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Time Series Trend Analysis of Rainfall and Temperature over Kolkata and Surrounding Region

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Highlights:

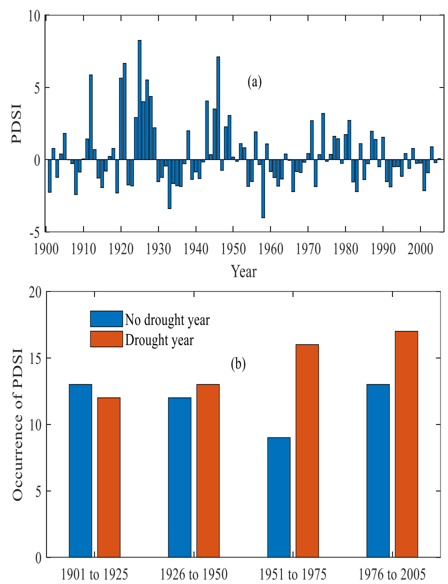
(i) Temperature and rainfall increased in 1991-2014 with respect to previous years.

(ii) A statistically significant increasing trend observed for most of the months.

(iii) Winter and monsoon period shows highest and lowest CV respectively.

(iv) The number of years with dry conditions increased but intensity close to zero.

GRAPHICAL ABSTRACT



The number of years with dry conditions increased but

Abstract

Studies of long term variability of temperature and rainfall in the context of climate change are important particularly in regions where rainfed agriculture is predominant. Long term trends of temperature and rainfall have been determined for Kolkata, India, a tropical region using gridded monthly data from Global Precipitation and Climate Centre (GPCC V7) with 0.5° X 0.5° resolution for the period 1901 to 2014. Precipitation concentration index, coefficient of variation, rainfall anomaly have been calculated and Palmer drought severity index has been analyzed. Furthermore, the Mann-Kendall test and sen's slope estimate have been used to detect time series trend. Annual temperature and rainfall have increased at a rate of 0.0082°C/ year and 0.03 mm/ year, respectively. Most months show statistically significant increasing trends for temperature and rainfall. Rainfall with high precipitation concentration index (16-20) has been observed for the period 1951-1975 and 1976-2000. The number of years with dry conditions has increased. However, the intensity of dryness is very close to zero. The information from this study will be helpful for the farmers to plan for resilient farming.

Resumen

Los estudios de la variabilidad a largo plazo de la temperatura y las precipitaciones en el contexto del cambio climático son importantes, especialmente en las regiones donde predomina la agricultura de secano. Se han determinado las tendencias a largo plazo de la temperatura y la lluvia para Kolkata, India, una región tropical utilizando datos mensuales cuadriculados del Global Precipitation and Climate Center (GPCC V7) con una resolución de 0,5 ° X 0,5 ° para el período 1901 a 2014. Índice de concentración de precipitación, Se ha calculado el coeficiente de variación, la anomalía de las precipitaciones y se ha analizado el índice de severidad de la sequía de Palmer. Además, la prueba de Mann-Kendall y la estimación de la pendiente de sen se han utilizado para detectar la tendencia de las series de tiempo. La temperatura y las precipitaciones anuales han aumentado a un ritmo de 0,0082 ° C / año y 0,03 mm / año, respectivamente. La mayoría de los meses muestran tendencias crecientes estadísticamente significativas para la temperatura y las precipitaciones. Se han observado precipitaciones con alto índice de concentración de precipitaciones (16-20) para el período 1951-1975 y 1976-2000. Ha aumentado el número de años con condiciones secas. Sin embargo, la intensidad de la sequedad es muy cercana a cero. La información de este estudio será útil para que los agricultores planifiquen una agricultura resiliente.

Keywords— Cloud attenuation; Radiometer; Elevation angle; Exceedance probability; Worst month statistics; Liquid water content.

1. Introduction

Climate change is one of the most important global environmental challenges, which has an impact on food production, water supply and health. Rapid urbanization and industrialization affect climate change [Matyssek et al., 2013; Krockenberger et al., 2004; Costa and Barbi, 2016]. Temperature and precipitation are the two most important parameters which characterize the climate change. It has been reported that the average temperature of the earth has been increased by 0.74°C for a decade (UNFCCC, 2007). As a result of deforestation and urbanization, the emission of greenhouse gases has increased. The highest warming has been experienced in the Antarctic over the last 50 years (Hughes et al., 2006). Nowadays, global warming is the most important issue world-wise. The variability of rainfall is of high interest for the countries where agricultural activities are mainly dependent on rainfall (Cheung et al. 2008). The change in temperature and rainfall influences the natural ecosystem and socio-economical condition of a country. The two parameters have an impact on the agricultural sector, food security and human health (PEACE, 2007). The effect of climate change has also been observed on sea-level rise and warmer ocean temperatures (Zikra et al., 2014). This will be alarming for frequent floods and tsunamis. For the above reasons, long term variability of temperature and rainfall are necessary to investigate. Based on the information, adaptation strategies may be taken.

A significant increasing trend of temperature has been revealed over the Nile river basin of Ethiopia while for precipitation the trend was mixed (Daniel et al. 2014). An increasing trend of the number of drought years has been observed over Ethiopia (Asfaw et al., 2018). An increasing trend of temperature has been observed over the Chand basin of Africa (Mahmood et al., 2019). It has been observed that the temperature has been increased by 1.5°C in Eastern China over the last 100 years (Zhao et al., 2014). An increasing trend of temperature has been reported in the summer season over Sweden for the period 1959–2008 (Ceppi et al., 2012). A similar increasing trend has been reported in Spain (Rio et al., 2011), United States (Degaetano et al., 2002) and Florida (Martinez et al., 2012). However, no significant trend of temperature has been reported in the two states of United states (Karmeshu, 2012). It has been observed using the CMIP5 model, that temperature will be rise significantly over 9 climatic zones in

India (Yaduvanshi et al., 2021). It has been reported that precipitation increased by 7%-12% over the northern hemisphere in the 20th century (Xu et al., 2005). The long-term trend of precipitation shows a negative trend over the Mediterranean region for the period 1901–2009 (Philandras et al., 2011). No significant trend has been observed in long term rainfall over Bulgaria (Bocheva et al., 2008). A negative trend of precipitation has been reported in South Italy (Longobardi et al., 2009).

Some studies have been done in India quantifying the long term variability of the above two parameters and the relation between them. A positive trend of annual rainfall has been observed over Central India for the period 1901-1960 (Parthasarathy and Dhar, 1954; Goswami et al., 2006; Rajeevan et al., 2008). The monsoon rainfall over the western Indo Gangetic Plain (IGP) has been significantly increased since the year 1900 (Singh and Sontakke, 2002). Pal and Al tabba have found that extreme post-monsoon and winter rainfall have been increased over Kerala (Pal and Al-Tabba, 2009). No significant trend has been observed in average annual rainfall over India (Mooley, 1984; Sarker, 1988; Thapliyal, 1991; Lal, 2001; Sinha et al., 2003; Kumar et al., 2010). Rainfall shows an increasing trend for the period 1980-2017 over Odisha (Panda and Sahu, 2019). A significant increase in mean annual temperature has been observed over the north-central, northeastern regions and west coast of India (Pant and Kumar, 1997; Hingane et al., 1985) and also over the Mahanadi river basin (Rao, 1993). However, a decreasing trend has been reported over the northwest Indian region for the period 1901–1982 (Pant and Hingane, 1988). An increasing trend of temperature has been evident at 121 stations in India for the period 1901–1987 (Kumar et al. 1994).

Studies on long term variation of temperature and rainfall are sparse over Kolkata and the surrounding region. A very few observations of long term variation of temperature and rainfall have been reported over Kolkata and West Bengal. Temporal variability of monthly temperature has been observed over Kolkata for 70 years (Khan et al., 2015). In this study, a decreasing trend of temperature has been observed for December-March. For the remaining months, an increasing trend of temperature has been observed. Long term change of temperature has been analyzed over Krishnanagar observatory, West Bengal for the period 1941-2010 (Bisai et al., 2014). They reported the major temperature changes has occurred after the year 2000. Rainfall anomaly, CV and PCI has been analyzed over West Bengal using monthly rainfall data for the period 1901-2016 (Nandargi and Barman, 2018). They showed an increase in the percentage of dry years after 1990. Kolkata is a densely populated and highly polluted city in India. It is one of the important regions of India and contributes significantly to the gross domestic production (GDP) of the country. Kolkata is located near the land-ocean boundary and substantial rainfall occur over this region. Convective rainfall occurs over Kolkata in the pre-monsoon season and mainly stratiform and mixed rainfall occurs in the monsoon period. All the seasons, namely summer, winter, monsoon, pre-monsoon of a year can be clearly distinguished over this region. Different temperature and rainfall characteristics can be observed for different periods over this region. Rainfall mainly occurs in monsoon (June-September) and pre-monsoon (March-May). However, localized post-monsoon and winter rainfall have also been observed. It is necessary to investigate the long term trend of temperature and rainfall over this region to analyze the effect of climate change.

In this paper, a descriptive analysis of long term variation of temperature and precipitation has been observed using gridded monthly data obtained from the Global Precipitation and Climate Centre (GPCC) for 114 years. The yearly box plot and trend analysis of the above parameters have been studied for the period 1901-2014 for four different seasons (December-February (DJF), March-May (MAM), June-September (JJAS) and October- November (ON)). The coefficient of variation (CV), precipitation anomaly and precipitation concentration index (PCI) has been calculated for statistical analysis (Asfaw et al., 2018; Hare, 2003; Oliver, 1980; Zhang et al., 2019). Furthermore, non-parametric tests (MK test and sen’s slope estimator) has been used to detect the trend of rainfall and temperature. Palmer Drought Severity Index (PDSI) have been observed to examine the extent of meteorological drought (Agnew and Chappel, 1999; Dai, 2011; Diodato et al., 2019; Szép et al., 2005).

2. Experimental Data and Methodology

The Gridded monthly precipitation and mean temperature data obtained from the Global Precipitation and Climate Centre (GPCC V7) are utilized to observe the trend analysis and the variability of the two parameters over Kolkata and the surrounding region. The resolution of the GPCC data is $0.5^\circ \times 0.5^\circ$ and for the year 1901 to 2014 (downloaded from Climate explorer: KNMI Climate change atlas. (Schneider et al., 2017; Becker A et al., 2013). In addition to the above way of extraction of data, Palmer Drought Severity Index (PDSI) data for the year, 1901–2005 was obtained from the same source. Several ways have been applied to observe the trend and anomalies of rainfall and temperature. This Variability requires the use of Coefficient of Variation (CV), Anomalies (percentage deviation from the mean), Precipitation Concentration Index (PCI) and slope (Asfaw et al., 2018). CV (Coefficient of Variation) is used to classify the degree of variability of rainfall. It can be represented as,

$$\mathrm{CV} = \frac{\sigma * 100}{\mu} \tag{1}$$

where σ denotes standard deviation and μ is the mean precipitation. According to (Hare (2003)), CV is used to classify the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), and high (CV > 30). PCI (Precipitation Concentration Index) is used to provide information on seasonal or annual rainfall variability to check whether the monthly rainfall is equally distributed or not. Mathematically, it is represented as (Oliver, 1980; Zhang et al., 2019):

$$PCI_{annual} = \frac{\sum_1^{12} P_i^2}{(\sum_1^{12} P_i)^2} X100 \tag{2}$$

It has been observed that PCI values that are less than 10 indicate low precipitation concentration, values between 11 and 15 denotes moderate concentration, values from 16 to 20 indicates high concentration and values above 21 indicates a very high concentration of precipitation (Oliver(1980)). Anomalies of rainfall have been evaluated to determine the dry and wet years in the record and used (Agnew and Chappel, 1999; Woldeamlak and Conway, 2007; Viste et al., 2012; Gebre et al., 2013). Mathematically, it is defined as:

$$Z=(X_i - X_i')/S \tag{3}$$

Where Z denotes standardized anomaly, X_i denotes annual rainfall of a particular year, X_i' represents long term mean annual rainfall and S is the standard deviation of annual rainfall. The drought severity classes can be divided as (Agnew and Chappel, 1999) extreme drought (Z < 1.65), severe drought (1.28 > Z > 1.65), moderate drought (0.84 > Z > 1.28 and no drought (Z > 0.84). Mann Kendall (MK) test and Sen's slope estimator are used to detecting the trend of temperature and rainfall (Karmeshu, 2012; Mann, 1945; Kendall (1975) and Yue et al. (2002)). The Palmer Drought Severity Index (PDSI) is an indicator of meteorological drought index which quantify the weather conditions related to abnormally dry or abnormally wet (Agnew and Chappel, 1999; Dai, 2011; Diodato et al., 2019; Szép et al., 2005). It is sensitive to soil moisture conditions and mostly used for agricultural applications. PDSI data for the year 1901-2005 has also been taken from the same source of KNMI.

3. Results

3.1 Long term variation of temperature and rainfall

The temperature and rainfall monthly data obtained from GPCC has been analyzed for the period 1901-2014 for different seasons, namely, Winter (December- February (DJF)), pre-monsoon (March-May (MAM)), monsoon (June-September (JJAS)) and post-monsoon (October- November (ON)). Figure 1 and 2 show the boxplots of temperature and rainfalls for four different seasons and four different period (1901-1930, 1931-1960, 1961-1990, 1991-2014). The trend in climate change can be identified for 25-30 years. So, the total data period obtained from GPCC into 4-time spans of 30 years. The average temperature and rainfall of the first and last five years of the above 30 years' time span have also been shown for different seasons. It has been evident from figure 1 that the average temperature value for DJF, indicated by the red line in the box plot of temperature lies in the middle of the upper and lower bound of the temperature for the period 1901-1930, 1931-1960 and 1961-1990. However, for the period, 1991-2014, the average value is nearer to the lower limit. For MAM, an average value is closer to the lower bound and upper bound for the period 1901-1930 and 1931-1960 respectively. For JJAS, an average value is closer to the upper limit for the period 1901-1930 and 1961-1990, and to the lower limit for the period 1991-2014.

For DJF, the average value of rainfall lies closer to the lower limit for the period, 1901-1930, 1961-1990 and 1991-2014. For MAM, an average value is closer to the lower limit for the period 1901-1930 and 1931-1960. For JJAS, the average value of rainfall is closer to the lower limit for the period 1901-1930, 1961-1990 and 1991-2014 and to the upper limit for the period 1931-1960. For ON, the average value of rainfall is closer to the lower limit for the period 1901-1930 and 1991-2014, and closer to the upper limit for the period 1931-1960. It is quite clear from the line plot, that the average temperature shows a higher value for the last five years with respect to the first five years for each period and each season. The average value of the rainfall for the last five years show higher values with respect to the first five years for JJAS for the period 1931-1960 and 1961-1990.

Table I shows the number of years with higher or lower temperature or rainfall values with respect to the average value. It can be seen from table I that, for DJF, MAM and JJAS number of years greater than the average temperature value has been increased for the period 1991-2014 with respect to the other three periods. However, for rainfall, the picture is not clear which indicates the uncertainty of tropical rain over this region. For rainfall, most of the year's show lower values than the average value for the period 1901-1930 and 1961-1990. The total rainfall for the period 1991-2014 is higher with respect to the other three periods.

3.2 Trend Analysis of temperature and rainfall

Figure 3 and 4 show the trend analysis of temperature and rainfall for the period 1901-2014 respectively. The annual average temperature for this location is 20.7°C, 29.11°C, 29.13°C and 25.64°C for the period DJF, MAM, JJAS and ON respectively. A linear regression model has been used to define the slope which in this case is about 0.0053°C/ year, 0.0086°C/ year, 0.0064°C/ year, 0.012°C/ year and 0.0082°C/ year for DJF, MAM, JJAS, ON and annual respectively. The average rainfall for this location is 5.15mm, 22.73 mm, 117.27 mm, 18.23 mm and 163.4 mm for DJF, MAM, JJAS, ON and annual respectively. The slope of rainfall is 0.04 mm/ year, 0.03 mm/ year, 0.219 mm/ year, 0.04 mm/ year and 0.3 mm/ year for DJF, MAM, JJAS, ON and annual respectively. The average percentage change of temperature and rainfall for the period 1931-1960, 1961-1990 and 1991-2014 with respect to the previous period, i.e, 1901-1930, 1931-1960 and 1960-1990 respectively have been shown in table II. In recent decades, the temperature in all the seasons has been increased with respect to the previous years except the winter season. When the rainfall amount of the recent decades (1991-2014) is compared with the previous years, a significant increase in the rainfall has been observed in the pre-monsoon period. It indicates the increased frequency of convective events over this region. However, for the case of monsoon season, average rainfall has been increased 12.39% in the period 1931-1960 with respect to the previous period 1901-1930. For winter and post-monsoon seasons, significant interannual variability has been observed. This phenomenon reveals the fact of significant non-monsoon rainfall over this region. MK test and sen's slope estimator has been applied to the time series data of temperature and rainfall for the period 1901-2014. MK test 'Z' statistics value has been derived for 5 % significance level and shown in supplementary Table I and II for temperature and rainfall respectively. A statistically significant increasing trend ($p < 0.05$) of temperature has been observed for all the months except January. A statistically significant increasing trend has been observed for most of the months' rainfall.

3.3 Descriptive statistics of Rainfall

The mean annual rainfall of the area during the study period was 163 mm with 182.44 mm standard deviation and 86.38 CV. The maximum rainfall that occurs over this region is in the monsoon season, mainly in July and minimum in the winter season. The Indian Summer Monsoon (ISM) contributes about 61% of the total rainfall. The pre-monsoon and post-monsoon periods also contribute a substantial amount of rainfall, around 15.88% and 19.1 % respectively of the total rainfall. This reveals the fact that a significant amount of non-monsoon rainfall occurs over this region which is mainly originated from the local convective activities. The highest and lowest CV has been shown for December and July respectively. DJF shows the highest CV compared to the other three seasons which implies more interannual variability for this season. JJAS shows the lowest inter-annual variability. Rainfall anomalies also show large interannual variability (Fig. 5), with low values indicating extreme drought conditions. Over this location, lower values of Z have decreased since 1975. The precipitation concentration index (PCI) is presented in figure 6.-High values of PCI (16-20) has been observed for the periods 1951-1975 and 1976-2000.

PDSI data has been utilized to investigate the extent of meteorological drought for the period 1901-2005. The yearly variation of PDSI data over this location is shown in figure 7. PDSI values extend from -5 to +5. Negative (positive) values represent dry (wet) conditions, while the value indicates the intensity. The number of years with dry conditions have increased. However, the intensity of dryness is very near zero. A clear difference of the period 1901-1950 with respect to the period 1951-2000 is observed in figure 7. The figure reveals that the value of PDSI has decreased for the period 1951-2000 which indicates a decreased intensity of dryness in Kolkata.

4. Conclusion

Kolkata, located near the land-ocean boundary of the Bay of Bengal, is one of the important cities of India and contributes significantly to the GDP of the country, together with its surrounding region with significant agricultural activities. Long term variations of temperature and precipitation over this region are analyzed in this paper, using gridded monthly data obtained from the Global Precipitation and Climate Centre (GPCC) for the period 1901-2014. The trend analysis is performed for four different seasons: (December-February (DJF), March-May (MAM), June-September (JJAS) and October- November (ON)).

Statistical parameters, namely, coefficient of variation (CV), precipitation anomaly and precipitation concentration index (PCI) were calculated to characterize the climate of the region. Furthermore, non-parametric tests (MK test and sen's slope estimator) were used to detect changes in trends of rainfall and temperature. Palmer Drought Severity Index (PDSI) have been observed to examine the extent of meteorological drought. The main conclusions are listed below:

(i) The number of years greater than the average temperature value in for DJF, MAM and JJAS has increased for the period 1991-2014 with respect to the previous period. For rainfall, more number of years less than average value has been observed for the period 1901-1930 and 1961-1990. However, total rainfall for the period 1991-2014 shows a higher value with respect to the other three periods.

(ii) A detailed analysis of seasonal temperature and rainfall values has been done and the numerical figures have been calculated. The average temperature for DJF, MAM, JJAS and ON period over this location is 20.7°C, 29.11°C, 29.13°C and 25.64°C respectively. The average rainfall is highest in the monsoon period (117 mm) due to the Indian Summer Monsoon (ISM). The annual slope of temperature is 0.0082°C/ year and rainfall is 0.03 mm/ year. Significant increases in the non-monsoon rainfall have been observed in recent decades which is an indication of an increase of local convective activities over this region. Average rainfall has also been increased for the monsoon period. Interannual variability of rainfall has been observed in winter and post-monsoon season which reveals the uncertainty of non-monsoon rainfall over this region. A statistically significant increasing trend has been observed for most of the months for temperature and rainfall.

(iii) The winter period shows the highest coefficient of variation (CV) compared to the other three seasons which implies more interannual variability for this season. Monsoon season shows the lowest inter-annual variability as every year a significant amount of rain occurs in the monsoon season due to ISM. The rainfall anomaly also witnessed the presence of interannual variability over this location. Rainfall with high precipitation concentration index (16-20) has been observed for the period 1951-1975 and 1976-2000.

(iv) As an indicator of meteorological drought over this region, analysis of PDSI indicates that though the number of years with dry conditions has increased, the intensity of dryness has decreased.

This long term study of temperature and rainfall based on GPCC observations over Kolkata and the surrounding region will be helpful to understand the climate change over this location. It will also help the smallholder farmers for resilient farming and to design adaptation strategies for agricultural activities for climate change.

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References

Agnew CT, Chappell A. 1999. Drought in the Sahel. GeoJournal 48.4: 299-311. https://doi.org/10.1126/science.1090849.

Asfaw A, Simane B, Hassen A, Bantider A. 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather and climate extremes 19: 29-41. https://doi.org/10.1016/j.wace.2017.12.002.

Becker A, Finger P, Meyer-Christoffer A, Rudolf B, Schamm K, Schneider U, Ziese M. 2013. A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901-present. Earth System Science Data, 5:71-99. https://doi.org/10.5194/essd-5-71-2013.

Bewket W, Declan C. 2007. A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society 27: 1467-1477. https://doi.org/10.1002/joc.1481.

Bisai D, Chatterjee S, Khan A, Barman NK. 2014. Long term temperature trend and change point: a statistical approach. Open journal of atmospheric and climate change 1.1: 32-42.

Bocheva L, Marinova T, Simeonov P, Gospodinov I. 2008. Variability and trends of extreme precipitation events over Bulgaria (1961–2005). Atmospheric Research 93(1-3):490-497. https://doi.org/10.1016/j.atmosres.2008.10.025.

Boucher K, Climates of South Asia. G.B.Pant and K.Rupa Kumar (eds). J.Wiley and Sons: Chichester, 1998. https://doi.org/10.1002/(SICI)1097-0088(199804)18:5%3C581::AID-JOC267%3E3.0.CO;2-%23.

Ceppi P, Scherrer SC, Fischer AM, Appenzeller C. 2012. Revisiting Swiss temperature trends 1959–2008. International Journal of Climatology 32: 203–213. https://doi.org/10.1002/joc.2260.

Cheung WH, Senay GB, Sing A. 2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. International Journal of Climatology 28: 1723–1734. https://doi.org/10.1002/joc.1623.

Daniel M, Woldeamlak B, Lal R. 2014. Recent spatiotemporal temperature and rainfall variability and trends over the upper Blue Nile river basin, Ethiopia. International Journal of Climatology 34: 2278–2292. https://doi.org/10.1002/joc.3837.

Da Costa FL, Fabiana B. 2016. The challenge of global environmental change in the anthropocene: An analysis of Brazil and China. Chinese Political Science Review 1.4: 685-697. https://doi.org/10.1007/s41111-016-0028-9.

Dai A. 2011. Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. Journal of Geophysical Research. Atmospheres 116: D12. https://doi.org/10.1029/2011JD016410.

Degaetano TA, Allen J R. 2002. Trends in twentieth-century temperature extremes across the United States. Journal of Climate 15: 3188–3205. https://doi.org/10.1175/1520-0442(2002)015%3C3188:TITCTE%3E2.0.CO;2.

De LM, Gonzalez-Hidalgo JC, Brunetti M, Longares LA, 2011. Precipitation concentration changes in Spain 1946–2005. Nat. Hazards Earth Syst. Sci. 11: 1259–1265. https://doi.org/10.5194/nhess-11-1259-2011.

Diodato N, De Guenni LB, Garcia M, Bellocchi G. 2019. Decadal Oscillation in the Predictability of Palmer Drought Severity Index in California. Climate 7.1: 6. https://doi.org/10.3390/cli7010006.

Gebre H, Kindie T, Girma M, Belay K. 2013. Trend and variability of rainfall in Tigray, northern Ethiopia: analysis of meteorological data and farmers' perception. Academia Journal of Agricultural Research 1.6: 088-100.

Goswami BN, Venugopal V, Sengupta D, Madhusoodanam MS, Xavier PK. 2006. Increasing trends of extreme rain events over India in a warming environment. Science, 314: 1442– 1445. https://doi.org/10.1126/science.1132027.

Hare W. 2003. Assessment of Knowledge on Impacts of Climate Change, Contribution to the Specification of Art, 2 of the UNFCCC. WBGU.

Hingane LS, Rupa K, Murty VR. 1985. Long-term trends of surface air temperature in India. International Journal of Climatology. 5: 521–528. https://doi.org/10.1002/joc.3370050505.

Hughes GL, Rao SS, Rao TS. 2006. Statistical analysis and time-series models for minimum/maximum temperatures in the Antarctic Peninsula. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences. 463.2077: 241-259. https://doi.org/10.1098/rspa.2006.1766.

Karmeshu N. 2012. Trend Detection in Annual Temperature & Precipitation Using the Mann Kendall Test—A Case Study to Assess Climate Change on Select States in the Northeastern United States. Master’s Thesis, University of Pennsylvania, Philadelphia, PA, USA.

Kendall M, 1975. Multivariate analysis. Charles Griffin. https://doi.org/10.1002/bimj.4710190413.

Khan A, Chatterjee S, Bisai D. 2015. On the long-term variability of temperature trends and changes in surface air temperature in Kolkata Weather Observatory, West Bengal, India. Meteorology Hydrology and Water Management. Research and Operational Applications. 3(2): 9–16. https://doi.org/10.26491/mhwm/59336.

Kumar V, Jain S K, Singh Y. 2010. Analysis of long-term rainfall trends in India. Hydrological Sciences Journal–Journal des Sciences Hydrologiques. 55: 484–496. https://doi.org/10.1080/02626667.2010.481373.

Kumar KR, Kumar KK, Pant GB. 1994. Diurnal asymmetry of surface temperature trends over India. Geophys Res Lett. 21.8: 677–680.

Krockenberger AK, Kitching RL, Turton SM. 2004. Environmental crisis: climate change and terrestrial biodiversity in Queensland. Rainforest CRC, ISBN 0 86443 708 0.

Longobardi A, Villani P. 2009. Trend Analysis of annual and seasonal rainfall time series in the Mediterranean area. International Journal of Climatology. 30: 1538-1546. https://doi.org/10.1002/joc.2001.

Lal M, 2001. Climatic change – implications for India's water resources. Journal of social and Economic development. 3(1): 57-97.

Mahmood R, Shaofeng J, Wenbin Z. 2019. Analysis of climate variability, trends, and prediction in the most active parts of the Lake Chad basin, Africa. Scientific Reports. 9.1: 1-18. https://doi.org/10.1038/s41598-019-42811-9.

Mann HB. 1945. Nonparametric tests against trend. Econometrica. Journal of the Econometric Society. 245-259. https://doi.org/10.2307/1907187.

Martinez JC, Maleski JJ, Miller FM. 2012. Trends in precipitation and temperature in Florida, USA. J. Hydrol. 452: 259–281. http://doi.org/10.1002/hyp.8259.

Matyssek R, Clarke N, Cudlín P, Mikkelsen TN, Tuovinen JP, Wieser G, Paoletti E. 2013. Climate change, air pollution and global challenges: understanding and perspectives from forest research. Developments in environmental science. 13: 3-16. https://doi.org/10.1016/B978-0-08-098349-3.00001-3.

Mooley DA, Parthasarthy B. 1984. Fluctuations of all India summer monsoon rainfall during 1871–1978. Climatic Change. 6: 287–301. https://doi.org/10.1007/BF00142477.

Nandargi SS, Barman K. 2018. Evaluation of climate change impact on rainfall variation in West Bengal. Acta Scientific Agriculture, ISSN: 2581-365X.

Oliver JE. 1980. Monthly precipitation distribution: a comparative index. The Professional Geographer 32 (3): 300–309. https://doi.org/10.1111/j.0033-0124.1980.00300.x.

Pal I, Al-Tabbaa A. 2009. Trends in seasonal precipitation extremes – an indicator of climate change in Kerala, India. Journal of Hydrology 367 (1-2): 62–69. http://doi:10.1016/j.jhydrol.2008.12.025.

Panda A, Sahu N. 2019. Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. Atmospheric Science Letters. 20.10: e932. https://doi.org/10.1002/asl.932.

Pant GB, Hingane LS. 1988. Climatic changes in and around the Rajasthan desert during the 20th century. International Journal of Climatology 8(4): 391–401. https://doi.org/10.1002/joc.3370080406.

Parthasarathy B, Dhar ON. 1974. Secular variations of regional rainfall over India. Quarterly Journal of the Royal Meteorological Society 100.424: 245–257. https://doi.org/10.1002/qj.49710042411.

Philandras, CM, Nastos PT, Kapsomenakis J, Douvis KC, Tselioudis CS, Zerefos CS. 2011. Long term precipitation trends and variability within the Mediterranean region. Natural Hazards and Earth System Sciences. 11.12: 3235–3250. https://doi.org/10.5194/nhess-11-3235-2011.

Rajeevan M, Bhate J, Jaswal AK. 2008. Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. Geophysical Research Letters 35:18. https://doi.org/10.1029/2008GL035143.

Rao PG. 1993. Climatic changes and trends over a major river basin in India. Climate Research 2: 215–223. http://doi.org/10.3354/cr002215.

Rio DS, Herrero L, Pinto-Gomes C, Penas A. 2011. Spatial analysis of mean temperature trends in Spain over the period 1961–2006. Glob. Platin. Chang. 78: 65–75. http://doi.org/10.1016/j.gloplacha.2011.05.012.

Sari AP, Sari RE, Butarbutar RN, Maulidya M, Rusmantoro W. 2007. Indonesia and climate change: Current status and policies. PT PEACE, Jakarta, Indonesia.

Sarker RP, Thapliyal V. 1988. Climate change and variability. Mausam. 39: 127–138.

Schneider U, Peter F, Anja MC, Elke R, Markus Z, Andreas B. 2017. Evaluating the Hydrological Cycle over Land Using the Newly-Corrected Precipitation Climatology from the Global Precipitation Climatology Centre (GPCC). Atmosphere. 8(3): 52. https://doi.org/10.3390/atmos8030052.

Singh N, Sontakke NA. 2002. On climatic fluctuations and environmental changes of the Indo-Gangetic Plains, India. Climatic Change. 52(3): 287–313. https://doi.org/10.1023/A:1013772505484.

Sinha KC, De US. 2003. Climate change in India as evidenced from instrumental records. WMO Bull. 52: 53–59, ISSN 0042-976.

Szép IJ, János M, Zoltán D. 2005. Palmer drought severity index as soil moisture indicator: physical interpretation, statistical behaviour and relation to global climate. Physics and Chemistry of the Earth, Parts a/B/C. 30.1: 231-243. https://doi.org/10.1016/j.pce.2004.08.039.

Thapliyal V, Kulshreshtha SM. 1991. Climate changes and trends over India. Mausam. 42.4: 333–338.

United Nations Framework Convention on Climate Change. 2007. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. United Nations Framework Convention on Climate Change. Bonn, Germany.

Viste E, Diriba K, Asgeir S. 2013. Recent drought and precipitation tendencies in Ethiopia. Theoretical and Applied Climatology. 112.3: 535-551. http://doi.org/10.1007/s00704-012-0746-3.

Xu ZX, Takeuchi K, Ishidaira H, Li JY. 2005. Long-term trend analysis for precipitation in Asia Pacific Friend river basin. Hydrological Processes: An International Journal. 19: 3517–3532. http://doi.org/10.1002/hyp.5846.

Yaduvanshi A, Bendapudi R, Nkemelang T, New M. 2021. Temperature and rainfall extremes change under current and future warming global warming levels across Indian climate zones. Weather and Climate Extremes. 31: 100291. https://doi.org/10.1016/j.wace.2020.100291.

Yue S, Pilon P, Cavadias G, 2002. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. Journal of hydrology. 259: 254-271. https://doi.org/10.1016/S0022-1694(01)00594-7.

Zhao P, Jones P, Cao L, Yan Z, Zha S, Zhu Y, Yu Y, Tang G. 2014. Trend of surface air temperature in Eastern China and associated large-scale climate variability over the last 100 years. Journal of climate 27(12): 4693–4703. https://doi.org/10.1175/JCLI-D-13-00397.1.

Zhang K, Yao Y, Qian X, Wang J. 2019. Various characteristics of precipitation concentration index and its cause analysis in China between 1960 and 2016. International Journal of Climatology 39.12: 4648-4658. https://doi.org/10.1002/joc.6092.

Zikra M, Suntoyo, Lukijanto. 2015. Climate change impacts on Indonesian coastal areas. Procedia Earth and Planetary Science, 14: 57-63. https://doi.org/10.1016/j.proeps.2015.07.085.

Figure:

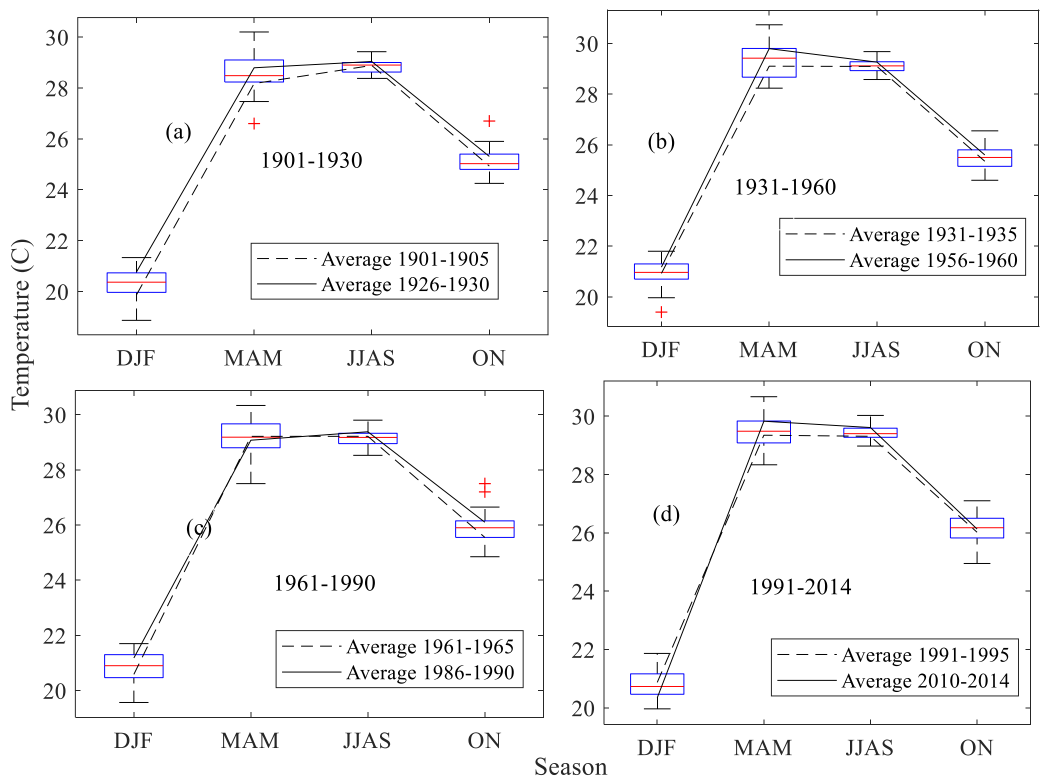


Figure 1. Boxplot of temperature for the period (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, (d) 1991-2014.

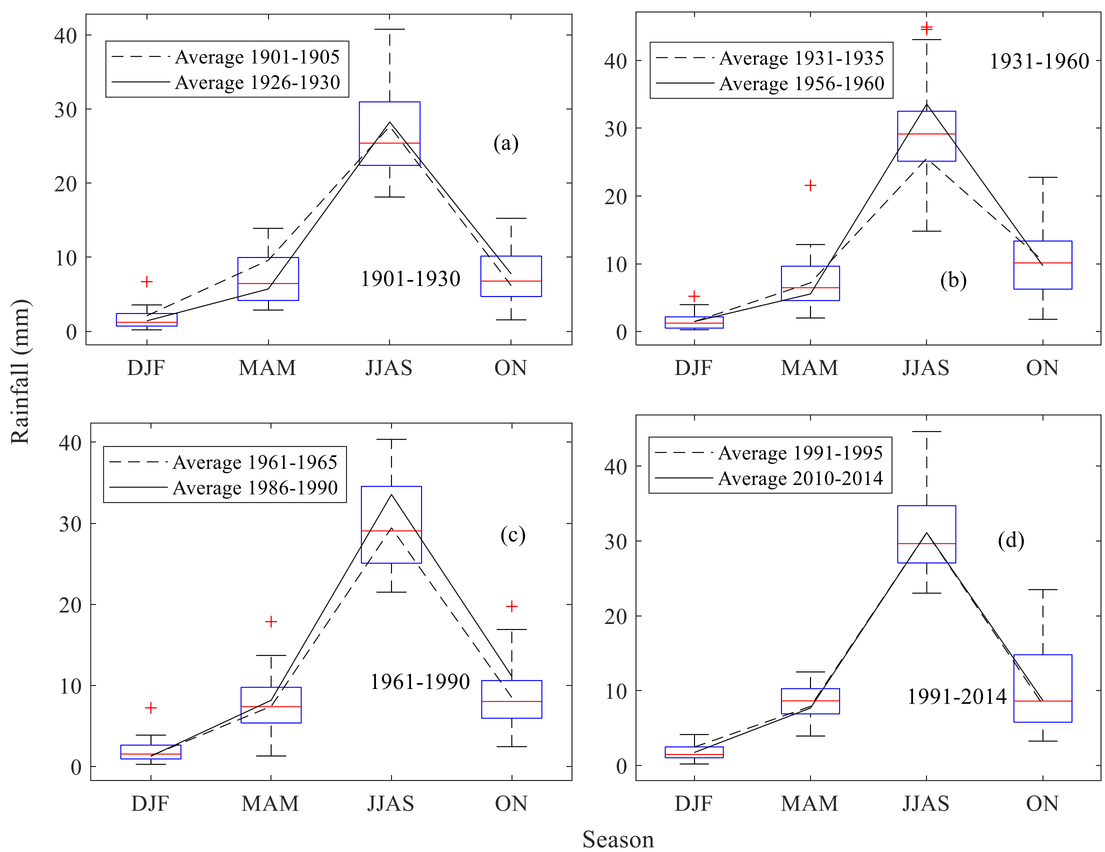


Figure 2. Boxplot of rainfall for the period (a) 1901-1930, (b) 1931-1960, (c) 1961-1990, (d) 1991-2014.

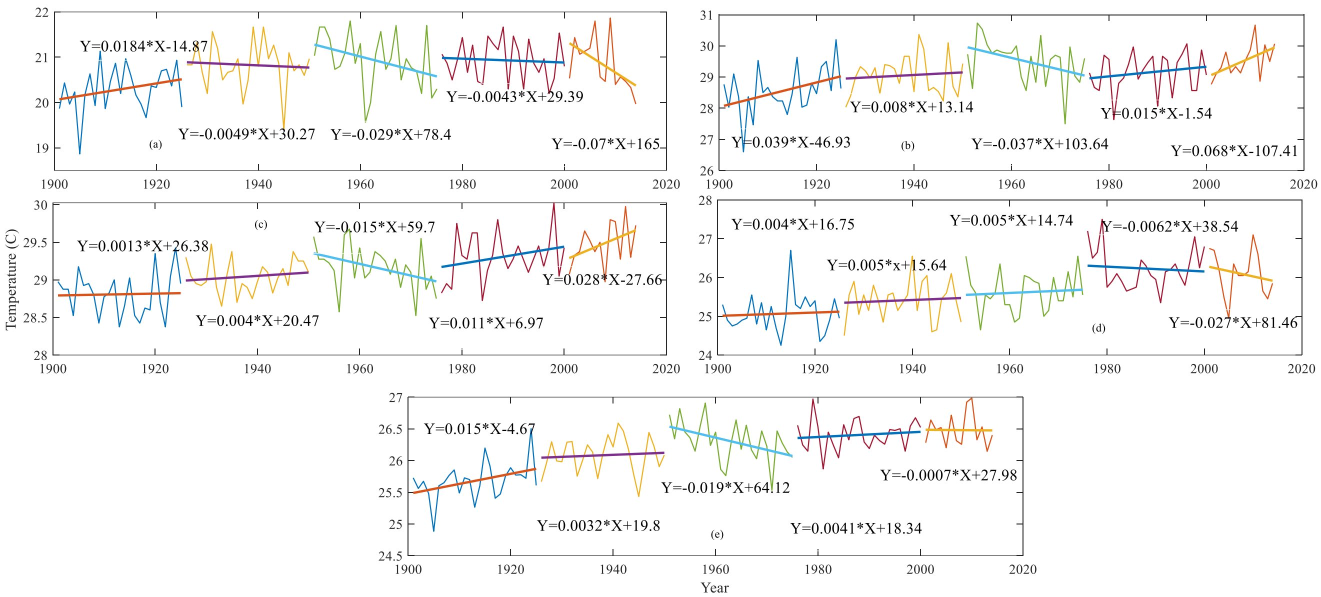


Figure 3. Trend analysis of temperature for the period 1901-2014 for (a) DJF, (b) MAM, (c) JJAS, (d) ON and (e) all year.

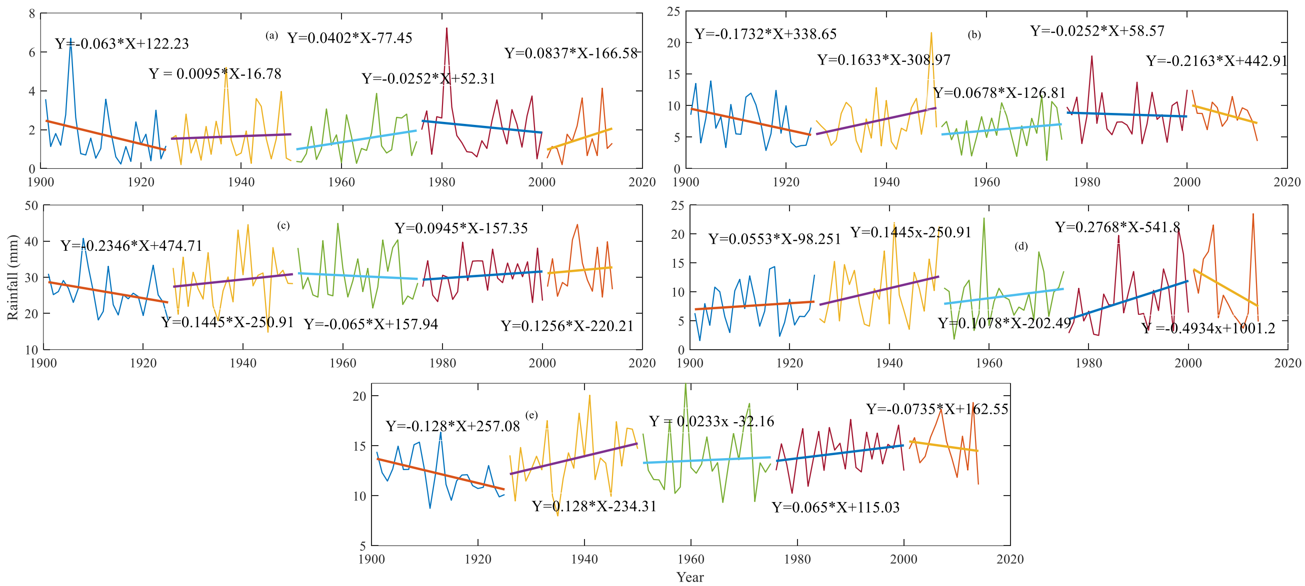
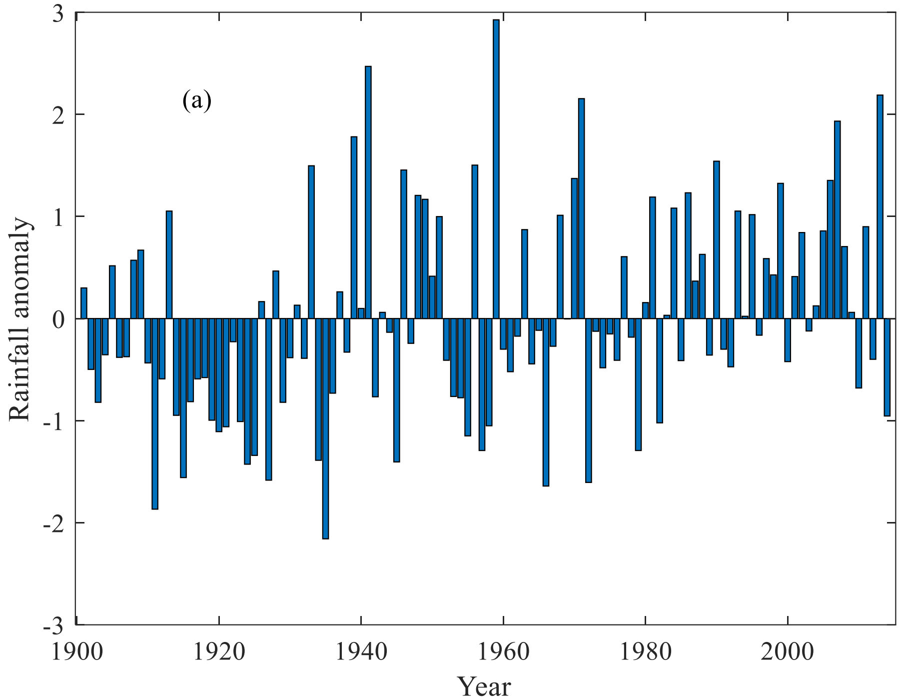


Figure 4. Trend analysis of rainfall for the period 1901-2014 for (a) DJF, (b) MAM, (c) JJAS, (d) ON and (e) all year.


(a)
Rainfall anomaly
3
2
1
0
-1
-2
-3
1900
1920
1940
1960
1980
2000
Year

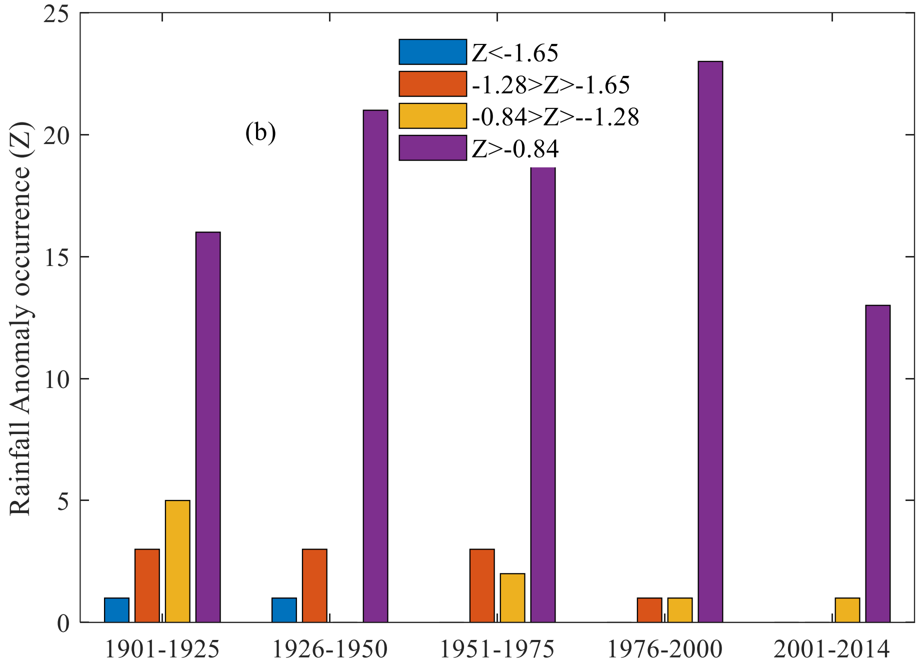


Figure 5 (a) yearly variation of rainfall anomaly, (b) rainfall anomaly occurrence for the different periods of 1901-2014.

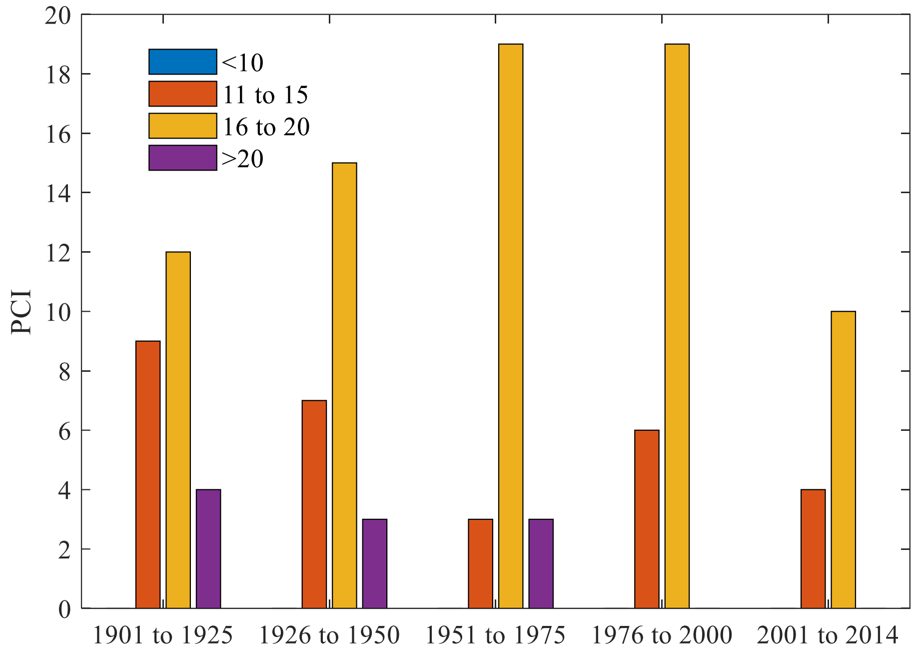


Figure 6. Occurrence of precipitation concentration index (PCI) for the different periods.

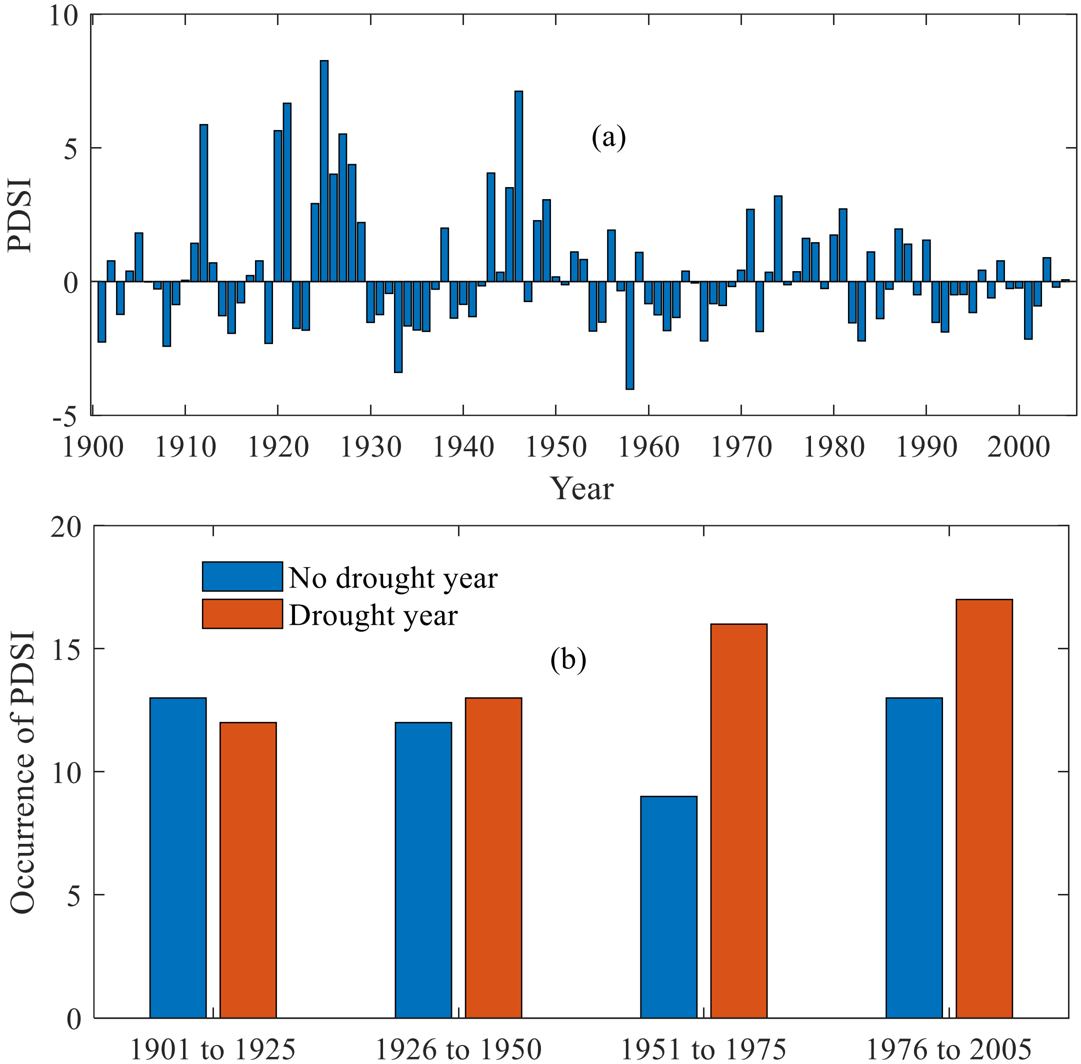


Figure 7 (a) Yearly variation of PDSI, (b) Occurrence of PDSI for the different periods.

Table:

Table I: Number of years temperature and rainfall exceeding average value for a different period

Period		1901-1930		1931-1960		1961-1990		1991-2014	
		Number of Years							
Season	Average value	T	R	T	R	T	R	T	R
DJF	>	14	11	13	13	15	11	16	9
	<	16	19	17	17	15	19	8	14
MAM	>	13	12	17	13	15	14	23	13
	<	17	18	13	17	15	16	1	10
JJAS	>	15	10	14	15	14	13	13	10
	<	15	20	16	15	16	17	11	14
ON	>	14	13	16	15	13	13	12	9
	<	16	17	14	15	17	17	12	15

Table II: Change in temperature and rainfall in 30 years span with respect to previous 30 years span

	Change in temperature			Change in rainfall		
Season	1931-1960 wrt 1901-1930	1961-1990 wrt 1931-1960	1991-2014 wrt 1961-1990	1931-1960 wrt 1901-1930	1961-1990 wrt 1931-1960	1991-2014 wrt 1961-1990
DJF	2.87	-0.55	-0.08	-8.99	19.95	-4.92
MAM	2.63	-0.71	0.88	0.43	7.52	8.65
JJAS	0.95	0.19	0.85	12.39	0.50	3.83
ON	1.52	1.64	0.89	24.62	-18.17	17.03

Supplementary Material:

Table I: Statistics of temperature

	Min (°C)	Max (°C)	Average (°C)	STD	slope	M-K test	Sen's slope
January	17.9	21.6	19.68	0.87	-0.0045	-1.68	-0.004
February	18.3	25.2	22.57	1.017	0.019	4.05	0.01
March	24.3	29.5	27.04	1.025	0.01	3.38	0.01
April	26.8	32.2	29.76	1.057	0.008	2.64	0.007
May	28.7	33.1	30.55	0.91	0.0069	2.55	0.006
June	27.7	31.7	29.93	0.86	0.0075	3.13	0.007
July	28	30.3	28.94	0.41	0.0057	4.85	0.005
August	27.6	29.7	28.83	0.43	0.0073	6.27	0.007
September	27.9	29.7	28.81	0.38	0.0051	4.77	0.005
October	26	28.9	27.5	0.58	0.0088	5.56	0.009
November	22.1	26.7	23.79	0.91	0.015	6.51	0.015
December	17.7	21.6	20.02	0.76	0.0095	4.55	0.009
DJF	18.8	21.8	20.7	0.5	0.0053	3.09	0.005
MAM	26.6	30.7	29.11	0.74	0.0086	4.23	0.008
JJAs	28.4	30	29.13	0.35	0.0064	6.71	0.006
ON	24.2	27.5	25.64	0.66	0.012	7.17	0.013
Annual	24.9	26.9	26.16	0.39	0.0082	7.58	0.007

Table II: Statistics of rainfall

	Min (mm)	Max (mm)	Mean (mm)	std	%	CV	Slope	M-K test	Sen’s slope
January	0.1	9.7	1.63	1.96	0.99	120.17	0.002	0.73	-0.007
February	0.2	16.3	2.96	2.81	1.81	94.83	-0.005	1.60	0.025
March	0.1	21.1	3.79	3.87	2.32	101.92	-0.0018	1.048	-0.007
April	0	20	5.60	4.21	3.42	75.10	0.005	1.02	-0.083
May	0.9	47.8	13.33	7.78	8.16	58.30	0.032	1.81	-0.013
June	3.5	63.8	26.48	12.69	16.20	47.92	0.027	1.24	-0.05
July	9.2	70.9	33.07	11.51	20.24	34.81	0.0431	1.56	0.03
August	12.7	58.1	31.79	11.29	19.46	35.51	0.064	1.82	-0.07
September	11.3	56	25.92	10.38	15.86	40.05	0.083	2.38	0.076
October	0	43.4	13.43	8.69	8.22	64.72	0.032	0.88	-0.11
November	0	26.1	4.80	4.30	2.94	89.51	0.008	0.95	-0.015
December	0	11.6	0.55	1.53	0.34	273.70	0.0026	-0.49	0
DJF	0.2	7.23	1.77	1.28	3.59	162.90	0.0014	0.76	-0.17
MAM	1.3	21.57	7.58	3.38	15.88	78.45	0.0122	1.66	-0.17
JJAS	14.8	44.92	29.32	6.39	61.42	39.585	0.054	2.89	-0.13

ON	1.55	23.5	9.12	4.96	19.10	77.193	0.023	0.97	-0.007
Annual	7.98	21.2 6	13.62	2.61	-	86.38	0.025	3.50	-0.48

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