



Trend analysis of climatic variables in Betwa river basin

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ABSTRACT

A study was undertaken to establish the annual trend in climatic variables of the Betwa basin located in Central India. District wise daily data (1971–2007) of rainfall, maximum and minimum temperature, relative humidity and wind speed were analysed using Mann-Kendall test and Sen's slope estimator. The annual rainfall in majority of the districts showed non-significant decreasing trend. Maximum temperature exhibited significant increasing trend in nine out of 14 districts, whereas minimum temperature exhibited significant increasing trend in only four districts. Relative humidity has increased significantly in Bhopal and Jhansi districts, whereas wind speed has significantly decreased in Bhopal, Jhansi, Tikamgarh and Vidisha districts. Decrease in the rainfall varied from 0.674 to 6.46 mm/year which was insignificant. The increase in mean daily maximum and minimum temperature varied from 0.014–0.022°C/year and 0.015–0.024°C/year, respectively. Significant increase in relative humidity was in the range of 0.18–0.34% per year, whereas decrease in the wind speed varied from -0.053 to -0.186 km/h/year. Results of the trend analysis indicated spatial variability in the changes in the different climatic variables. These results will be useful for planning appropriate water management strategies, agricultural crop planning, and preparing location specific adaptation measures.

Key words: Betwa basin, Mann-Kendall test, Sen's slope, Trend analysis

Climate of any region is described by climatic variables such as rainfall, temperature, sunshine duration, relative humidity and wind speed. The long term climatic data is analysed to understand the spatio-temporal variability of climatic variables. The global mean surface temperature is projected to increase in the range of 0.3°C to 0.7°C for the period 2016–2035 relative to 1986–2005 under different Representative Concentration Pathways (RCPs) (IPCC 2014). The mean annual temperature in India has increased at the rate of 0.05°C per 10 years during 1901–2003, and 0.22°C per 10 years during 1971–2003 due to unprecedented warming during the last decade (Kothawale and Rupa Kumar 2005). Increase in the concentration of greenhouse gases is said to be responsible for climate change and global warming. Changing climate has extreme effect on the hydrological cycle (Abdulla *et al.* 2009, Wu *et al.* 2012) and will have serious implications in the water resource management and future planning. As Indian agriculture is monsoon dependent, any changes in rainfall pattern (trend and variability) will have serious implications on agricultural production, particularly rainfed agriculture.

Trend analysis helps to establish whether climate change has already altered hydro-climatic process of rainfall, temperature, relative humidity, and streamflow etc. Trend analysis and estimation of monthly and annual precipitation, temperature, reference evapotranspiration, and rainfall deficit are essential for water resources management and cropping system design. There are two approaches to analyse the trend in climatic variables, namely non-parametric and parametric numerical methods. The parametric method assumes that data is distributed normally which is generally not common in hydrological studies. On the other side non-parametric methods do not make such assumption (Hamed and Rao 1998). Mann-Kendall test (MK) (Mann 1945, Kendall 1975) is one of the most popularly used non-parametric method for analysing the trend in the time series. It is one of the most extensively used methods for trend detection in hydrological and meteorological studies. The evaluation of historical climatic trends or future projections should be a compulsory exercise for planning appropriate adaptation strategies in a river basin (Rai *et al.* 2010) as global or continental scale analysis is of less importance for local or regional scale planning (Barsugli *et al.* 2009). In recent years, many researchers have compared and analysed trends in the climatic variables at basin scale. Aziz and Burn (2006) investigated the patterns in hydrological regime for the Mackenzie river basin in northern Canada. Taxak *et al.* (2014) utilized gridded data (0.50° × 0.50°) of precipitation to examine the long term temporal and spatial patterns in Wainganga river basin of central India. Rai *et al.* (2010)

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dissected the temporal variability of climatic parameters in Yamuna basin. Jain and Kumar (2012) studied the basin wise trend in temperature and rainfall over India. Murumkar and Arya (2014) estimated the yearly and seasonal pattern in precipitation utilizing 104 years information in Nira Basin of central India for assessing trend and periodicity. Gajbhiye *et al.* (2016) examined the yearly, seasonal and monthly patterns of precipitation using data for the periods 1901–2002 and 1942–2002 in the Sind river basin. The review of above studies suggests that the focus has been mainly on long-term variability of temperature and precipitation. However, the other climate governing variables such as relative humidity, wind speed and sunshine hours are also important as they have influence on the hydrological cycle. Quite a few literatures are available on trend analysis of these parameters in India (Bandyopadhyay *et al.* 2009, Jhajharia *et al.* 2009, Mandal *et al.* 2013, Padmakumari *et al.* 2013, Patle *et al.* 2013). The knowledge of variability of climatic parameters is essential for water resource planning and management especially in arid and semi-arid region (Rai *et al.* 2010, Dodangeh *et al.* 2012). Therefore, the present analysis was done to examine the long term annual trend of climatic variables in particular precipitation, maximum and minimum temperature, relative humidity and wind speed in the districts covered by Betwa basin of Bundelkhand region falling under semi-arid region.

MATERIALS AND METHODS

The Betwa river basin is located in the semi-arid central part of India. It is one of the major rivers traversing in the Bundelkhand region. The Betwa river drains a total area of about 43, 946 km². It extends between the latitude 22°59'57"–26°03'23" N and longitude of 77°05' 51"–80°13'01" E covering nine districts of Madhya Pradesh and five districts of Uttar Pradesh. The upper part of Betwa basin is characterized by hot dry sub-humid climate, whereas the lower part is characterized as hot moist semi-arid. The minimum temperature ranges from 8–12°C and maximum temperature ranges from 38–43°C. The average annual precipitation in the Betwa basin varies from 750–1200 mm. The topography is undulating with the presence of steep slopes in the upper part. The elevation ranges from 63–724 m amsl (Desai *et al.* 2016).

The daily time series data of climatic variables, viz. maximum temperature, minimum temperature and rainfall for 37 years (1971–2007) were downloaded from the NICRA portal (<http://www.nicra-icar.in>) for 14 districts falling in Betwa river basin. The other climatic parameters, viz. relative humidity and wind speed were collected from India Meteorological Department (IMD), Delhi. The time series data on relative humidity and wind speed for 30 years period was available for Bhopal, Jhansi, Tikamgarh and Vidisha districts. The data for all the five climatic variables was available in the above four districts, whereas in the remaining districts the data was available for maximum and minimum temperature and rainfall. Mann-Kendall test (Mann 1945, Kendall 1975) and Sen's slope estimator

test (Sen 1968) were used to analyse the long term trend of these parameters. The different parameters such as S statistic, Kendall's tau and Z_c statistics with Sen's slope were considered for identifying the increasing or decreasing trend in the time series of climatic parameters. An Excel program Addinsoft's XLSTAT 2012 downloaded (free version) from www.xlstat.com was utilized to perform Mann-Kendall test and Sen's slope test.

RESULTS AND DISCUSSION

Annual rainfall: In most of the districts rainfall had a decreasing trend. The decrease in rainfall was in the range of -0.674 to -6.46 mm/year. Hamirpur, Mahoba and Jhansi districts exhibited increasing rainfall trend in the range of 0.854–1.474 mm/year. However, the values of Z Statistics revealed that in none of the districts, the trend (increasing/decreasing) was significant. Previously reported studies on changes in rainfall pattern over India revealed that there is no significant increasing and decreasing trend in the average annual rainfall (Mooley and Parthasarathy 1984). Investigation on trend and persistence of rainfall for Ganges basin by Mirza *et al.* (1998) also revealed that precipitation in Ganges basin is almost stable. The values of Mann-Kendall test statistics for rainfall in the districts of Betwa basin are presented in supplementary Table 1. The rainfall trend for 37 years in the Bhopal, Jhansi, Tikamgarh and Vidisha districts are shown in Fig 1(a), Fig 2(a), Fig 3(a) and Fig 4(a), respectively.

Maximum temperature: The analysis of annual mean of daily maximum temperature revealed that it has increased in all the districts of Betwa basin. Positive value of Kendall's tau and S statistics showed increasing trend in time series. The values of Z_c statistics revealed that except in Hamirpur, Jalaun, Mahoba, Jhansi and Chattarpur districts, there was a statistically significant increasing trend at 95% confidence level in all other districts. The increase in the maximum temperature was in the range of 0.014–0.022°C/year. Kothawale and Rupa Kumar (2005) have also reported that maximum temperature has increased by 0.07°C/decade for India during the period 1901–2005. The values of Mann-Kendall test statistics for maximum temperature in the districts of Betwa basin are presented in supplementary Table 2. The trend in maximum temperature in Bhopal, Jhansi, Tikamgarh and Vidisha districts are shown in Fig 1(b), Fig 2(b), Fig 3(b) and Fig 4(b), respectively.

Minimum temperature: In case of annual mean of daily minimum temperature, positive values of Kendall's tau and S statistics showed increasing trend in the time series data in all the districts of Betwa basin. The values of Z_c statistics revealed that, Ashoknagar, Shivpuri, Jalaun and Bhopal districts exhibited a statistically significant increasing trend at 95% confidence level. However, the trend in other districts were not significant. The increase in the minimum temperature was in the range of 0.015–0.024 °C/year. Kothawale and Rupa Kumar (2005) has also reported increase in minimum temperature by 0.02 °C/decade for India during the period 1901–2005. The values

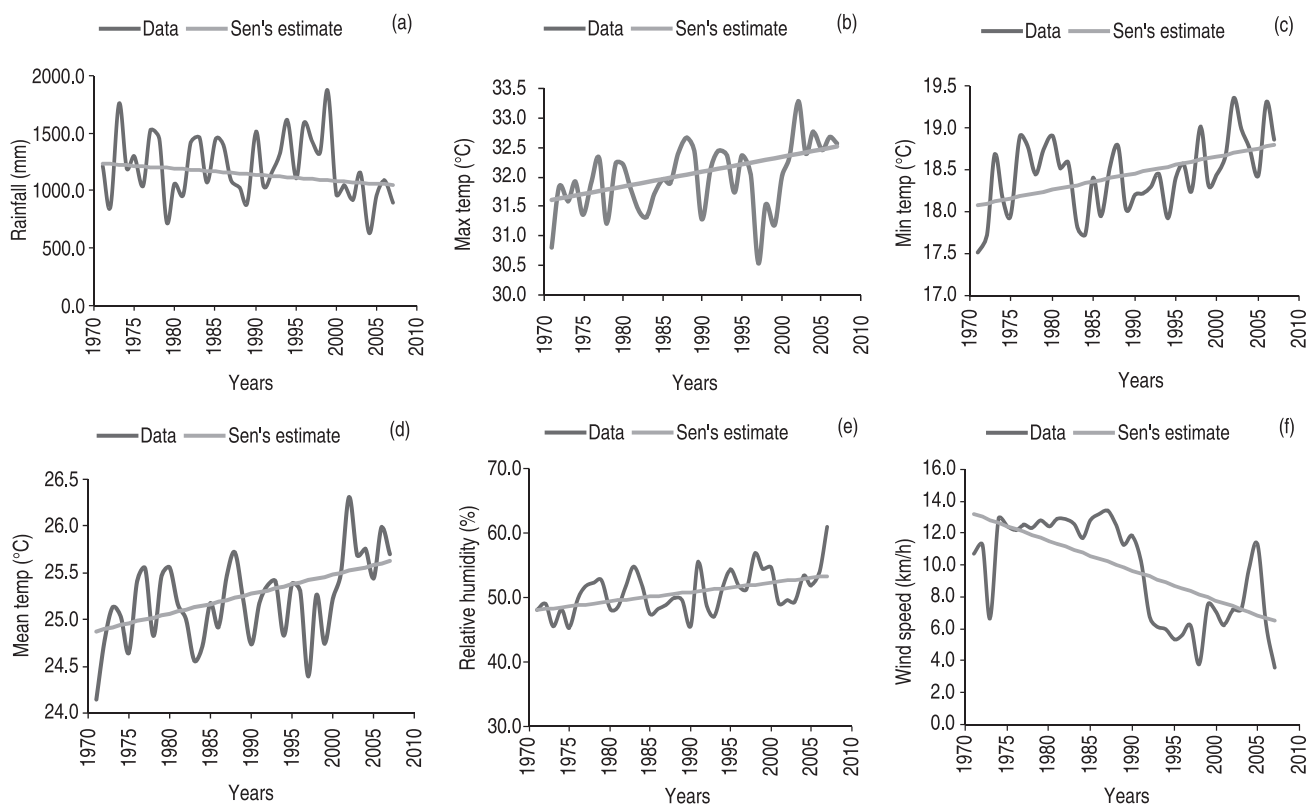


Fig 1 Sen's linear estimates for Bhopal. (a) Rainfall, (b) Maximum temperature, (c) Minimum temperature, (d) Mean temperature, (e) Relative humidity, (f) Wind speed.

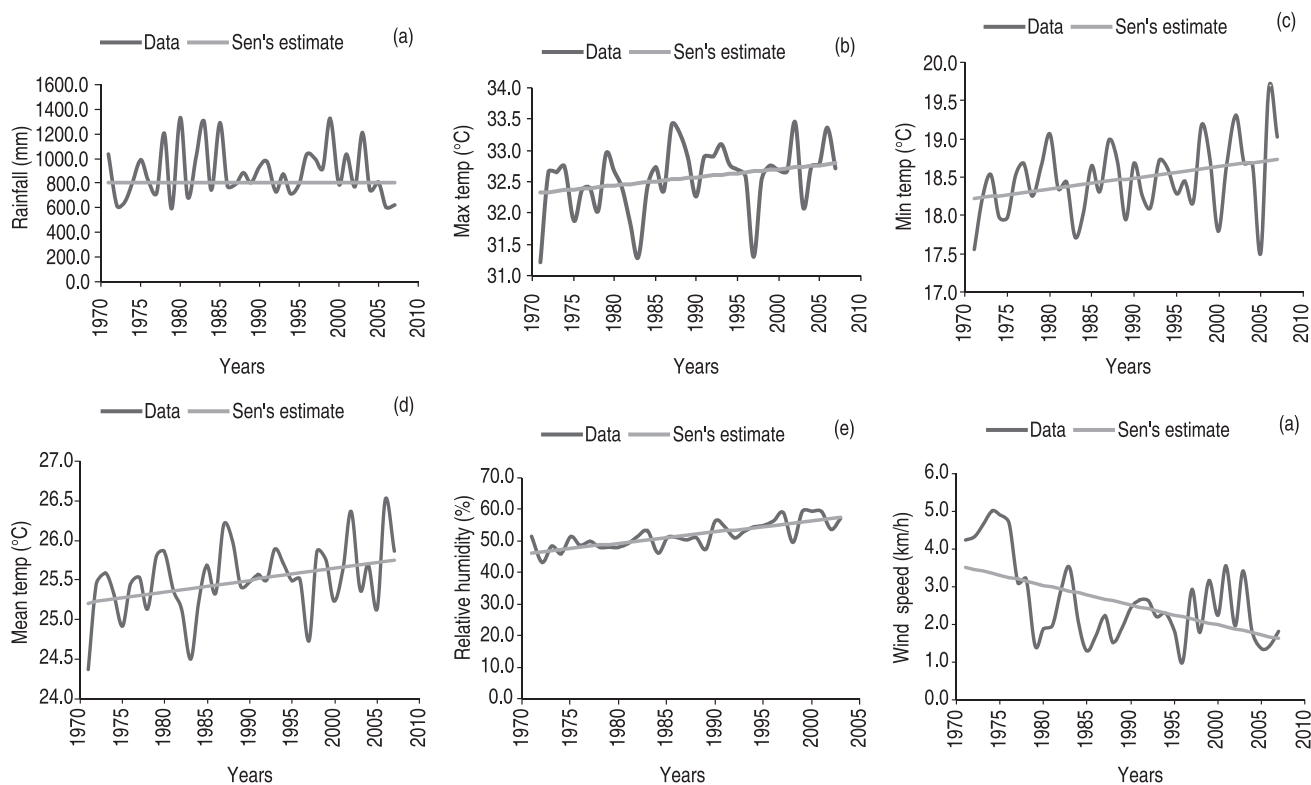


Fig 2 Sen's linear estimates for Jhansi. (a) Rainfall, (b) Maximum temperature, (c) Minimum temperature, (d) Mean temperature, (e) Relative humidity, (f) Wind speed.

of Mann-Kendall test statistics for minimum temperature in the districts of Betwa basin are presented in supplementary Table 3. The trend in minimum temperature for Bhopal, Jhansi, Tikamgarh and Vidisha districts is shown in Fig 1(c), Fig 2(c), Fig 3(c) and Fig 4(c), respectively.

Mean temperature: In case of daily mean temperature, positive value of Kendall's tau and S statistics indicated increasing trend over the period of 1971–2007. Lalitpur, Ashoknagar, Shivpuri, Bhopal, Raisen, Sehore and Vidisha districts showed a statistically significant increasing trend at 95% confidence level. In the remaining districts the trend was not significant. Increase in the mean temperature was in the range of 0.013 to 0.018°C/year. Pant and Kumar (1997) also reported increasing pattern of mean annual temperature at a rate of 0.57°C/100 years over India. The Mann-Kendall test statistics for the mean temperature in the districts of Betwa basin is shown in supplementary Table 4. The trend in mean temperature for 37 years in the Bhopal, Jhansi, Tikamgarh and Vidisha districts are shown in Fig 1(d), Fig 2(d), Fig 3(d) and Fig 4(d), respectively.

Relative humidity: The daily long term data of relative humidity was available only for four districts, viz. Bhopal, Jhansi, Tikamgarh and Vidisha. The positive value of Kendall's tau and S Statistics indicated increasing trend of relative humidity in all four districts. However, the value of Z_c statistics revealed that the trend was significant in Bhopal and Jhansi districts at 95% confidence level. No significant trend was observed in Tikamgarh and Vidisha districts. The increase in the relative humidity was in the range of 0.183

to 0.35% per year. Bandyopadhyay *et al.* (2009) has also reported a significant increase in relative humidity for India by 2.4% per 100 years. The Mann-Kendall test statistics for the relative humidity in the four districts of Betwa basin is presented in supplementary Table 5. The trend in relative humidity is shown in Fig 1(e), Fig 2(e), Fig 3(e) and Fig 4(e), respectively.

Wind speed: The long term data of wind speed was also available only for four districts, i.e. Bhopal, Jhansi, Tikamgarh and Vidisha. The negative value of Kendall's tau and S Statistics indicated decreasing trend of wind speed in all four districts. The value of Z_c statistics revealed that the trend was significant in Bhopal, Jhansi, Tikamgarh and Vidisha districts at 95% confidence level. The decrease in the wind speed was in the range of -0.053 to -0.186 km/h/year. Jhaharia *et al.* (2009) also reported a declining trend in wind speed for northeast India. The Mann-Kendall test statistics for the wind speed in the four districts of Betwa basin is presented in supplementary Table 6. The trend in wind speed for 37 years in the Bhopal, Jhansi, Tikamgarh and Vidisha districts are shown in Fig 1(f), Fig 2(f), Fig 3(f) and Fig 4(f), respectively.

The changes in trend of different climatic variables will have effect on evapotranspiration demand and crop water requirement trend. The decreasing annual rainfall trend in most of the districts coupled with increasing temperature trend, indicates a need for more irrigation water for supplementary irrigation and drought proofing. The Betwa sub-basin, located in the Bundelkhand region,

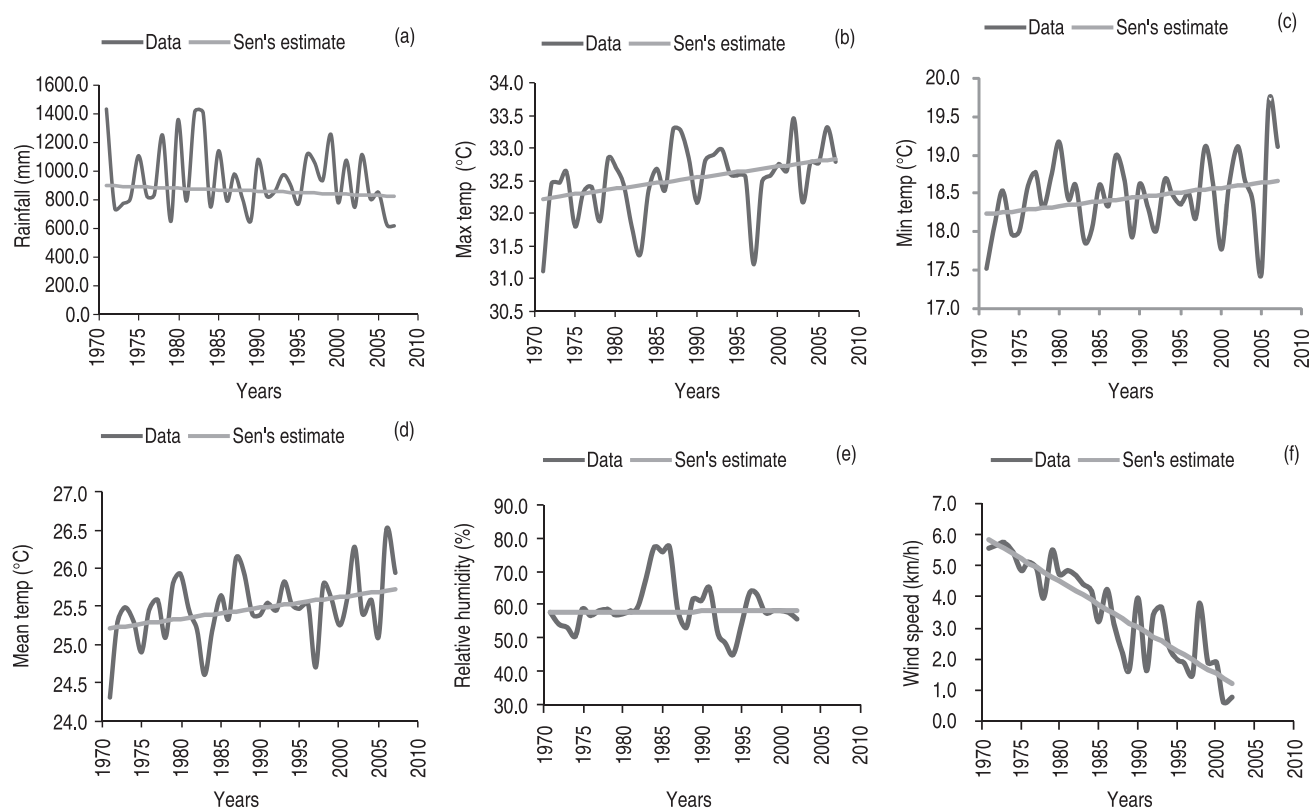


Fig 3 Sen's linear estimates for Tikamgarh. (a) Rainfall, (b) Maximum temperature, (c) Minimum temperature, (d) Mean temperature, (e) Relative humidity, (f) Wind speed.

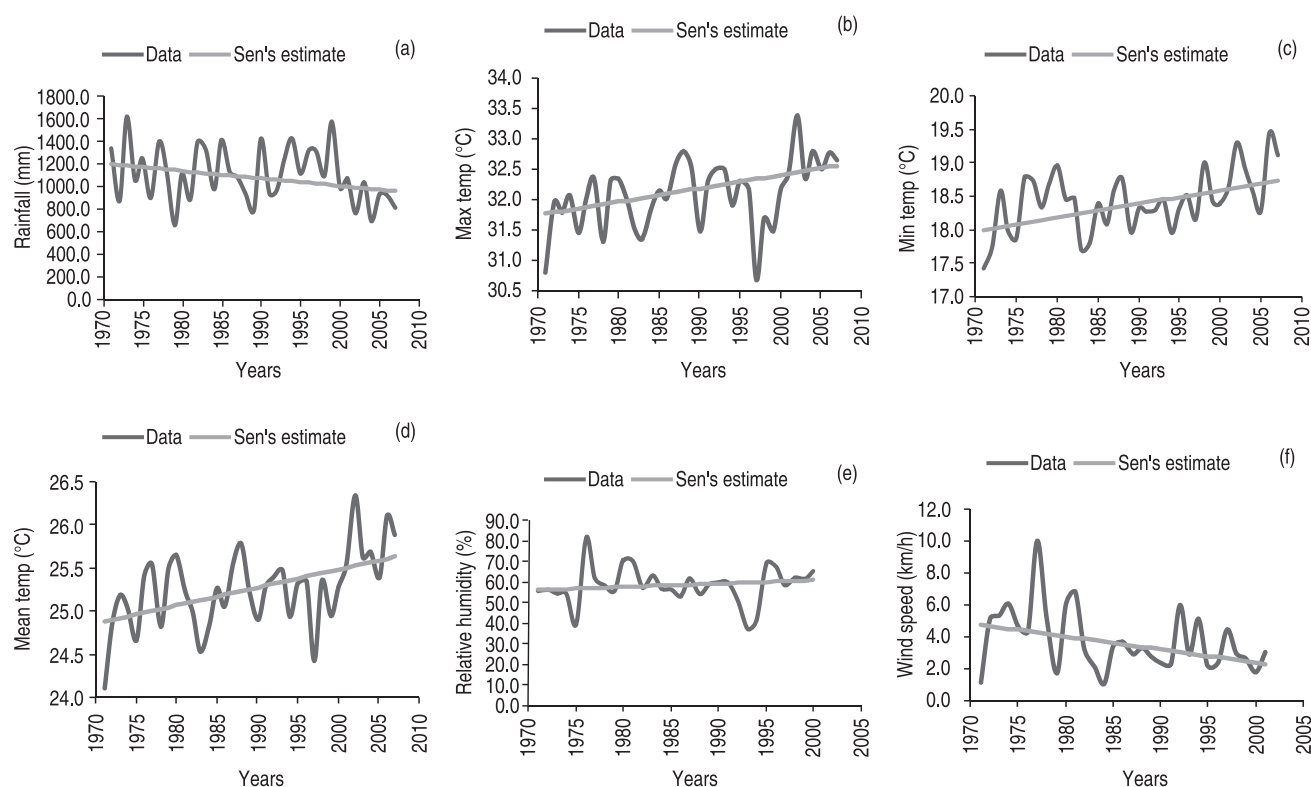


Fig 4 Sen's linear estimates for Vidisha. (a) Rainfall, (b) Maximum temperature, (c) Minimum temperature, (d) Mean temperature, (e) Relative humidity, (f) Wind speed.

faces severe drought condition in the upper reaches of river course and moderate or mild droughts in the lower reaches (Pandey *et al.* 2008). Adaptation measures such as water harvesting and storing excess water in ponds and reservoirs during monsoon will mitigate water scarcity problem during non-monsoon season, improve groundwater recharge, and moderate the risk of flooding (Sikka *et al.* 2018). Results of the trend analysis also indicated spatial variability in the changes in the different climatic variables, suggesting the need for different adaptation measures for different locations. Thus, analysis of historical climatic trends on a river basin scale is necessary to establish whether climate change has already altered hydro-climatic process of rainfall, temperature, relative humidity, and stream flow etc. over the basin, and for planning appropriate water management strategies, agricultural crop planning, and preparing location specific adaptation measures.

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REFERENCES

- Abdulla F, Eshtawi T and Assaf H. 2009. Assessment of the impact of potential climate change on the water balance of a semi-arid watershed. *Water Resources Management* **23**(10): 2051–68.
- Aziz O I A and Burn D H. 2006. Trends and variability in the hydrological regime of the Mackenzie River Basin. *Journal of Hydrology* **319**(1): 282–94.
- Bandyopadhyay A, Bhadra A, Raghuwanshi N S and Singh R. 2009. Temporal trends in estimates of reference evapotranspiration over India. *Journal of Hydrologic Engineering* **14**(5): 508–15.
- Barsugli J, Anderson C, Smith J B and Vogel J M. 2009. Options for improving climate modeling to assist water utility planning for climate change. Water Utilities Climate Alliance (WUCA) WhitePaper: **144**. [Available online at www.wucaonline.org/assets/pdf/actions_whitepaper_120909.pdf.]
- Desai S, Singh D K, Sarangi A, Khanna M, Sahoo R N and Pathak H. 2016. Extraction of geomorphological parameters of Betwa basin using GIS and Watershed Morphology Estimation Tool (WMET). *Indian Journal of Soil Conservation* **44**(3): 241–8.
- Dodangeh S, Abedi Koupai J and Gohari S A. 2012. Application of time series modelling to investigate future climatic parameters trend for water resources management purposes. *Journal of Science and Technology of Agriculture and Natural Resources* **15** (59): 59–74.
- Gajbhiye S, Meshram C, Mirabbasi R and Sharma S K. 2016. Trend analysis of rainfall time series for Sindh river basin in India. *Theoretical and Applied Climatology* **125**(3–4): 593–608.
- Hamed K H and Rao A R. 1998. A modified Mann-Kendall trend test for auto-correlated data. *Journal of Hydrology* **204**: 182–96.
- IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth assessment report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri R K and Meyer L A (eds.)]. IPCC, Geneva, Switzerland, p 151.
- Jain S K and Kumar V. 2012. Trend analysis of rainfall and temperature data for India. *Current Science* **102**(1): 37–49.

- Jhajharia D, Shrivastava S K, Sarkar D and Sarkar S. 2009. Temporal characteristics of pan evaporation trends under the humid conditions of northeast India. *Agricultural and Forest Meteorology* **149**(5): 763–70.
- Kendall M. 1975. *Rank Correlation Methods*, 4th edn. Charles Griffin. San Francisco, CA, 8.
- Kothawale D R and Rupa Kumar K. 2005. On the recent changes in surface temperature trends over India. *Geophysical Research Letters* **32**(18).
- Mandal S, Choudhury B U, Mondal M and Bej S. 2013. Trend analysis of weather variables in Sagar Island, West Bengal, India: a long-term perspective (1982–2010). *Current Science* : 947–53.
- Mann H B. 1945. Nonparametric tests against trend. *Econometrica* **13**: 245–59.
- Mirza M Q, Warrick R A, Ericksen N J and Kenny G J. 1998. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. *Hydrological Sciences Journal* **43**(6): 845–58.
- Mooley D A and Parthasarathy B. 1984. Fluctuations in all-India summer monsoon rainfall during 1871–1978. *Climatic Change* **6**(3): 287–301.
- Murumkar A R and Arya D S. 2014. Trend and periodicity analysis in rainfall pattern of Nira basin, Central India. *American Journal of Climate Change* **3**(1): 60.
- Padmakumari B, Jaswal A K and Goswami B N. 2013. Decrease in evaporation over the Indian monsoon region: implication on regional hydrological cycle. *Climatic change* **121**(4): 787–99.
- Pandey R P, Mishra S K, Singh R and Ramasastri K S. 2008. Streamflow drought severity analysis of Betwa river system (India). *Water Resources Management* **22**(8): 1127–41.
- Pant G B and Kumar K R. 1997. *Climates of south Asia*. John Wiley & Sons, Chichester, UK.
- Patle G T, Singh D K, Sarangi A, Rai, Anil, Khanna, Manoj and Sahoo R N. 2013. Temporal variability of climatic parameters and potential evapotranspiration. *Indian Journal of Agricultural Sciences* **83** (4): 518–24.
- Rai R K, Upadhyay A and Ojha C S P. 2010. Temporal variability of climatic parameters of Yamuna River Basin: spatial analysis of persistence, trend and periodicity. *Open Hydrology Journal* **4**(1): 184–210.
- Salmi T, Maata A, Antilla P, Ruoho Airola T and Amnell T. 2002. Detecting trends of annual values of atmospheric pollutants by the Mann–Kendall test and Sen's slope estimates - the Excel template application Makesens. Finnish Meteorological Institute, Helsinki, Finland, p 35.
- Sen P K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association* **39**: 1379–89.
- Sikka A K, Islam A and Rao K V. 2018. Climate smart land and water management for sustainable agriculture. *Irrigation and Drainage* **67**(1): 72–81.
- Sutcliffe J V, Agrawal R P and Tucker J M. 1981. The water balance of the Betwa basin, India/Le bilan hydrologique du bassin versant de Betwa en Inde. *Hydrological Sciences Journal* **26**(2): 149–58.
- Taxak A K, Murumkar A R and Arya D S. 2014. Long term spatial and temporal rainfall trends and homogeneity analysis in Wainganga basin, Central India. *Weather and Climate Extremes* **4**: 50–61.
- Wu Y, Liu S and Gallant A L. 2012. Predicting impacts of increased CO₂ and climate change on the water cycle and water quality in the semiarid James river basin of the Midwestern USA. *Science of the Total Environment* **430**: 150–60.