Spatial and Temporal Variation in Rainfall Trends in Victoria

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Abstract

In the present day context, climate change is due to increased release of aerosols into the earth's atmosphere may be of either natural or anthropogenic origin, which in turn raises the atmospheric temperature causing changes in climatic parameters. Changes in rainfall is an important climatic parameter, have a direct influence on human life. This study aims to assess climate change trends focusing on time series monthly rainfall pattern at three closely located rainfall stations in Victoria, Australia for around 130 years. It has been aimed to capture spatial and temporal rainfall variation in the study area and to assess dependency of trends on the selection of the length of the data period. Thus rainfall data of selected three meteorological stations was analyzed for different time-periods: 1889-2016, 1953-2016, 1987-2016 and 1996-2009. Two non-parametric trend tests: Mann–Kendall (MK) and Sen's slope (Q) were used for selected stations to identify trends in annual total and annual maximum rainfall. For annual total rainfall, significant decreasing trends were at the Essendon Airport station for all the periods except the longest period 1889-2016.On the other hand, it showed insignificant trends for all selected periods at the Narre Warren North station whereas a significant decreasing trend was found at the Lovely Banks station for the period 1953-2016. However, annual maximum rainfall had significant trend only at the Lovely Banks station for the period 1987-2016.In general, annual total rainfall was decreasing over time for most cases and had a higher decreasing rate in recent time periods, yet the rate was highly dependent on the time period of the data analysis selected. On the other hand, no significant conclusion can be drawn on annual maximum rainfall for all the stations except the Lovely Banks during 1987-2016. Thus, it could be concluded that climate change is not a simple process, where the interpretation of data is highly dependent on the time period of the data analysis selected.

Keywords**:** Rainfall trends, climate change, non-parametric trend test, Mann–Kendall test, Sen's slope.

1. INTRODUCTION

Climate change relates to the changes in the earth's climate due to increasing release of aerosols into the earth's atmosphere may be of either natural or anthropogenic origin, which in turn increases the atmospheric temperature and changes all other climatic parameters. The international scientific community accepted that increases in greenhouse gases due to human activity, have been the dominant cause of observed global warming since the mid-20th century (CSIRO, 2017). Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system (CSIRO, 2017).

The primary concern related to the climatic impact on hydrologic cycle is the effect on change in rainfall patterns such as rainfall intensity, frequency, and spatial and temporal distributions. Australia's changing climate represents a significant challenge to individuals, communities, governments, businesses, industries and the entire environment. Australia has already experienced increases in average temperatures over the past 60 years, with more frequent hot weather, fewer cold days, shifting rainfall patterns and rising sea levels (DoEE, 2017). The leading scientists advise climate change will cause increases to the frequency and intensity of extreme weather events (DoEE, 2017).

Rainfall variability makes sustainable water resources management more challenging. Understanding this variability and the factors influencing this phenomenon is very important for water managers and policy makers (Loch et al., 2013). The Intergovernmental Panel on Climate Change (IPCC, 2014) reported that significant trends have been observed in precipitation in many regions from 1951 to 2010. Precipitation decreased in the Mediterranean coast, southern Africa and parts of southern Asia, whereas precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia. However, in the study area (South West of Victoria) annual total rainfall 2.4% during 1900-2014 (Timbal et al., 2016).

According to the World Climate Research, in near future (2030) there is high confidence that natural climate variability in Victoria will remain the major driver of rainfall changes from the climate of 1986–2005. Late in the century (2090) under both RCP4.5 and RCP8.5, there is high confidence that cool season rainfall will continue to decline in this region (Timbal et al., 2016).

However, detecting changes in climatic variables are crucial for adaptation measures such as in designing infrastructure and hydrologic modeling. Identifying trends of climate variables are highly dependent on the starting and end dates of data for analysis (Smith, 2004; Stern et al., 2004; Barua et al., 2012). Smith (2004) found no significant trend in Australian rainfall data for the period 1900-2006. Similar results were found by Stern et al. (2004) by analyzing rainfall data of Melbourne for the period 1855-2004. However, Barua et al. (2012) had different conclusions from rainfall trend analysis using data from Yarra River catchment in Victoria, Australia between1953-2006. This study obtained decreasing trends which highlights the importance in the selection of the time period of data when analyzing for climatic trends.

Barua et al. (2012) and Sharma & Shakya (2006) had recommended for local scale analysis of hydro-climatic variables rather than at a large or global scale as there is a high spatial variability in above data.

This study aims to analyze spatial and temporal changes of rainfall data for different time periods for three stations in Victoria, Australia. The study will determine annual total and annual maximum rainfall trends using the non-parametric Mann–Kendall (MK) and Sen's slope (Q) trend tests for varying time-periods, to explore the effect of data lengths on trends of past rainfall observations.

2. METHODOLOGY

2.1. Study Area, Climatic Parameter and Time-periods

Three stations around Port Phillip Bay (in Victoria, Australia) having aerial distance between 50 and 75 km, have been selected to determine the spatial variability of rainfall trends within a comparatively short distance (Figure 1). Two climatic parameters: annual total rainfall and annual maximum rainfall were analyzed for those selected three stations for four study periods 1889-2016, 1953-2016, 1987-2016 and 1996-2009. The study period 1889-2016 was selected to find out long-term trends as it was the available longest period. On the other hand, time period 1953-2016 was selected to analyze mid-term trend and the period 1987-2016 was selected to find out recent climatic trends. In addition, the study period 1996-2009 was selected as it was the millennium drought period in Australia (BoM, 2017), yet though it did not support a standard practice of using at least three-decadal data to determine climatic trends.

The selected three stations were: the Essendon Airport close to the center of Melbourne, the Lovely

Banks at the west of Melbourne and the Narre Warren North to the east of Melbourne. The data used in this study was daily rainfall "patched point" data obtained from SILO (https://www.longpaddock.qld.gov.au/silo/) for the period 1889-2016. As huge gaps were identified for study period in available raw data of BoM site, the SILO data was used in this study. The raw data available for Essendon Airport stations was for the periods 1929-1952, 1960-1986 and 2003-2016; whereas the availability in Lovely Banks was for 1889 and 1892-2016. On the other hand, BoM has raw data of North Narre Warren for the periods 1889-1894, 1896- 2009. In fact SILO has infilled missing data with interpolation which might have implications on the trend analysis.

The historical mean of annual (total) rainfall and median of annual maximum rainfall for the four different time periods are presented in Table 1. Mean annual rainfall for all those time periods at the Essendon Airport and the Lovely Banks stations varied between 455 mm and 583 mm. However, the range of this parameter was much higher at the Narre Warren North station, between 785 mm and 919 mm for the four study periods. Similar patterns were also found for median of annual maximum rainfall (Table 1).

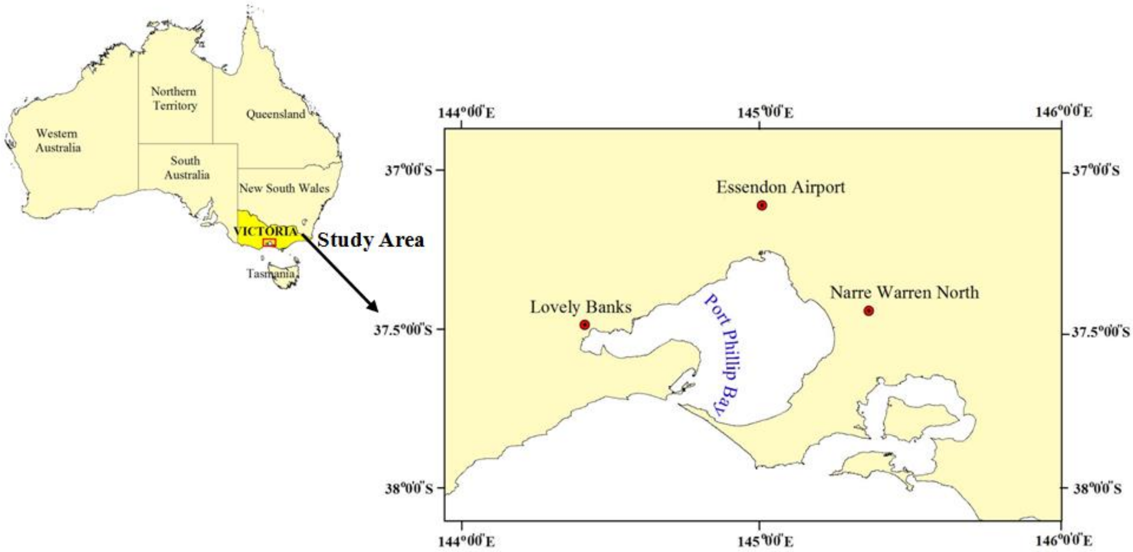

Figure 1. Study area map

Table 1. Mean annual total rainfall and median maximum annual rainfall values in different stations and time periods

Period	Essendon Airport		Lovely Banks		Narre Warren North	
	MATR (mm)	MAMR (mm)	MATR (mm)	MAMR (mm)	MATR (mm)	MAMR (mm)
1889-2016	574	41	522	36	919	48
1953-2016	583	42	523	38	912	48
1987-2016	556	41	505	37	898	50
1996-2009	486	38	455	43	785	45

MATR - Mean annual total rainfall (mm); MMAR - Median annual maximum rainfall (mm)

2.2. Detecting Trends

The purpose of trend tests is to determine if the value of a random variable increase or decrease over a selected period of time is statistically significant (Helsel & Hirsch 2002). Both parametric and non-parametric methods are used to detect significant hydro-climatologic time series trends (Tabari et al. 2011). It is a matter of choice to incline to either of the methods.

The Mann-Kendall (MK), Spearman's Rho (SR) and Sen's slope (Q) tests are examples of non-parametric tests that have been applied widely to detect trends and slopes (Yue et al., 2002; Drapela & Drapelova, 2011; Paulo et al., 2012). The main advantage of MK and SR tests is that the data do not have to fit any particular probability distribution to validate the tests. The studies of Yue et al. (2002);Yenigun et al. (2008); Tabari et al. (2012); Soltani et al. (2012) and Nazahiyah et al. (2012) showed that SR provides results similar to those obtained for the MK test when identifying time series trends. Hence, using one of the techniques is sufficient to get a reliable result.

Non-parametric Mann–Kendall test and Sen's slope have been used in this study to find out trends in rainfall for different time periods and its rate of change of rainfall with time.

It should be noted that Z values derived from MK test represent the presence of a statistically significant trend in the data series. Positive values of Z indicate increasing trends, while negative values show decreasing trends. In addition, if $|Z|> 1.96$, then data series has a significant trend (with95% level of confidence).On the other hand, Sen's estimator of slope represents median of all slopes exists between combinations of any two years.

3. RESULTS

3.1. Mean of Annual Total Rainfall and Median Annual Maximum Rainfall

Table 1 depicts the mean annual total rainfall (MATR) and the median annual maximum rainfall (MAMR) for all the three stations at four selected time periods. In fact, there is a reason of selecting median value for the annual maximum rainfall, instead of mean value. Basically, the annual maximum rainfall is an extreme value in a year and it could be too high or too low. If mean is calculated with that type of data series, it will give wrong impression of data series where this value would be inclined to the extreme value/values (too high or too low maximum rainfall) of that data series. In that case, median is more meaningful which ultimately gives the value of the middle one in the series. However, the long term MATR at the Essendon Airport and the Lovely Bank stations were 37.5% and 43.1% lower than the MATR at the Narre Warren North station. The MATR at the Essendon Airport station varied between 556 mm and583 mm for first three periods, whereas during the millennium drought period it was much lower (486 mm) compared to the other three periods. Similar to the Essendon Airport station the other two stations also have the lowest mean annual total rainfall values during the millennium drought period. All three stations showed almost the same MATR values for the first three periods for each station. At the Essendon Airport station the MATR had decreased between 13% and17% when it was compared to the long term average (full data period). Similarly, at the Lovely Banks station and the Narre Warren North station, the rainfall during the last three periods have decreased by 11% to 13% and 12% to 15% respectively compared to the long term average. However, a similar pattern was not detected for MAMR at all three stations. During the drought period (1996-2009) the MAMR value was lowest at both the Essendon station and the Narre Warren North station. In contrast, the Lovely Banks station had the highest MAMR during the millennium drought period. In fact, the Lovely Banks area had been experiencing low rainfall over long term. However, in 2005 a major storm occurred covering the Port Phillip Bay region. The high MAMR in the Lovely Banks station during the period 1996-2009 was due to that high rainfall value (94.8 mm) in 2005.

3.2. Trends of Annual Total Rainfall

Trend analysis for annual total rainfall (ATR) for the selected stations was conducted for different time periods: 1889-2016, 1953-2016, 1987-2016 and 1996-2009. It was aimed to compare similarity or dissimilarity of trends when data of different periods was used in the analysis. Table 2 shows levels of significance and trends for the three selected stations whereas Figure 2 represent variations in average rate and trend lines for different periods at any station (Essendon Airport).

Table 2. MK and Sen's slope tests for annual total rainfall

Period	Essendon Airport		Lovely Banks		Narre Warren North	
	Z	Q (mm/yr)	Z	Q (mm/yr)	Z	Q (mm/yr)
1889-2016	0.07	0.05	0.03	0.01	-0.68	-0.48
1953-2016	-2.40*	-2.70	-2.42*	-1.13	-1.22	-2.51
1987-2016	-2.03*	-8.15	-1.01	-5.73	0	0.61
1996-2009	-1.97*	-18.90	-1.31	-3.78	-1.64	-6.08

*significant

As presented in Figure 2, the value of average ATR and pattern of trend line of ATR for any period is completely different for other study periods at Essendon airport station which is true for other two stations.

In addition, Table 2 depicts that for the Essendon Airport station, ATR had significant trends for all periods except for 1889-2016. Z values for the periods 1953-2016, 1987-2016 and 1996-2009 are-2.40, -2.03 and -1.97 respectively. For these time periods, ATR had decreasing trends of 2.70 mm/year, 8.15 mm/year and 18.9 mm/year respectively.

The trend patterns were different for the Lovely Banks station. Trend of ATR was significant only for the period 1953-2016 having a decreasing rate of 1.13 mm/year.

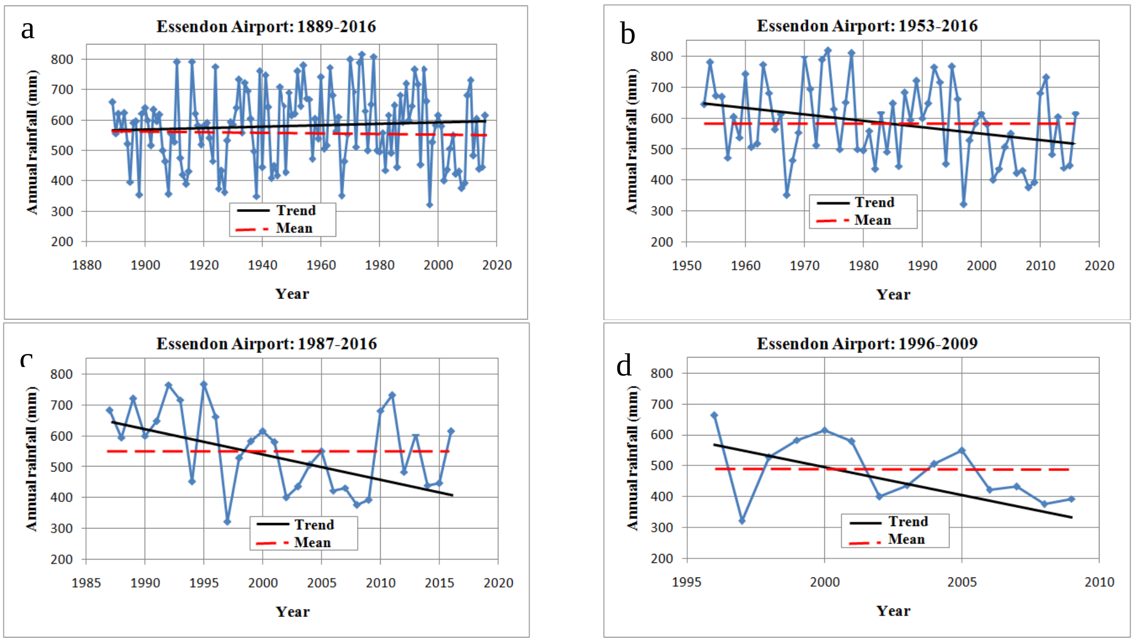

Figure 2. Annual rainfall trend at the Essendon Airport station

At the Narre Warren North station no significant trends for ATR were found for all time periods. Z value was equal to the mean value for the period 1987-2016. At this station the type of change of ATR were different from the other two stations.

For most cases, annual total rainfall was decreasing over time and had a higher decreasing rate in recent time periods accept between the periods 1953-2016 and 1987-2016 at the Narre Warren station. Moreover, for both the Essendon Airport and the Lovely Bank stations the slopes of the trend lines for all other periods were decreasing except for the longest data period (1889-2016) whereas, the Narre Warren North station exhibited a decreasing trend for the longest data period.

3.3. Trends of Annual Maximum Rainfall

Same time periods as above were used to analyze trends for annual maximum rainfall (AMR). In this part of analysis, it was aimed to find out similarity or dissimilarity in extreme rainfall among different periods and locations. Table 3 represents significance of trends and rate of change for the selected stations whereas Figure 3 represent variations in median rate and trend lines for different periods at any station (Lovely Banks).

Table 3. MK and Sen's slope tests for annual maximum rainfall

Period	Essendon Airport		Lovely Banks		Narre Warren North	
	Z	Q (mm/yr)	Z	Q (mm/yr)	Z	Q (mm/yr)
1889-2016	1.17	0.03	1.92	0.09	0.19	0.03
1953-2016	-0.83	-0.18	-0.42	-0.11	-0.84	-0.22
1987-2016	0	-0.21	-2.07*	-1.03	0.03	0.70
1996-2009	0.44	1.44	0	-0.48	0.44	0.95

*significant

Similar to ATR, the value of median AMR and pattern of trend line of AMR for any period is completely different for other study periods at Lovely Banks station (as presented in Figure 3) which is true for other two stations.

In fact, significant trend for AMR was found only at Lovely Banks staion for the period 1987-2016 which was a decreasing rate of 1.03 mm/year (Table 3).

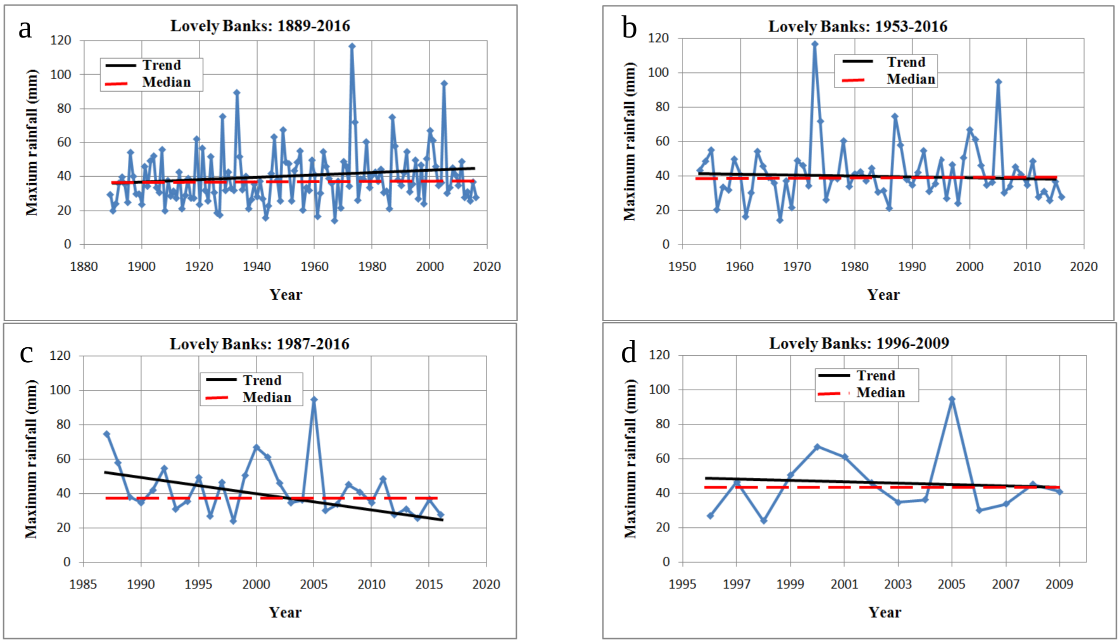

Figure 3. Maximum rainfall trend at the Lovely Banks station

4. DISCUSSION

For both annual total rainfall and annual maximum rainfall, the longest period (1889-2016) doesn't have any trends.

In general trends at any particular period could be significant or insignificant in close by stations. For instance, during 1953-2016, annual total rainfall had significant decreasing trend at the Essendon Airport and the Lovely Banks stations. But it was insignificant for the same period at the Narre Warren North station.

In addition, for any particular time-period, closely located stations may have different types of trends. For instance, during 1987-2016 maximum rainfall had decreasing change rate at the Essendon Airport and the Lovely Banks stations whereas it showed increasing change rate at the Narre Warren North station for the same study period. Furthermore, during recent times (1996 – 2009) although the annual total rainfall was decreasing for all three stations the maximum annual rainfall was increasing for Essendon Airport and Narre Warren North stations. In fact, any station may have higher amount of annual maximum rainfall even when it is experiencing lower annual total rainfall. Basically that happened to Essendon Airport and Narre Warren North stations during drought period which actually explained increasing rate of annual maximum rainfall with decreasing rate of annual total rainfall.

However, the annual total rainfall had highest decreasing rate at drought period (1996-2009) at all stations except for the Lovely Banks station. In fact, Lovely Banks station had been experiencing lower rainfall over the time so that drought was not that much visible in that area. That might be a reason of that particular station didn't have highest rainfall decreasing rate during drought period.
Furthermore, drought period might also have influenced trend for the period 1987-2016 which was especially visible at Essendon Airport station having much higher decreasing rate of annual total rainfall than that of the previous longer period (1953-2016).

In fact, the results from the current study confirm the findings by Smith (2004); Stern et al. (2004) and Barua et al. (2012). Similar to Smith (2004) and Stern et al. (2004) no significant trends in the study stations were found for the period 1889-2016. Furthermore, all three stations showed decreasing trends in rainfall data during the period from 1953 to 2016 which confirms the finding by Barua et al. (2012). This highlights the importance in the selection of the time period of data when analyzing for climatic trends. It also confirms Barua et al. (2012) recommendation of importance of analyzing the data on local scale rather than at a large or global scale as there is a high spatial variability in the data.

5. CONCLUSION

The study was carried out to identify the dependency of the data periods selected and the location of the data analysis on rainfall trends. For the same rainfall station different rainfall trends were identified based on the time periods selected for the analysis. Furthermore, although the three stations selected were only 50 to 75 km apart, different trends were identified for the same data period. In general, it is clear that the rainfall trends are dependent on the selection of time-period as well as the location of the rainfall stations.

In addition, drought might not be that much prominent in any locality which has been experiencing lower rainfall over the period and it might influence trend of nearest study period with extreme decreasing rate.

It cannot be concluded from the study that the selection of any particular time-period of data had significant or insignificant trends in annual total rainfall or the maximum annual rainfall. It is also dependent on the location of the study. In trend analysis, the selection of time period should be completely dependent on the objective of the analysis or the research.

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