% for TS, TDS and TSS, respectively. It is an effective technique to remove multi-pollutants from water, wastewater and leachate.

Keywords: Textile effluent, Dolichos lablab, coagulation, flocculation, multi pollutants

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Treatment of Hazaribagh Channel Surface Water by Using Synthetic Coagulant and Dolichos Lablab

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Abstract

Dhaka city is situated on of the bank of the river Buriganga, which at present is one of the most polluted rivers in Bangladesh. The river receives wastewater from numerous pollution sources. A large share of pollution of the river Buriganga comes from the tannery industries. Hazaribagh channel of the Buriganga river receives huge quantities of complex chemical substances. The surface water of Hazaribagh channel is treated with various physical and chemical treatments such as bucket filter, synthetic coagulant and Dolichos lablab. The parameters tested are TS, TDS, TSS, BOD and COD. The average removal efficiencies of Dolichos lablab are 3.23, 4.54 and 22.92% for TS, TDS and TSS, respectively. The average removal efficiencies of bucket filter are 5.21, 3.20 and 33.22% and of Synthetic Coagulant are 3.46, 14.50, 15.88, 14.94, 0 and 5% for pH, TDS, TSS, TS, BOD and COD, respectively. The average combined removal efficiencies of bucket filter and Dolichos lablab are 8.26, 7.59 and 49.14% for TS, TDS and TSS, respectively. Therefore, these techniques can be applied to remove multi-pollutants from water, wastewater and leachate.

Keywords: Buriganga river, tannery industry, synthetic coagulant, coagulation, flocculation, multi pollutants

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