Heavy metal contamination and related risk in private and government installed hand-pumps. A comparative study in industrial area of Saharanpur district, India.

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Abstract

Groundwater contamination is a major concern in industrial areas of Saharanpur district. Long term use of wastewater as irrigation source contributed considerably to the metal concentration in the groundwater. Serious health related issues are prevalent in the area due to contaminated groundwater. Hand-pumps are the major equipment for drawing groundwater for household purposes. Surveying with local people revealed the fact that 80% of the population suffering from health related issues use private hand-pumps, which was further justified by the estimation of heavy metal concentration sampled from both private and government installed hand-pumps. Total of 30 samples; 11 samples from government installed hand-pumps and 19 from private hand-pumps were collected and heavy metal contamination was analysed. Samples from private hand-pumps were found to be more contaminated than government installed hand-pumps. High concentration of As, Cd, Cr, Ni and Pb; 5.28µg/l, 0.54 µg/l, 16.3 µg/l, 71.4 µg/l and 7.82 µg/l respectively were observed in the sample collected from private hand-pumps. Health risk was estimated by Health quotient (HQ) in both adult and children population; risk was found to be high in children. It has been observed that the depth at which hand-pumps are installed has a crucial impact on the quality of water. Survey also revealed that most of the private hand-pumps installed at the depth of 18.2 m to 56.38 m whereas government hand-pumps are installed on average of 67.05 m depth. The upper level of water aquifer is highly contaminated due to poor environmental management strategies, lack of environmental education in the population and various other factors which has been briefed in this work.

Keywords: Heavy metal, groundwater contamination, health risk, health quotient.

1. INTRODUCTION

Industrial expansion without adequate environmental management is a serious concern in developing countries like India. Unmanaged disposal of industrial effluents and long term application of industrial effluents for irrigation purpose has resulted into severe groundwater contamination in various regions of India [Purandara et al., (2003); Shankar et al., (2008); Crévecoeur et al., (2011)]. The leachates and wastewater that percolate carry considerable amount of heavy metals and contaminate the aquifer. Heavy metals characterized as toxic, persistent, non-biodegradable and probably carcinogenic in soil as well as in aquatic environment [Bhutiani et al. (2016); Li et al. (2014); Dermentzis et al. (2011); Chai et al. (2010)]. Groundwater contamination by anthropogenic activities is major concern in India and is well reported since a decade [Srinivasa and Govil, (2007); Kavcar et al., (2009)] and it needs gross investigation to counter the issue. Economical and

educational status of the population also plays a vital role in the establishment of effective environmental management in an area. Limited availability of clean groundwater in developing countries results in severe health related issues and overall life expectancy [Nash et al., (1995); Henry et al., (2006)].

Saharanpur is basically agriculture based district, located close to some commercially important cities of India like Delhi, Chandigarh, Ambala and Dehradun; due to which with the time Saharanpur has experienced considerable expansion of industrialization since last few decades. The study area lies in one of the industrial zones of Saharanpur district which includes a highly water intensive paper industry. Groundwater quality in some areas of this industrial zone is highly deteriorated due to unmanaged disposal of industrial and domestic wastewater. Hand pumps are the most common medium to draw groundwater for drinking purpose in the study area; about 52.08% of rural household of Saharanpur district uses Hand pump or tube well as a source of drinking water. Installed hand pumps in the study area are either Government (India Mark-II) Hand pumps (GHs) or Private Hand pumps (PHs). Most of the population in the study area lies under Below Poverty Line (BPL), thus many family uses GHs or PHs with a shallow depth. Installation of PHs of shallow depth (15-35 meters) reduces the installation expenses, with a compromise of not much clear water, whereas GHs are deeply bored 35 to 55 meters, even up to 67 meters at certain low water table regions.

2. MATERIAL AND METHODS

Study area and Sampling

The study was carried out in one of the industrial areas of Saharanpur situated near Railway Road. This area comprises of some small and medium scale industry including a distillery, brick kiln units etc and one large scale Paper Industry. Paper industry is a highly water intensive industry which generate high volume of wastewater, which get confluences with the river Hindon (tributary of river Yamuna) in this area. The study area receives this contaminated stream of water, which serves as one of the major source of water for irrigation in the area. Long term wastewater irrigation and its vicinity to the industry resulted into high enrichment and geo-accumulation of metals in the soil of this area resulting in percolation and contaminating groundwater reservoir.

Water samples were collected from randomly selected 11 government installed hand-pumps and 19 private hand-pumps. Samples were collected in polypropylene bottles after several strokes of hand-pump in order to avoid any possible contamination from suspended dust, rusting of pipe etc. Acidification of sample ($pH<2$) were done soon after sampling in order to avoid adsorption to sampling bottle wall, crystallization and microbial degradation; samples were stored in 4°C till complete analysis. With the help of ICP-OES, heavy metal concentration was estimated.

Questionnaires and Personal Interviews (QPI)

Survey was done in the study area in order to gather information related to the depth of hand-pump boring, average daily intake (ADI), body weight (BW), health related problems etc. Questionnaires were also distributed in the local schools with the help of local volunteers to harvest more data related to the source of water used for consumption, amount of consumption and health related issues in the study area.

Health Risk Assessment

Health risk assessment model (USEPA, 1992) was used for the estimation non-carcinogenic and carcinogenic risk associated with the heavy metal contaminated groundwater.

$$ADI = \frac{C \times IngR \times EF \times ED}{BW \times AT} \quad (1)$$

In the above expression (1) ADI: Average daily intake from ingestion (mg L^{-1} d^{-1}); C: heavy metal concentration in groundwater; IngR: Rate of water ingestion (L d^{-1}); ED: Exposure duration (y); EF: Exposure frequency (d y^{-1}); AT: Average time (d); BW: Body weight (Kg). Input variables for the health risk model are briefed in Table.1

Health quotient (HQ) is calculated using given expression (2); it also indicates the non-carcinogenic risk.

$$HQ = ADI / RfD \quad (2)$$

Where, RfD is referred as Referral Dose.

Product of slope factor (SF) and ADI represent the cancer risk which was using expression 3, (USEPA, 2010).

Table1: Input variable for Health Risk Assessment model

Input Parameter	Description	Value	References
IngR	Ingestion Rate (Ld^{-1})	1.5*; 3**	QPI
EF	Exposure Frequency (days/year)	350	USDoE (2011)
ED	Exposure Duration (year)	24 years*; 6 years**	USEPA (2001)
BW	Body weight (Kg)	60*; 15**	USEPA (1989)
AT	Average time	ED x 365[a] ;LT x 365[b]	USDoE (2011)
LT	Life Time	65 years (India)	Ministry of Health and Family welfare, India (2010)

*Adult; **Children; [a] Non carcinogenic, [b] Carcinogenic; QPI= Questionnaire & Personal Interview

$$\text{Cancer Risk} = ADI \times SF \quad (3)$$

Value of oral reference dose and slope factor is taken from Table. 2

Table 2: Oral reference dose (RfD) and slope factor (SF) of metals (USEPA, IRIS, 2011).

Metal	Cd	Pb	Cr	Ni	As
RfD*	1.00E-03	3.50E-03	3.00E-03	2.00E-02	3.00E-04
Oral SF*	6.30E-01	4.20E-02	4.25E+01	8.40E-01	1.50E+00

*unit is mg/kg/day

3. RESULT AND DISCUSSION

Heavy metal concentration

The heavy metal contamination in the samples collected from government installed hand pump and private hand pumps is summarized in the **Table 4.** The concentration of As, sampled from GH and PH was found to be in the range of ND to 0.68 μgL^{-1} and 1.92 to 11.82 μgL^{-1} respectively. Out of 19 samples; two samples were found to be exceeding the standard limits and four samples were close to the limit described by the USEPA (2012) and WHO (2011). Cd concentration in both GHs and PHs were found to be under the standard limits, ranging from ND-0.48 μgL^{-1} and ND-1.38 μgL^{-1} respectively. Concentration of Cr was found to be in the range of 3.38-14.23 μgL^{-1} in GHs, where as considerable variation was observed in the PHs samples ranging from 6.54-88.46 μgL^{-1}. The permissible limit of Ni concentration according to WHO (2011) is 70 μgL^{-1}; the GH samples (ranging from 18.35-62.4 μgL^{-1}) were found to be under the permissible range, where as in the PH samples (ranging from 44.38-122.32 μgL^{-1}) more than half of the samples were found to be beyond the permissible limit. The concentration of Pb in GH samples was observed to be in the range of 3.62-14.32 μgL^{-1}, where as PH samples in the range of 2.86-24.8 μgL^{-1}.

Table 4: Heavy metal concentration in groundwater (μgL^{-1}) and groundwater (drinking) standard limit

Metal	G (n=11)	P (n=19)	USEPA (2012) (μgL^{-1})	WHO (2011) (μgL^{-1})
As	0.26 ± 0.19	5.95 ± 2.88	10	10
Cd	0.24 ± 0.12	0.65 ± 0.36	5	3
Cr	8.61± 3.74	24.21 ± 24.94	100	50
Ni	35.01 ± 12.90	74.55 ± 22.99	NA	70
Pb	7.62 ± 3.37	8.45 ± 5.23	15	10

G: Govt. installed hand pump; P: private hand pump; n: no. of samples.

Health Risk Assessment

On the basis of the result obtained from heavy metal analysis of the samples collected and QPI, health risk was assessed in the study area. QPI is the fundamental approach to obtain first-hand information about the study area. Variables of Health risk model like body weight, Average daily consumption by an individual, age and any health related issues were enquired with the randomly selected 50 individuals from the study area. More than 70 questionnaires were distributed in a very simplified and native language for the required information. Average age of children participants were 8.5±3.5 years where as the adult participants were in the age group of 51±33 years, whereas weight of children participants and adult participant were 20±8 Kg and 65±20 Kg respectively. The population in the study area is based on agricultural practices and other works that involve extensive physical work, thus the average water intake per day is quite high which was estimated as 1.5±1.00 Ld^{-1} and 3.00±1.5 Ld^{-1} for children and adult respectively.

Average daily intake (ADI) of heavy metal in both adult and children population through contaminated groundwater from GHs and PHs is graphically represented in the Fig. 1 & 2 respectively. Most of the population in the study area involved in agriculture related work or other labor work that requires intense physical activity moreover, the climate is warm and temperate almost throughout the year except winters thus average water consumption by an

individual per day is quite high. Non-carcinogenic risk in terms of Health Quotient (HQ) and Carcinogenic Risk is briefly presented in **Table 5**. Analysis of health risk data revealed that the Non carcinogenic risk (HQ) associated with heavy metal contamination in the study area is under the safe limit except Pb in adult population using GHs, whereas in Children population consuming water from GHs Non carcinogenic risk associated with As, Cr and Ni was found to be considerably closer to the risk mark. Non carcinogenic risk associated with As was observed to be higher in the children population using PHs followed by the Adult population using PHs. High Pb concentration in both GHs and PHs which may be due to the leachates from plumbing system or by other anthropogenic sources is a serious concern in the study area.

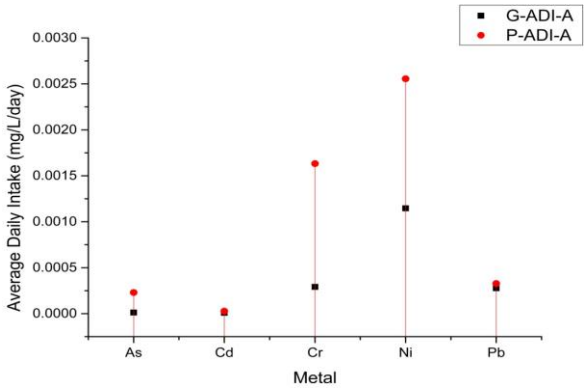

Figure 1. ADI of metal (95% UCL) in Adults

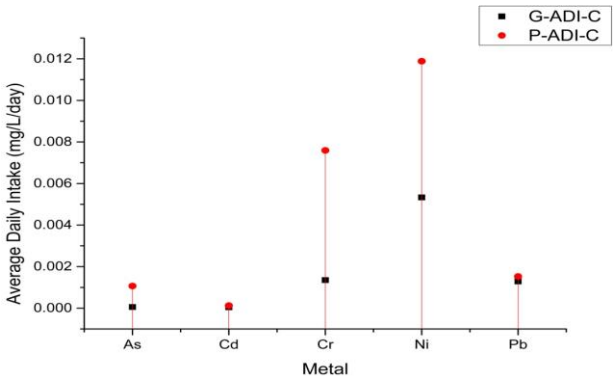

Figure 2. ADI (95%UCL) of metal in Children

Value of Carcinogenic risks above the range of 1E-06 to 1E-04 infers the potential cancer risk (USEPA 1990, 1991a, b). The result revealed that the cancer risk associated with the Cr and Ni are considerably high in comparison to other metals in the study area n both GHs and PHs.

Table 5. Non-carcinogenic (HQ) and carcinogenic risk (CR) for adult and children (95%UCL)

Metals	As	Cd	Cr	Ni	Pb
HQ-A*	4.01E-02	9.03E-03	9.69E-02	5.73E-02	1.98E+00
HQ-C*	1.87E-01	4.20E-02	4.51E-01	2.67E-01	8.30E-02
HQ-A**	7.66E-01	2.70E-02	5.44E-01	1.28E-01	2.34E+00
HQ-C**	3.56E+00	1.26E-07	2.28E-05	2.38E-04	2.13E-07
CR-A*	1.81E-05	5.69E-06	1.22E-02	9.63E-04	1.16E-05
CR-C*	8.40E-05	2.65E-05	5.68E-02	4.48E-03	5.41E-05
CR-A**	3.45E-04	1.70E-05	6.86E-02	2.15E-03	1.38E-05
CR-C**	1.60E-03	7.92E-05	9.57E-04	9.99E-03	6.40E-05

* Govt. installed Hand pump; ** Private hand pump; HQ: Health Quotient; CR: Cancer Risk; A: Adult; C: Children.

4. CONCLUSION

The study conclude that the upper layer of aquifer is not fit for consumption as hand pumps of shallow depth were found to be severely contaminated with the heavy metals. Most of the PHs in the study area was of shallow depth, where as GHs were installed at fair depths, thus low metal contamination was observed in GHs. Health risk assessment model revealed that children population are comparatively more susceptible to both Carcinogenic and Non-carcinogenic risk than Adult population. Non Carcinogenic risk associated with As and Pb and carcinogenic risk associated with Cr and Ni were observed to be potentially high in the study area. The information harvested from QPI

supports health risk model estimation as the health related problems are very prevalent in the study area. Measures in terms of technical innovations and at policy level must be established properly to facilitate effective environmental management.

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