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Temperature and Rainfall Dynamics in Penganga Sub-Watershed, Maharashtra

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Abstract

Temperature and rainfall variability are making agrarian economies in semi-arid parts across the globe highly vulnerable. In India, Penganga Sub-watershed located in one of the semi-arid zone too faces frequent crop failures. This paper attempts to investigate the presence and absence of trends in temperature and rainfall as well as their spatial variability over a period of 30 years. Non parametric Mann Kendall test on monthly rainfall and temperature data obtained from India Metrological Department for ten stations were conducted to identify trends. Inverse Distance Weighted interpolation technique was also applied to identify a spatial pattern of the deviations in temperature and precipitation from that of the monthly normal. A rising trend in temperature during pre-monsoon, monsoon and post monsoon months were observed. A declining trend in the amount of rainfall was assessed during the monsoon and the pre monsoon seasons. Spatial pattern of temperature and rainfall trends showed that during monsoon the southern parts of the sub-watershed faced considerable increase in temperature and fall in precipitation concurrently.

Introduction

The marginal semi-arid lands all across the globe are being converted to arable ones (Lopez et.al, 2001a, b; Hammer et.al, 1987; Verburg et.al, 2001; Granger, 1998; Francisco et.al, 2008). These marginal lands experience high temperature conditions and scanty rainfall pattern. Climate variability is making these already stressed conditions more vulnerable due to introduction of unsustainable agrarian practices. India too has been experiencing high variability in climatic conditions. Temperature variability during summer months and rainfall variability in the monsoon season have become quite pronounced and even alarming at places Pal et.al, (2009).

The Penganga sub-watershed located in the Central parts of Deccan India experiences scanty rainfall and extreme summer temperatures that largely affect the agricultural productivity. Normally, average annual rainfall varies from 200 - 300 cm. January is the coldest month with temperature ranging between 20 - 25ºC and April is the hottest month when it rises above 30ºC. The river is a rain fed one and remains almost dry during the most parts of the year. The major sources of irrigation are wells, canals and tanks. Wells account for 60% of the irrigated area, canals for 20%, and tanks for the remaining 20%. Canal irrigation is largely confined to the areas where topography favours construction of reservoirs.

About 60% of the area in the sub-watershed is under cultivation and only 1/10th of it receives irrigation. Agrarian policies and market demand has led to changes in cropping pattern from less water intensive crops to more water intensive crops. Instead of Gram, Jowar and Maize, water intensive crops like hybrid-Cotton, Orange, Wheat are being emphasized upon for cultivation (Steduto, et. al, 2012), thus creating pressure on the available water resources.

Temperature and rainfall pattern determine the water availability in an area to a substantial extent. Scholars (Zhang et.al, 2013; Francisco et.al, 2008; Wang et.al, 2014) have explicitly proved the impacts of climate variability on agricultural productivity and cropping pattern changes. Hence identification of trend of temperature and rainfall pattern would enable better decision making and policy planning initiatives for sustainable agricultural practices and optimal water utilization in the region under study. Hence, the current analysis to identify the nature of the monthly trends of temperature and rainfall and its spatial variation across the sub-watershed.

Materials and Methods

According to Gandhi and Namboodiri, 2009 hybrid varieties of cotton were introduced in the area during the early 1970s. To suffice for the crop water requirement the number of irrigational structures in the form of minor, medium and major irrigation tanks started increasing. Yet crop failures were frequently reported during this time frame.An assessment of climate trends led to the collection and analysis of rainfall and temperature data for 1970-2002. Monthly maximum temperature, monthly minimum temperature, monthly average temperature and monthly rainfall data were obtained for Buldana, Parbhani, Nanded, Washim, Yeotmal, Amravati, Wardha, Nagpur, Betul and Chandrapur (Fig. 1).

Climate trends assessments have been studied through various statistical analysis like linear and non-linear trend analysis (Fiona, 2009;Schneider, 2004; Antonio, 2010), climate change models (Blenkinsop, 2007; Jian et.al, 2006) and Mann-Kendall trend test (Khaled, 2008; Dileepet.al, 2007; Xu, 2003; Yonghui et.al, 2009). The Mann-Kendall test is the most widely used technique for the analysis of increasing or decreasing trends in hydro-meteorological studies, especially to identify the climatic variability (Hirsch et.al; 1991 Cannarozzo et.al, 2006).

In this study to identify the variability in temperature and precipitation for all the months across ten stations, Mann-Kendall trend test (Mann, 1945; Kendall and Gibbons, 1990) has been applied. This help inascertaining the direction and magnitude of the trend. The non-parametric Mann-Kendall tests involve computing a statistic S, which is the difference between the numbers of pairwise slopes. That is positive values minus the negative values. If S shows a large positive value, then there is indication of an increasing trend in the data. If S shows a large negative value, then there isa suggestion of a decreasing trend in the data. The basic Mann-Kendall trend test engages listing the values in temporal order, and computing all differences that may be formed between current measurements and earlier measurements. The test statistic (S) shows the difference between the number of positive and negative values. If these differences were positive then there is an upward trend. Differences of zero are not included in the test statistic. Equations 1, 2, 3, 4 and 5 have been used consecutively for the computation of Mann - Kendall Z value.

$$\operatorname{sgn}(Xj - Xk) = \begin{cases} +1 & if\,(Xj - Xk) > 0 \\ 0 & if\,(Xj - Xk) = 0 \\ -1 & if\,(Xj - Xk) < 0 \end{cases} \quad \text{------(1)}$$

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(Xj - Xk) \quad \text{-------(2)}$$

$$Var(S) = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)/18 \right] \quad \text{-------(3)}$$

$$Var(S) = \left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5) + \sum_t t(t-1)(2t+5)/18 \right] \quad \text{------ (4)}$$

In the above equations X_j and X_k are the actual values of temperature and precipitation for the j^{th} and k^{th} year, n is the total number of years and t is the tied observations (i.e., when two or more measurements are equal) that degrade the statistical power and are avoided.

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{s+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases} \quad \text{----- (5)}$$

After calculation of variance *Var(S)* the standard normal variate *Z* is calculated using equation 5.

For testing the hypothesis, H0 (no trend) would appear in case $Z = 0$. H1 an upward trend hypothesis would be accepted if $Z > 0$ or $Z_{1-\alpha}$ and H2 a downward trend hypothesis would be accepted if $Z < 0$ or $Z_{1-\alpha}$value were obtained from table values of student's distribution. *Z* values obtained were tested for their significance data at 95% level of confidence.

If the values were above or below ±1.645 then it would indicate significant positive and negative trends respectively. In order to analyse and compare the monthly variations in trends, the Mann-Kendall *Z* values were graphically plotted for each station. In addition to estimate the amount of change in trend it is also necessary to look into the deviations in the observed values from that of the normal, especially in unevaluated regions.

The data for the ungauged and unevaluated regions can be obtained through spatial interpolation. Spatial interpolation becomes particularly challenging when climatic stations are few and widely separated as well as long term records are rarely available for particular sites, so as a surrogate regional climate data from nearby climate stations are frequently utilized (Running et.al., 1987; Nalder and Merriam, 1995; Sykes and Prentice, 1995.

Spatial Interpolation for representation of spatial variability has been extensively used in different research works which includes mapping of temperature and rainfall Jones and Thornton (1997), Bitew and Gebremichael, (2010). There are large numbers of interpolation techniques as well. Shepards (1968) discussed in details Inverse Distance Weighted (IDW) technique, Deutsch and Journel (1998) kriging, Goodman and O'Roorke (1997) splines and Harbaugh and Presian (1968) Fourier series. Distance weighting, which estimates the variable of interest by assigning more weight to closer points, is the simplest technique (Ware et.al, 1991).

The generic equation for IDW interpolation is shown in equation 6, as follows —

$$Z_{xy} = \sum_{i=1}^{n} Z_i W_i \Big/ \sum_{i=1}^{n} W_i \quad \text{---------- (6)}$$

where Z_{xy} is the point to be estimated, Z_i represents the control value for the i^{th} sample point. W_i is a weight that determines the relative importance of individual control point Z_i in the interpolation procedure. $i = 1$ for the n control points nearest to the point being interpolated. In this analysis, the IDW interpolation technique has been applied to understand the spatial variation in the deviation of observed data to that of the climatological normal of 1951-1980. This would present the areas where maximum changes in temperature and rainfall has occurred, in addition to the trend analysis.

Results and Discussion

The sequential Mann Kendall test applied on the monthly temperature and rainfall data for ten stations in the Penganga sub-watershed have shown high seasonality as well as high variability. Figure 2 graphically represents the months and stations with trends for both maximum and minimum temperatures. The analysis of maximum and minimum temperature data over the months in Penganga sub watershed shows that during August, September, October and November that is in the monsoon and post monsoon seasons, there has been significant rise in temperature in all the stations. The confidence level of the rising trend during these months can be statistically confirmed to range from 80-99%.

The stations Buldana, Yeotmal, Parbhani and Wardha have shown stepper and higher upwards trend of monthly maximum temperatures in comparison to the monthly minimum temperatures. On the other hand in Nanded, Chandrapur, Washim, Amravati and Betul showed faster rise in monthly minimum temperatures than maximum temperatures. The second half of the post monsoon months, December and January showed a rather contrasting scenario in most of the stations. In Buldana, Yeotmal, Parbhani, Nagpur, Wardha and Chandrapur declining trends were seen in December, whereas rising trends in January. Though the declining trends were insignificant, the ascending trends during January were mostly significant across all the stations. Exceptional cases have also been observed in Washim, Amravati and Betul, where during both December and January the temperatures showed significant rising trend.

In February however, both maximum and minimum temperatures showed downward trends in Buldana, Yeotmal, Nagpur, Amravati and Betul of which the significant drop in maximum temperature was realized only in Amravati and Betul. Though rising temperature trends are also recorded during February in Parbhani, Nanded and Chandrapur, but they are negligible except for Wardha and Washim. In Washim the rising trend during February reflected 99% level of significance. Thus during pre monsoons, especially in March, April and May positive temperature trends in Buldana, Yeotmal, Parbhani and Nanded were experienced of which Washim had a significant trend. Negligible declining trends in monthly minimum temperatures have been observed in Nagpur, Wardha, Amravati and Betul. The overall scenario of temperature trends show significant rise during the monsoon and post monsoon.

The Figure 3 shows a similar assessment of the trends with monthly average temperatures and monthly rainfall. The monsoon season which comprises June, July, August and September, according to India Meteorological Department categorization, hardly experiences any significant rising trend in rainfall. In June, Buldana, Parbhani, Wardha, Amravati, and Betul observed a negligible upward trend in rainfall, whereas Washim, Chandrapur,Nagpur, Nanded and Yeotmal observed downward trend. In July Buldana, Yeotmal, Parbhani, Nanded, Nagpur, Washim, Amravati and Betul experienced significant declining trend with 80-90% confidence level. The only exceptions were Wardha and Chandrapur stations which experienced rising trends in rainfall, the latter having a significant value. In August though all the stations experienced rising trends, significant ones were observed only in Nanded and Chandrapur.

On the other hand in September while Buldana and Yeotmal had experienced significant ascending rainfall pattern, the other eight stations had faced significant declining trend. All the stations during October had seen increasing rainfall trends, with Nagpur and Wardha stations having 95% level of confidence. Similar spatial trend is also seen during November in the sub watershed. During the post monsoon season, December observes downtrend rainfall trend in Buldana, Nagpur, Chandrapur, Washim, Amravati and Betul. Of all, Chandrapur station experienced the maximum change. During January negligible positive trends were found in most of the stations except for Washim and Buldana, which experienced negative trend. In February the significant rising trend in rainfall were identified for all the stations.

During the summer months significant declining trends were observed during March and April except for Parbhani. In May rising rainfall trends were identified in Buldana, Yeotmal, Nanded, Nagpur, Wardha, Chandrapur, Amravati and Betul. Parbhani and Washim showed negligible descending trend on the other hand. Thus the overall scenario of temperature and rainfall pattern in the sub watershed showed no significant rising rainfall trend during the monsoons, but prominent ascending temperature trends. The post monsoon season too observes steep rise in temperature, but noteworthy rise is. In summers high variability in both temperature and precipitation is witnessed. In order to understand the gravity of the situation, and to assess the impact of deficiency of water on the agrarian economy, it is necessary to look into the magnitude of change and the regions of change. The estimation of the deviations of the observed from the normal was thus plotted spatially through spatial interpolation technique IDW.

The Figure 4 shows the deviations in the rainfall and temperature conditions on a monthly basis. The deviations in rainfall had been classified at 2mm interval while the departures in temperature had been classified into 0.05°C intervals. Figure 4 shows, in January the temperature deviations are positive in all the stations ranging from +0.11°C to +0.22°C. Maximum positive deviations have occurred near Parbhani and Nanded. A gradual decline in the deviation is observed towards the central parts of the sub watershed. The least positive deviations of +0.05°C have been observed towards the western and northern region. In spatial conformity with the temperature there has been a rise in the rainfall, the deviations of which ranged from +1.7 mm to +4.4 mm. In February with the beginning of the pre monsoon season, an opposite scenario is visible. Areas with negative deviations in temperature -0.2°C to -0.15°C along the north and north western parts, observed deviations in rainfall ranging from -4mm to -6 mm. Except for areas around Nanded and Chandrapur there has been temperature -2 °C below normal in the rest of the parts of the sub watershed. Similar spatial pattern is observed in March too. The southern parts of the sub watershed experienced more than normal temperature (+0.25°C).

The gap between the normal and the observed temperature declined gradually till Yeotmal, where observed temperature equaled the normal. The northern region around Buldana, Betul, Wardha and Nagpur had experienced below normal temperature which varied from -0.15° to -0.2°C. But concurrently the rainfall did not show much spatial variation, rather Parbhani, Nanded and Chandrapur experienced +4 mm more rainfall than the normal. In April, higher temperature deviations in positive direction +0.29°C were concentrated towards the south. The deviation slowly minimized as one moved northwards. In May however towards the south the deviation had been -0.05°C. Moving northwards, the negative deviations in temperature were recorded to have increased. A slightly opposite spatial trend is seen in rainfall. The southern corners had lesser rainfall than normal and are seen tending towards normal in the northwest. In May the eastern half the temperatures have deviated -0.2° C below the normal. Areas with lesser drop in temperature have observed more descent in rainfall. Positive deviations from the normal rainfall were seen in rest of the parts of the sub watershed, especially in the southwest.

During monsoon in June the eastern half experienced normal temperature conditions but gradually the negative differences between the observed and the normal increased, near the western and southern parts with temperatures -0.5° C below normal. In June, rainfall alarmingly below normal was also observed in the central and southern parts. In the central parts of the watershed rainfall received was the least. Regions around Yeotmal experienced -18mm below normal rainfall. The differences from the normal reduced as one moved towards the water divide, but below normal rainfall still persisted -8mm to -2 mm. In July the southern parts around Parbhani, Nanded and Chandrapur experienced over +22°C higher temperature than normal. Almost the entire sub watershed experienced additional temperatures than the normal, ranging from +0.15° C to +0.05° C. Along the western margins adjoining Amravati and Washim near normal temperature prevailed.

Making the water availability situation worse an inverse spatial pattern of rainfall was seen in comparison to the temperature. Areas with maximum increase in temperature observed the highest decline in rainfall, below -14mm. The entire sub watershed in July observed negative deviations in rainfall varying from -12mm to -2 mm. In August, negligible spatial variation but positive deviance in temperature was seen.+0.28°C more than the normal are seen towards the south, the deviations lessening towards the north by 0.10°C. The spatial contrast in rainfall pattern was also visible in this month. Only areas around Chandrapur were seen to experience more than normal rainfall. The negative deviations were highest of around -20mm around Amravati and Wardha. The gap between the normal and the observed lessened towards the watershed boundary reaching a minimum of -4 mm near Nanded and Betul. An extremely high and homogeneous positive deviation in temperature was also seen in September. The deviation near Chandrapur was around +0.28°C and reduced towards the west to +0.07°C. During monsoon the scenario showed an obvious inverse spatial correlation between rainfall and temperature, south western arm and the central parts of the sub watershed being the worst affected in term of water availability.

The post monsoon months of October, November, and December showed positive deviations in both temperature and rainfall throughout the sub watershed. In October the south western and northern part experienced temperatures which were +0.20°C above the normal. The other parts recorded normal temperatures. The rainfall trend during this month was also higher than the normal. 4 mm plus the normal were observed in western, central and eastern parts, while 2 mm plus the normal were observed at the northern tip and south eastern part of the sub watershed. During November a consistent increase in temperature trend was observed all across the region. The deviation varied from +0.15°C to +0.20°C than the normal. The rainfall too did not show much spatial variation in November. Only about +2 mm of above normal rainfall was observed in central and southern parts of the watershed while - 4 mm below normal was assessed in the western, northern and eastern half. In December too the southern region experienced around +0.15°C to +0.05°C above normal temperature and rainfall had also been spatially homogeneous but around +2 mm more than the normal. The post monsoon scenario showed both increased temperature and increased rainfall.

Conclusion

The climate change analysis across ten stations in the Penganga sub watershed shows increasing temperature and declining rainfall especially during pre monsoon and monsoon. This would definitely be hampering the kharif crops in the region especially sorghum, jowar, pigeon pea that are the dominant crops in the region. But the post monsoon increased rainfall tends to be beneficial for the rabi crops. The western and southern region of the sub watershed are the most adversely affected by the rising temperature and declining rainfall. With hardly any surface irrigational facilities and depleting ground water conditions with super imposed water intensive farming practices, this region becomes highly vulnerable. Dry farming practices are suggested for this region to make the farming practices climate resilient.

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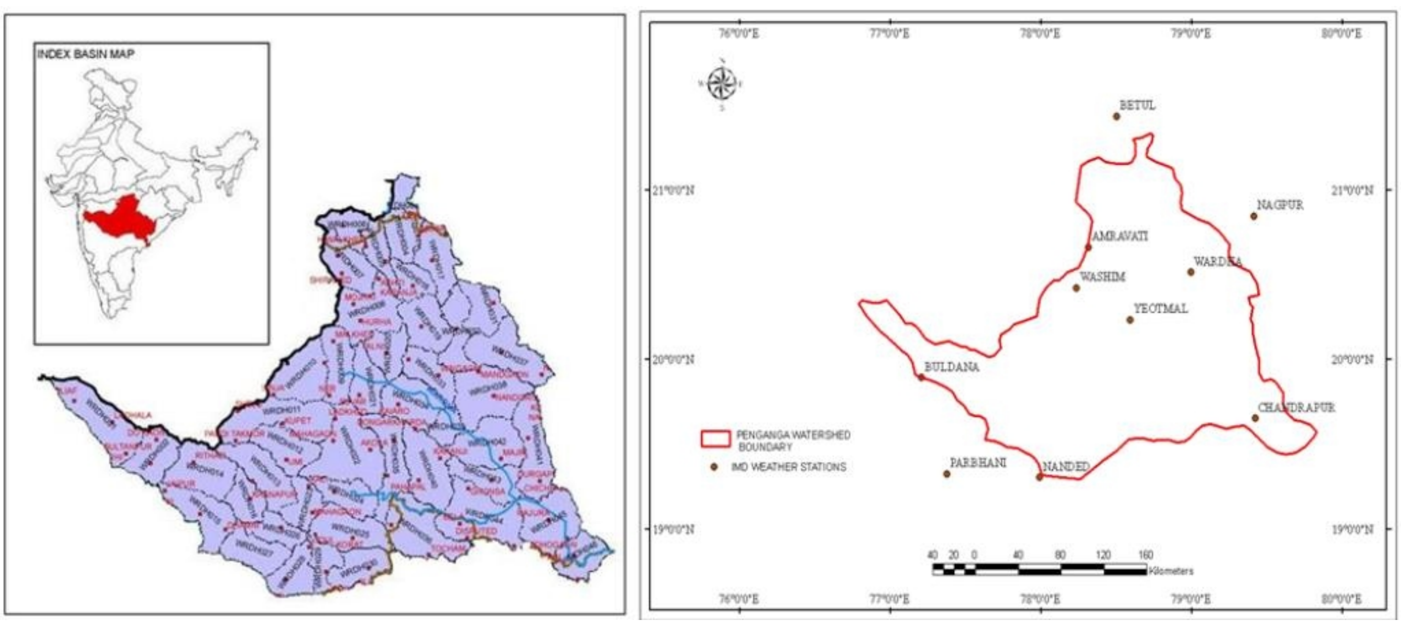

Fig.1: Penganga Sub-watershed with IMD Stations

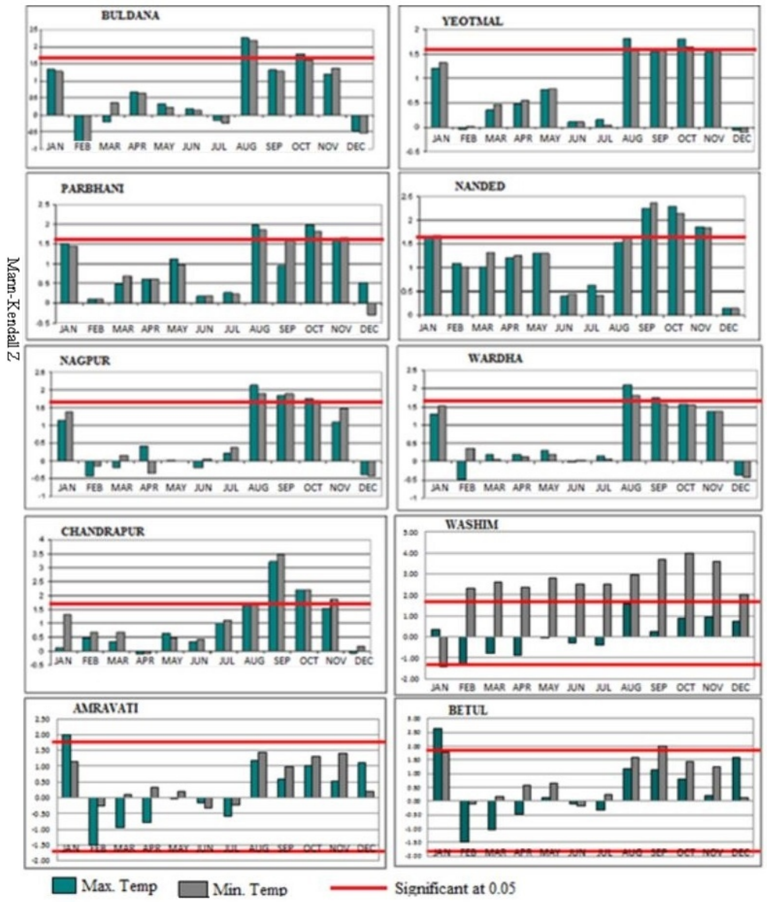

Fig.2: Mann-Kendall Z values of Monthly Maximum and Minimum Temperature with significant trends of IMD Gauging Stations in Penganga Sub-watershed

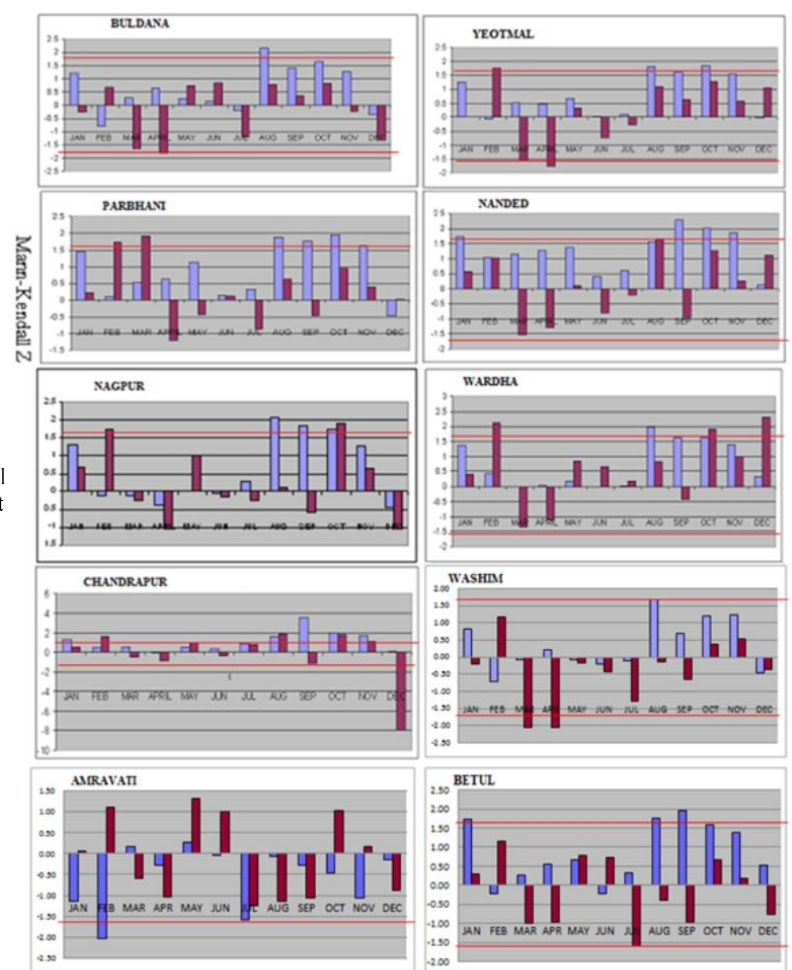

Fig. 3: Mann-Kendall Z Values of Monthly Rainfall and Average Temparature with Significant Trends at IMD Gauging Stations in Penganga Sub-watershed

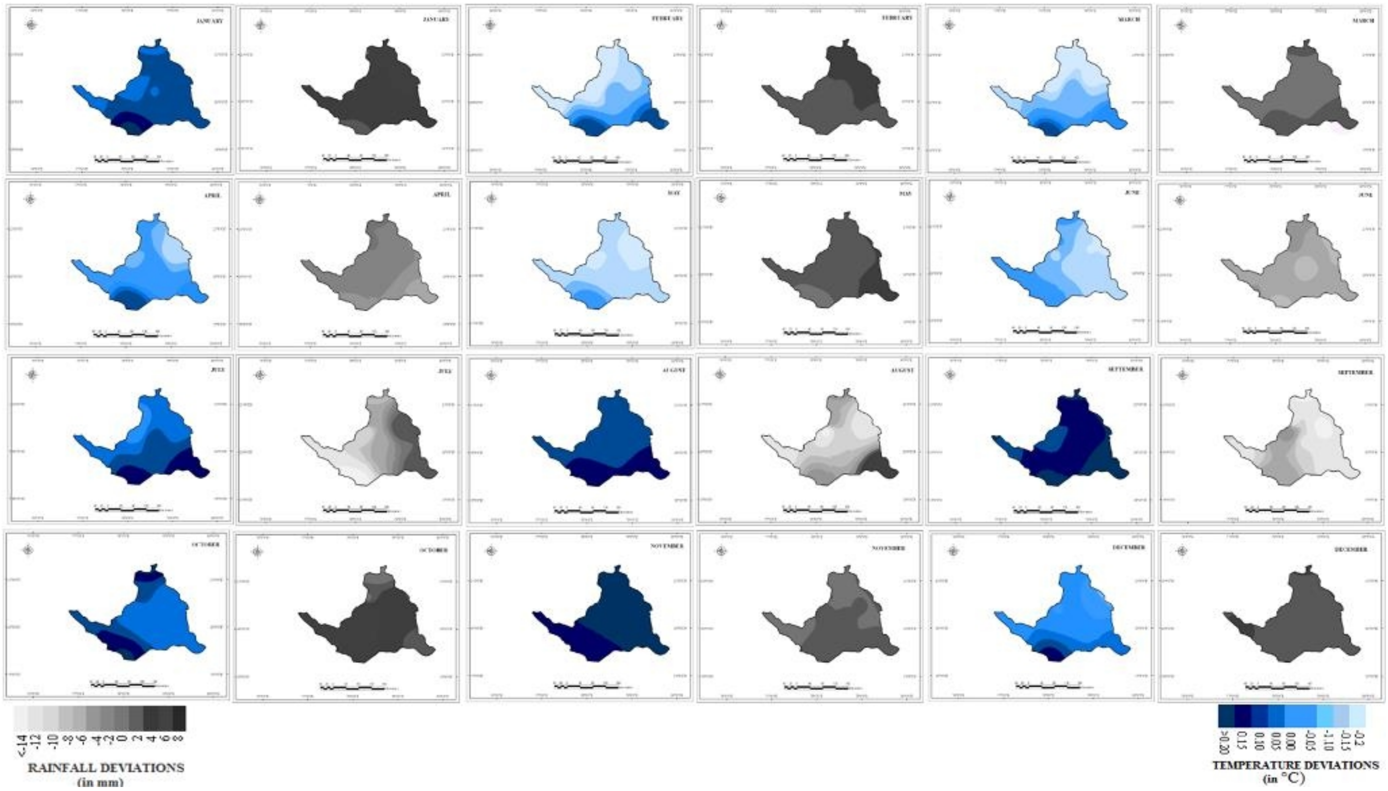

Fig. 4: Spatial Interpolation of Deviations of Observed Mean Monthly Temperatures and Rainfall (1970-2002) from Normal of 1951-80

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