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Analysis of Historical Climate Change Trends in Bharathapuzha River Basin, Kerala, India

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ABSTRACT

Climate change is considered as a global phenomenon, but investigations at the regional level are essential to understand the changes induced, and to suggest suitable adaptation strategies. This study is mainly concerned with the variation of temperature and rainfall in a river basin which lies in the tropical climate of India. Observed temperature and rainfall data were compared with the gridded data prepared by the Indian Meteorological Department (IMD) and was found comparable. The trend analysis of mean, maximum and minimum temperatures during 1951-2013 showed a significant warming trend with Mann-Kendall test statistic values of 4.63, 5.52 and 3.63 respectively. The increase in mean, maximum and minimum temperatures during the period were at the rate of 0.07°C/decade, 0.14°C/decade and 0.04°C/decade respectively. Trend analysis of the gridded rainfall data for the period 1971-2005 showed statistically significant decreasing trend, at the rate of 15 mm/year. Mann-Kendall and t-test gave a statistical significance at a level of a=0.1 and a=0.05 respectively. Trend analysis of seasonal rainfall indicated that there was no significant trend in rainfall except during the south-west monsoon period. Appropriate mitigation measures need to be undertaken for controlling the future scarcity of water considering the increasing temperature trends and decreasing rainfall pattern.

INTRODUCTION

Climate change, rapidly increasing population and depletion of natural resources has become global challenges which influence the socio-economic well-being of the people. Agricultural production and water resource availability are affected by the changes in rainfall and temperature. Several researchers have studied the variability and trends in temperature and rainfall across the globe to understand the severity of climate change. An increase of 0.89°C (0.69-1.08°C) in the global land and ocean temperature combined, was reported during the period 1901-2010 (IPCC 2013). Many researchers worldwide (Longobardi & Villani 2010, Mondal et al. 2012, Dash et al. 2013) have contributed to the study of climate change based on the analysis of long term climate data. Study of the temperature regimes and changes in the general rainfall pattern at local level is needed for understanding the regional scenarios. Increasing trends in maximum temperature have been reported from various parts of the world (Kothawale et al. 2010, Keggenhoff et al. 2014 and Opiyo et al. 2014). For the proper planning of regional water resources it is essential to study the trend of past rainfall (Ziv et al. 2013, Keggenhoff et al. 2014, Nyatuame et al. 2014, Thomas et al. 2014).

In the Indian context, the spatial and temporal pattern of monsoon rainfall is strongly affected by the changes in the air and ocean temperatures (Jagadeesh & Anupama 2014, Goswami et al. 2006). Agriculture and other related sectors of India (George et al. 2002) and especially Kerala depends mainly on the monsoon rainfall, viz. South-West (June-Oct) and the North-East (Oct-Nov). In addition to agriculture and related sectors, electricity generation (hydroelectric), industries and various other activities depend on the monsoon rains. Proper planning of strategies needed to mitigate the extreme events can be done based on the results of the trend analysis. Though Kerala, the southernmost state of India is blessed with an annual average rainfall of 3107 mm (India-Wris 2015), the flow in the rivers during summer has become meagre. The variations of different climatological parameters are highly location specific, and hence studies need to be done at the regional level. It has been reported that there is a severe drought and shortage of water in the basin (CWRDM 2004). So this paper aims to understand the temporal variability of temperature and rainfall as well as to study the occurrence of drought in the Bharathapuzha river basin in Kerala. The results of the study will help in developing management strategies which bridge the gap between the water needs and the possible supply.

STUDY AREA

The Bharathapuzha river basin, which lies between 10°25'-11°25'N and 75° 50'- 76°55'E, is the second longest basin in Kerala with a length of around 209 km. It extends over an area of 6186 square kilometres spread over the two states of India, namely Kerala and Tamil Nadu with an aerial extent of 71% and 29% respectively. The river originates from the Anamudi Peak having a height of 2695 m above MSL in Devikulam Taluk, Idukki District, Kerala to the southern portion of Western Ghats and flows west through the Palakkad gap and finally drains into the Arabian sea at Ponnani, Malappuram district, Kerala. Sand mining and unsustainable exploitation of natural resources have caused a dying state of the river during the summer season.

DATA AND METHODOLOGY

Gridded data of rainfall (0.5° × 0.5°) and temperature (1° × 1°) prepared by the Indian Meteorological Department (IMD) for the Indian region have been used in the study. The gridded data on rainfall was prepared based on 1803 rain gauge stations with a minimum data availability of 90% for the period 1951-2008. Shepard (1968) method was used for data interpolation. The weighted sum of the observations at the surrounding rain gauge stations falling within the predefined radius of influence is considered. The entire data of Indian region has been interpolated into 35 × 32 grid cells.

The daily gridded interpolated rainfall data for the area were taken from the data of the Indian region. It was compared with the direct observation for the grid where rain gauge data were available (Alathur) for the period 1976-97. This comparison was done based on the coefficient of determination (R^2) between the gridded and observed data. The range of R^2 values obtained was 0.53-0.99 which showed moderate to very strong correlation between the two sets of data. Rainfall analysis was carried out for all the seasons as well as the whole year separately for each station. The statistical parameters mean, maximum, minimum, standard deviation and coefficient of variation for rainfall data have been computed for seasonal and annual periods. Gridded data of mean, maximum and minimum temperature were also analysed to study the temporal changes in temperature.

Trend analysis: The magnitude of the trend was determined using regression analysis (parametric test) and using Mann-Kendall test (non-parametric method). Both these methods assume a linear trend in the time series. Time is taken as the independent variable and rainfall/temperature as the dependent variable in the regression analysis. The linear trend value represented by the slope of the simple least-square regression line provided the rate of increase/decrease in the variable. The trend analysis was carried out for the temperature (mean, maximum and minimum) and rainfall data using the Mann-Kendall test as well as using t-test.

Mann-Kendall test: The Mann-Kendall test is a non-parametric statistical procedure which is well suited for identifying trends in data over long time periods (Mann 1945, Burn et al. 2004, Thomas et al. 2014).

$$S = \sum_{k=1}^{n-1} \sum_{j=i+1}^{n} sgn(xj - xk) \qquad ...(1)$$

The Mann-Kendall statistic 'S' measures the trend in the data and the positive values indicate an increasing trend, whereas, negative values indicate a decrease in value over time. There are n data points and xi, xj, xk represents data points at time i, j and k respectively. The strength of trend is proportional to the magnitude of 'S' (i.e., large magnitudes indicate a strong trend).

The null hypothesis is that there is no trend (H_0) in the time series. Using the Kendall probability table and by assessing the 'S' result along with the number of samples 'n' we get the probability of rejecting the null hypothesis for a given level of significance.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \text{for } S > 0 \\ 0 \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \text{for } S < 0 \end{cases} \qquad ...(2)$$

'Z' follows a normal distribution and if the 'Z' value is positive and the computed probability is greater than the level of significance, there is an increasing trend. If the 'Z' value is negative and the computed probability is greater than the level of significance, there is a decreasing trend.

RESULTS AND DISCUSSION

Analysis of Temporal Trends in Temperature

The monthly gridded temperature data were first compared with the observed data and the R^2 values obtained showed satisfactory correlation between the two. The R^2 values showed moderate to very strong correlation between the two data sets and it varies from 0.53 to 0.82 for maximum temperature and 0.25 to 0.90 for minimum temperature.

The changes in temperature affect the hydrologic cycle and hence in the climate change studies of river basins, the trend in temperature is important. The statistical characteristics of the mean, maximum and minimum annual temperature in the Bharathapuzha basin obtained from the gridded data (1°×1°) of IMD for the period 1951-2013 are presented in Table 1. The mean monthly maximum temperature was recorded for the month April (31.4°C) and the minimum temperature was recorded for the month of January (16.8°C).

Month-wise variation of mean temperature and maximum temperature are plotted in Fig. 1. The region experiences maximum temperature during March-April and minimum during December-January. The temporal variation of mean temperature during 1951-2013 is shown in Fig. 2. There is an increasing linear trend which implies that there is a positive linear relationship between annual averages of mean temperature and time. This warming up is at the rate of 0.069°C/decade. Similar increasing trends in mean annual temperatures have been reported from various parts of India (Arora et al. 2005, Bhutiyani et al. 2007, Thomas et al. 2014). While comparing the trend of maximum temperature from various parts of India, Rathore et al. (2013) reported maximum rate of increase in Himachal Pradesh (0.06°C per year).

The temporal variation of mean maximum temperature with time was also studied by plotting trend lines as well as using the Mann-Kendall test and t-test. Variation of maximum and minimum temperature with time during the period 1951-2013 is plotted in Figs. 3 and 4 respectively.

The trend is shown by the linear regression line whose equation and R^2 values are also given in the figure.There is an increasing trend in maximum temperature with an increase of 0.14°C/decade and there is an increase of 0.68°C during the period 1951-2013. Studies conducted by Kothawale et al. (2010) also revealed that the annual mean (average of maximum and minimum), maximum and minimum temperatures showed significant warming trends of 0.51, 0.72 and 0.27°C respectively over 100 years during 1901-2007. The results of the Mann-Kendall test and the t-test (Tables 2 and 3) also confirmed the results obtained from the linear regression analysis. At an annual scale the Mann-Kendall test of maximum temperature resulted in an increasing trend at 1% level of significance. The data set is divided into two (1951-1981 & 1982-2013) and t-test was conducted to test the significance of these two data sets. The mean of maximum temperature for the periods 1951-1981 and 1982-2013 were estimated as 28.17°C and 28.71°C and the t-test results showed that the two data sets are significantly different. Similar analysis was conducted for average temperature and minimum temperature and the means were found statistically different.

Studies of Trends in Rainfall

Comparison of observed and gridded rainfall data: The gridded data were compared with the observed data and the R^2 values obtained showed satisfactory correlation between the two. R^2 values ranged between 0.53 and 0.99 which showed moderate to very strong correlation between the data.

Hence the gridded data were used for analysing the temporal and seasonal changes in rainfall. The statistical characteristics of rainfall in the Bharathapuzha basin obtained from the gridded data (0.5° × 0.5°) of IMD for the period 1971-2005 are presented in Table 4. About 60% of rainfall occur in the months of June, July and August. Maximum average monthly rainfall was received during July and minimum was recorded in January.

Temporal variation of rainfall: The temporal variation of rainfall during 1971-2005 is shown in Fig. 5. The trend line is fitted with a linear equation, with a coefficient of determination (R^2) value of 0.118. There is a decreasing trend in rainfall and a decrease of 15 mm/year is noted in case of average annual rainfall during this period. The results of the Mann-Kendall test and linear regression analysis (Table 5) also showed a statistically significant decline in rainfall at 99% and 95% confidence level. Analysis of climatological data for 140 years (1871-2007) over Kerala (Krishnakumar et al. 2009) in India indicated cyclic trend in annual rainfall, whereas during the past 60 years (1950-2010) there was a decreasing trend in annual and southwest monsoon rainfall, whereas in certain locations the rainfall trends were uncertain.

Seasonal trend in rainfall: While analysing the average monthly variation of rainfall during the period 1971 to 2005 it is seen that maximum rainfall occurred during the month of July (515.5 mm) and minimum during January (2.5 mm). Around 60% of the average annual rainfall occurred during the months of June, July and August. For assessing the trend of rainfall based during four major rain giving seasons (Ananthakrishnan et al. 1979), annual rainfall was divided into south-west monsoon (June-September), north-east monsoon (October-November), pre-monsoon months or summer rains (March-May), and winter rains (December-February). Rainfall trend during the four seasons is shown in Fig. 6.

Mann-Kendall test done to test the trend of seasonal rainfall indicated that there is a significant decreasing trend in case of south-west monsoon in the region during 1971-2005. In all the other seasons (North-East, summer and winter) there is no significant trend in rainfall. Krishnakumar et al. (2009) analysed the seasonal trend of rainfall in Kerala state as a whole during the period 1871 to 2005 and found that there was a significant decreasing trend in the south-west monsoon and increase in post monsoon season, whereas rainfall during summer and winter had an insignificant decreasing trend. A better understanding of the trends or variations in temperature and rainfall of an area will thus be helpful for evaluating the uncertainties associated with the

Table 1: Statistical summary of monthly averages of maximum temperature, mean temperature and minimum temperature during 1951-2013.

	Maximum temperature (ºC)			Mean temperature (ºC)			Minimum temperature(ºC)		
	Mean	SD	CV(%)	Mean	SD	CV(%)	Mean	SD	CV(%).
January	28.0	0.54	1.92	22.4	0.60	2.68	16.7	0.66	3.92
February	29.4	0.59	2.00	23.6	0.51	2.18	17.8	0.68	3.80
March	31.1	0.85	2.74	25.3	0.61	2.41	19.5	0.50	2.55
April	31.4	0.92	2.92	26.2	0.86	3.29	21.0	0.47	2.25
May	30.4	0.91	3.00	25.8	1.21	4.68	21.0	0.51	2.44
June	27.7	0.75	2.71	24.0	1.06	4.40	20.1	0.41	2.02
July	26.6	0.72	2.69	23.2	0.68	2.95	19.6	0.28	1.40
August	26.7	0.51	1.92	23.3	0.53	2.29	19.7	0.29	1.47
September	27.6	0.60	2.17	23.7	0.47	1.99	19.7	0.27	1.38
October	27.6	0.58	2.10	23.6	0.46	1.96	19.5	0.35	1.79
November	27.2	0.50	1.85	23.0	0.34	1.46	18.8	0.55	2.93
December	27.3	0.57	2.07	22.4	0.47	2.10	17.6	0.69	3.93

Table 2: Mann-Kendall test results for climatic variables of Bharathapuzha basin.

Variable	S-value	Z-value	Results
Maximum temperature	931	5.52	Statistically significant trend (at a<0.01)
Mean Temperature	782	4.63	Statistically significant trend (at a<0.01)
Minimum temperature	121	3.63	Statistically significant trend (at a=0.01)

Table 3: Results of t-test for climatic variables of Bharathapuzha river basin.

	1951-1981	1982-2013	Results
Mean of Max. temperature	28.17	28.72	Mean of 1951-81 and 1982-2013 is significantly different at a<0.01
Mean of Avg. temperature	23.74	24.03	Mean of 1951-81 and 1982-2013 is significantly different at a<0.01
Mean of Min. temperature	19.15	19.37	Mean of 1951-81 and 1982-2013 is significantly different at a<0.01

Table 4: Statistical summary of monthly averages of rainfall during 1971-2005.

	Mean(mm)	SD	CV(%)
January	2.5	0.08	3.4
February	6.8	0.24	3.6
March	14.8	0.24	1.6
April	73.7	0.57	0.8
May	135.8	0.89	0.6
June	473.6	2.36	0.5
July	515.5	1.82	0.4
August	341.0	1.23	0.4
September	169.6	1.14	0.7
October	226.5	1.06	0.5
November	118.8	0.98	0.8
December	24.8	0.47	1.9

management of water resources.

The regional scale variations in rainfall over India have been studied by many researchers with the analysis of annual and seasonal series of rainfall. Rathore et al. (2013) reported that in case of monthly rainfall, spatially coherent increasing trends were observed in Feb, May and June while in Jan, March, July and September there were decreasing trends in most states of India. Increase in extreme rainfall events have been reported from various parts of the country (Thomas et al. 2014, Goswami et al. 2006, Rajeevan et al. 2008), whereas varying trends in different seasons for the same area were also reported (Krishnakumar et al. 2009, Manikandan & Tamilmani 2012, Thomas et al. 2014).

SUMMARY AND CONCLUSION

This study analysed changes in temperature and precipitation in the Bharathapuzha river basin based on the gridded data provided by IMD. The trend in daily rainfall, mean, maximum and minimum temperature were analysed considering those as indicative of climate change phenomenon and that which influences the catchment hydrology. The gridded data were compared with the observed data for the grids and corresponding time period and R^2 values showed moderate to strong correlation between the two data sets.

The trend analysis of mean temperature during 1951-2013 showed an increasing trend, which indicates that there is a positive linear relationship between annual averages of

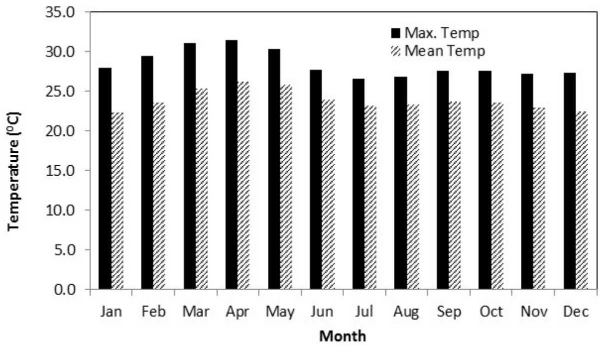

Fig. 1: Month-wise variation of mean and maximum temperature.

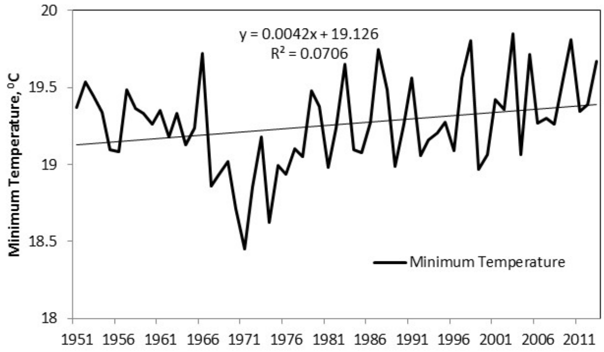

Fig. 4: Variation of minimum temperature with time.

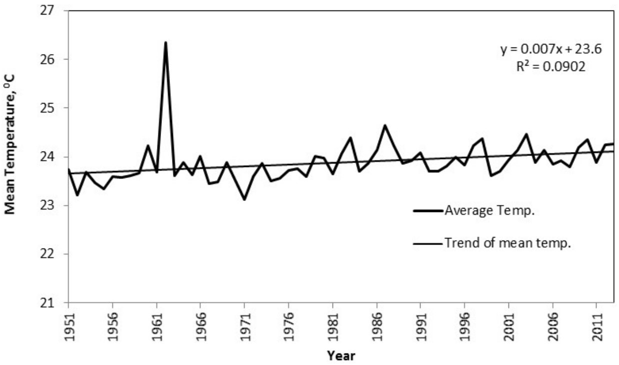

Fig. 2: Variation of mean temperature with time.

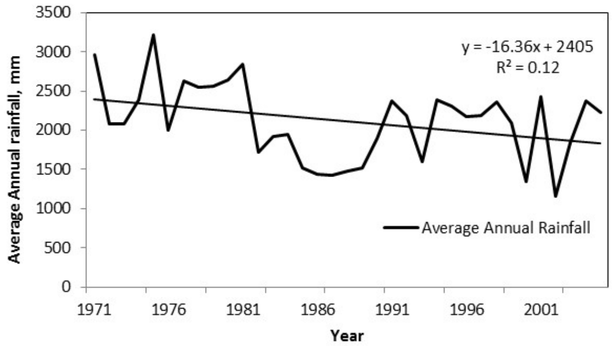

Fig. 5: Temporal variation of rainfall.

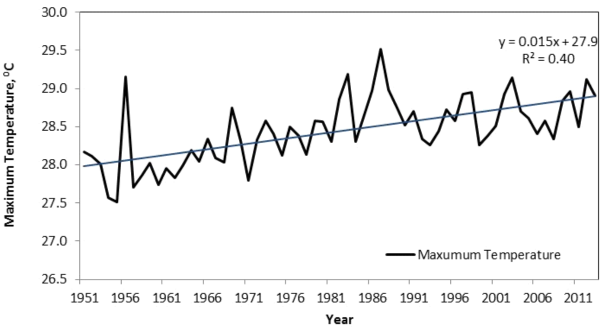

Fig. 3: Variation of maximum temperature with time.

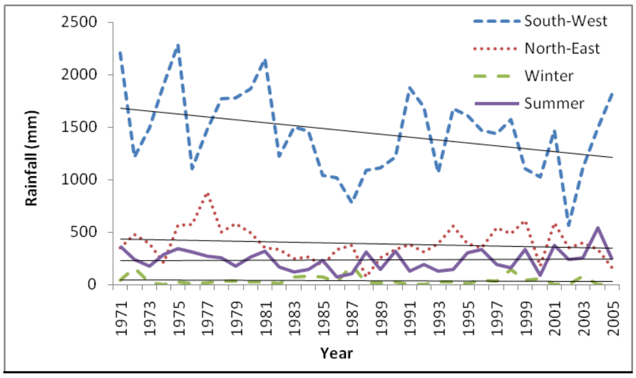

Fig. 6: Seasonal trend of rainfall in Bharathapuzha basin.

mean temperature and time and that the rate of increase is in the rate of 0.0069°C/year. The maximum temperatures during this period also showed a similar trend. The results were confirmed using the Mann-Kendall test and t-test. The z-values obtained for mean temperature and maximum temperature was 4.632 and 5.516 respectively, which show that the variation is statistically significant at 95% level of significance.

The trend in rainfall in the region was also analysed. The trend in average rainfall showed statistically significant decreasing trend and the decrease is at the rate of 15 mm/year during 1971-2005. Mann-Kendall test gave a statistical significance at a=0.1. In the t-test also, statistical significance was at a=0.1. In case of rainfall, seasonal trend was also analysed. Significant increasing trend occurs in case of south-west monsoon in the area during 1971-2005. In all the other cases (North-East, summer and winter) there is no significant trend in rainfall at 99% level of significance.

Bharathapuzha basin is the major drinking water source for most of the villages in the Palakkad, Thrissur and Malappuram districts of Kerala. The river is the main water source for several minor irrigation schemes. An expert committee appointed by the Government of Kerala to investi-

Table 5: Mann-Kendall and linear regression results for rainfall.

	Test statistic	Critical values (Statistical Table)			Results
		a=0.1	a=0.05	a=0.01	
Mann-Kendall	-1.70	1.65	1.96	2.58	Statistically significant decreasing trend at a=0.1
Linear regression	-2.11	1.69	2.04	2.74	Statistically significant decreasing trend at a=0.05

gate into the problems of Bharathapuzha reported that the system is seriously affected by unsustainable exploitation of its surface and groundwater resources, particularly during the lean period. A drastic increase in urban areas, deforestation, sand mining and decrease in natural vegetation in the area might have caused increase in temperature and decrease in rainfall over the area. This study will give an insight to the hydrologists and planners in arriving at potential solutions which can bring down the ill effects of climate change and variability in the study area.

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