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Analysis of Trend and Variability of Rainfall in the Mid-Mahanadi River Basin of Eastern India

Rabindra K. Panda, Gurjeet Singh

***Abstract*—**The major objective of this study was to analyze the trend and variability of rainfall in the middle Mahandi river basin located in eastern India. The trend of variation of extreme rainfall events has predominant effect on agricultural water management and extreme hydrological events such as floods and droughts. Mahanadi river basin is one of the major river basins of India having an area of 1,41,589 km^2 and divided into three regions: Upper, middle and delta region. The middle region of Mahanadi river basin has an area of 48,700 km^2 and it is mostly dominated by agricultural land, where agriculture is mostly rainfed. The study region has five Agro-climatic zones namely: East and South Eastern Coastal Plain, North Eastern Ghat, Western Undulating Zone, Western Central Table Land and Mid Central Table Land, which were numbered as zones 1 to 5 respectively for convenience in reporting. In the present study, analysis of variability and trends of annual, seasonal, and monthly rainfall was carried out, using the daily rainfall data collected from the Indian Meteorological Department (IMD) for 35 years (1979-2013) for the 5 agro-climatic zones. The long term variability of rainfall was investigated by evaluating the mean, standard deviation and coefficient of variation. The long term trend of rainfall was analyzed using the Mann-Kendall test on monthly, seasonal and annual time scales. It was found that there is a decreasing trend in the rainfall during the winter and pre monsoon seasons for zones 2, 3 and 4; whereas in the monsoon (rainy) season there is an increasing trend for zones 1, 4 and 5 with a level of significance ranging between 90-95%. On the other hand, the mean annual rainfall has an increasing trend at 99% significance level. The estimated seasonality index showed that the rainfall distribution is asymmetric and distributed over 3-4 months period. The study will help to understand the spatio-temporal variation of rainfall and to determine the correlation between the current rainfall trend and climate change scenario of the study region for multifarious use.

***Keywords*—**Eastern India, long-term variability and trends, Mann-Kendall test, seasonality index, spatio-temporal variation.

I. Introduction

RAINFALL is an important hydro-meteorological variable but due to the influence of global warming, the trends of rainfall extreme are expected to change. The change in the trends of extremes rainfall events have predominant effect on hydrological extreme events such as floods and droughts, and are likely to increase in frequency [1], [2]. Most of the studies using various numerical models [3], [4] illustrate that there will be increase in the inter-annual variability of monsoon rainfall and number of heavy rainfall events during monsoon in India. In the past several studies have been conducted to quantify the extent of impact of the climate variability. A climate variability study on 12 river basins of India was carried out [5] which concluded that, there may be severe droughts and intense floods simultaneously in various parts of the country.

The hydrological extreme events (flood and drought) have significant impact on the agricultural sector particular crop production. Anthropogenic climatic changes are considered to be impacting long-term monsoon patterns [6] and will likely impact the country's food security and economic development. Thus, there is a need to investigate the climate variability, especially for agricultural zones to understand the climate extremes.

II. Study Area

The geographical boundary of the study river basin lies between longitude 80°28' and 86°43' E, and latitudes 19°8' and 23°32' N. The Mahanadi rivers flow through Chhattisgarh and Odisha and flow for about 851 km before it discharges into the Bay of Bengal. The average annual rainfall of the Mahanadi river basin is 1572 mm, of which 70% occurs in the south-west monsoon season (June-October). The Mahanadi river basin has been divided into three regions i.e. upper, middle and delta region (Fig. 1) [12]

The middle region of Mahanadi river basin (48,700 km^2) is an agricultural dominating area (approximately 60%) followed by forest area (approximately 25%). The middle region of Mahanadi river basin is a part of the east Indian state, Odisha, where the economic background of the farmers is quite low in comparison to the rest of the country and agriculture is heavily dependent on rainfall. The pivotal role of rainfall in agriculture, the principal source of livelihood of the population and low economic background of the farmers in Odisha motivated to investigate the climate variability in terms of rainfall pattern in middle region of Mahanadi river basin [12].

On the basis of soil type, humidity, elevation, topography, existing cropping pattern, rainfall, availability of irrigation water and other agro-climatic factors, the Odisha state has been divided in 10 agro-climatic zones, in such a manner that there is very little variation in these parameters within each zone; under the National Agricultural Research Project (NARP). The selected area for the present study is middle region of Mahanadi river basin which is a part of Odisha state and covers five different agro-climatic zones. The zones are numbered as 1 to 5 for convenience in reporting (Fig. 2).

R. K. Panda is a Professor in the School of Infrastructure, Indian Institute of Technology Bhubaneswar, Bhubaneswar-751007, Odisha, India (phone: +91-674-2576122, e-mail: rkpanda@iitbbs.ac.in).
Gurjeet Singh is with School of Earth, Ocean and Climate Sciences, Indian Institute of Technology Bhubaneswar, Bhubaneswar-751007, Odisha, India (e-mail: gs17@iitbbs.ac.in).

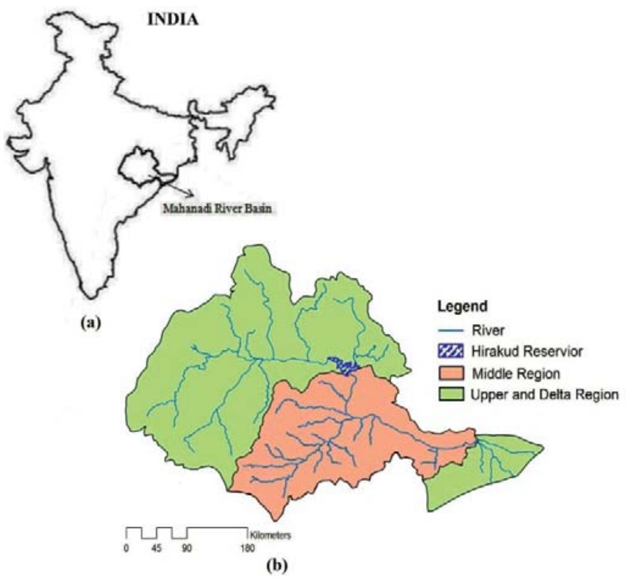

Fig. 1 Location of (a) Mahanadi river basin in India (b) Index map of Mahanadi river basin showing the Upper, Middle and Delta region

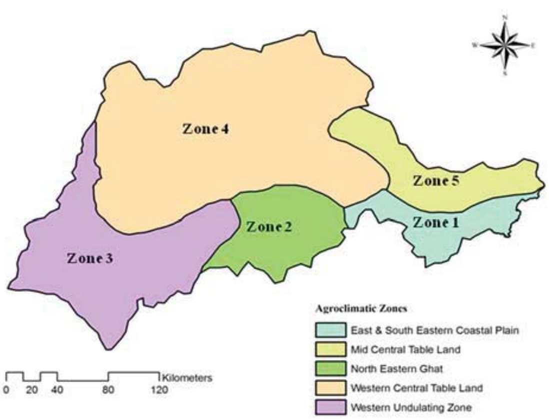

Fig. 2 Map of Agro-climatic zones in middle region of Mahanadi river basin

III. Data and Methodology

The boundaries of the agro-climatic zones of Odisha were manually digitized in polygon mode using ArcMap of ArcGIS 10.2 software. Further, the boundary of middle region of Mahanadi river basin was overlapped over the digitized agro-climatic zones to clip (using Analysis tool of ArcMap) the areal extent of the middle region. The daily rainfall data having 0.25 degree spatial resolution for 35 years (from 1979-2013) were collected from IMD, Pune.

The long term variability of rainfall for the five Agro-climatic zones of middle region of Mahanadi river basin was investigated by evaluating the mean, standard deviation and coefficient of variation on monthly, seasonal and annual timescale.

The long term trend analysis for rainfall was carried out for the period 1979-2013 using the Mann-Kendall test. It is a non-parametric test and first used by [7] and the test statistic was derived by [8].

The Mann-Kendall statistics S is given as

$$S = \sum_{i=1}^{n-1} \sum_{j=1+1}^{n} sgn(x_j - x_i) \quad (1)$$

Given two time series x_i and x_j where x_i is ranked from *i=1,2,...n-1* and, x_j is ranked from *j=i+1,2,.......n*. For every x_i (taken as a reference point), each x_j is compared such that,

$$Sgn(x_j - x_i) = \begin{cases} +1, (x_j - x_i) > 0 \\ 0, (x_j - x_i) = 0 \\ -1, (x_j - x_i) < 0 \end{cases} \quad (2)$$

The variance statistic is given as

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i)(t_i-1)(2t_i+5)}{18} \quad (3)$$

where t_i is considered as the number of ties upto sample *i*. The test statistic Z_c is given as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(s)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (4)$$

Here, Z_c follows a standard normal distribution.

The seasonality index (SI), which quantifies the degree of variability in monthly rainfall through the year, is estimated by the summation of the absolute deviations of mean monthly rainfall from the overall monthly mean, divided by the mean annual rainfall [9], [10]. The SI can vary from 0 to 1.83 having equal rainfall in all the months and all the rainfall in one month respectively [11].

IV. Results and Discussion

Analysis of spatial variability in monthly rainfall (mean and standard deviation) for all the Agro-climatic zones of mid-Mahanadi river basin from 1979 to 2013 is shown in Fig. 3. It was observed from the figure that most of the rainfall occurs during the months of June, July, August and September months in the all Agro-climatic zones. The higher rainfall in these months are due to monsoon season. It very well matches with the classification of seasons according to the India Metrological Department (IMD). For further analysis, the seasons are characterized according to the classification of IMD as winter (January and February), Pre-monsoon (March-April-May), Monsoon (June-July-August-September) and post-monsoon (October-November-December). It was also observed from the Fig. 3 that the zone 3 and 4 receive less rainfall in the non-monsoon season and higher rainfall in the monsoon season as compared to others zones.

Fig. 3 shows that the inter-annual variability is high in zone 1, 2 and 5 during May and October months. The high inter-annual variability in these zones may be due to development and persistence of low pressure over northwest Bay and their subsequent movement and persistence over Odisha [12].

Fig. 4 shows the contribution of the monthly rainfall to the total annual rainfall, which implies that all zones are primarily affected by monsoonal activities. Fig. 4 also reveals that the contribution of July and August month rainfall is more to the total rainfall as compare to other months across all the zones.

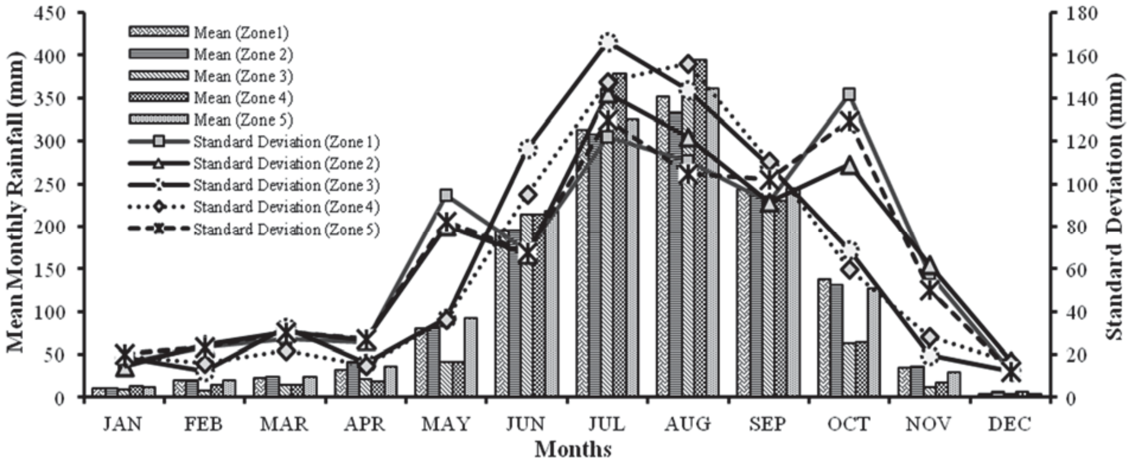

Fig. 3 Annual cycle of monthly precipitation in agro-climatic zones of mid-Mahanadi river basin from 1979-2013

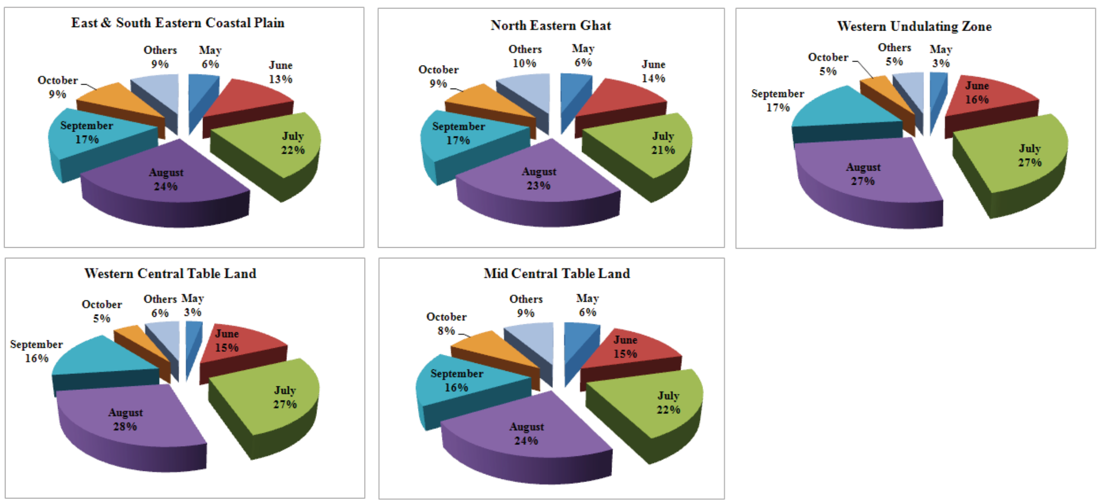

Fig. 4 Contribution of the monthly rainfall to the total annual rainfall

The rainfall trend analysis for each Agro-climatic zone of mid-Mahanadi river basin on seasonal timescale over the last 35 years (1979-2013) is shown in Fig. 5. In winter season, only one Agro-climatic zone-3 shows decreasing trend at 90% significance level, whereas in pre-monsoon season zone 2 and 4 have decreasing trend at 95 and 90% significance levels. During monsoon season, in three zones (zone 1, 4 and 5) more than 50% area of mid-Mahanadi river basin shows significant increasing trend, where zones 1 and 5 have 95% significance level. The annual trend is found to be increasing in zones 1 and 5 at 99% significance level.

The trend analysis shows only the changes in the rainfall pattern. The above results therefore reveal only the changes in the rainfall pattern in the last 35 years period (1979-2013), but unable to provide the information on changes occurred in rainfall distribution from one period to another. Hence, the seasonality index (SI) was calculated for the period 1979-2013, which helps in identifying the rainfall regimes on the monthly distribution of the rainfall. The calculated SI values are presented in Table I.

TABLE I
ESTIMATED SI INDEX FOR 1979-2013 PERIOD

Agro-climatic Zone	Agro-climatic Zone Name	SI Index
Zone 1	East & South Eastern Coastal Plain	0.877
Zone 2	North Eastern Ghat	0.842
Zone 3	Western Undulating Zone	1.013
Zone 4	Western Central Table Land	1.036
Zone 5	Mid Central Table Land	0.893

It is very clear from the definition of the seasonality index [11] that, the lower value of SI shows better distribution of monthly rainfall among all the months of a year, whereas higher values (>1) indicates that the distribution of the monthly rainfall is mostly attributed to three months or less. The SI index values of 1.013 and 1.036 corresponding to the zone 3 and 4 respectively, shows that the distribution of monthly rainfall in these zones is mostly attributed to 1 or 2 months. The other zones (1, 2 and 5) have value of SI in the rage of 0.8 to 0.9, which shows the distribution of monthly rainfall in these zones was markedly seasonal and distributed in 3-4 months period with long dry season.

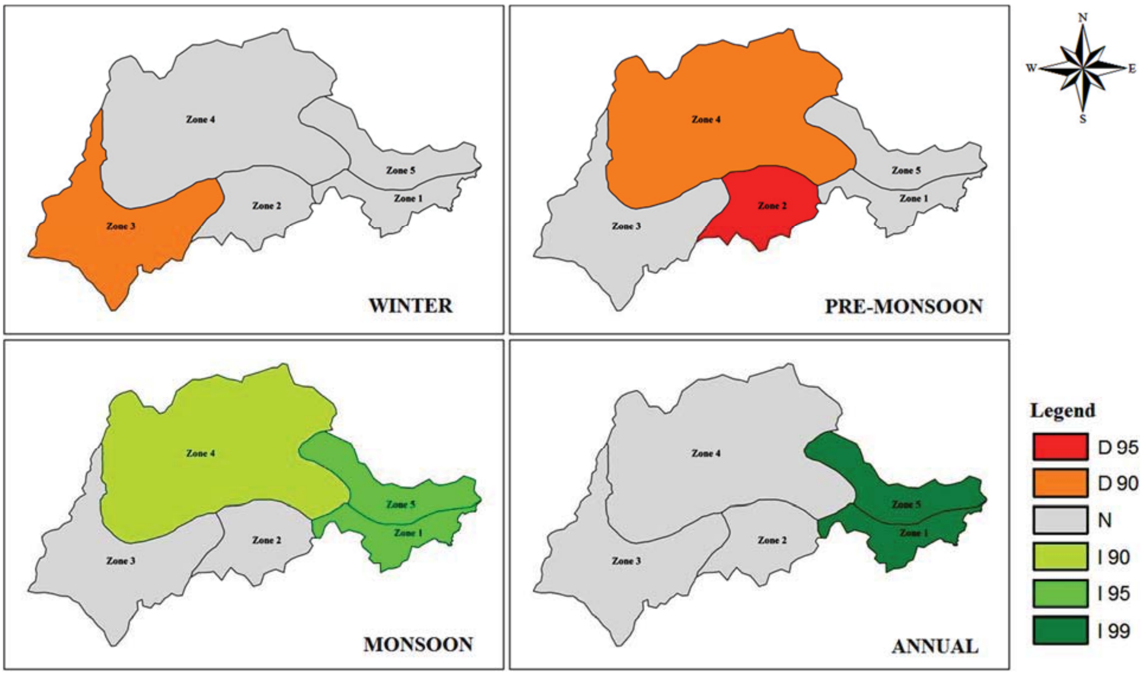

Fig. 5 Map of the seasonal trend of rainfall in the Agro-climatic zones of mid-Mahanadi region. 'D' represent the decreasing trend, 'I' represent the increasing trend and the insignificant trend represented by 'N'. The levels of significance are represented as 90, 95 and 99. The post-monsoon season do not have any trend in any zone

V. Conclusions

In this study, the monthly, seasonal and annual characteristics of the rainfall were studied in the five Agro-climatic zones of the mid-Mahanadi river basin. The long term variability and long term trend of rainfall was analyzed at different time scales. The seasonality index of the rainfall has been evaluated to understand the monthly distribution of the rainfall regimes. The following conclusions are drawn from the study.

1. Most of the rainfall occurs in the months of June, July, August and September in all Agro-climatic zones of mid-Mahanadi river basin
2. The contribution of July and August months rainfall is more to the total rainfall as compare to other months across all the zones.
3. The zones 3 and 4 receive lesser rainfall in the non-monsoon season but receive higher rainfall in the monsoon season as compared to others zones.
4. The inter-annual variability is high in zones 1, 2 and 5 during the months of May and October, which may be due to low pressure or thunderstorm activities prevailing over the region.
5. The rainfall has a decreasing trend in the non-monsoon season and increasing trend in the monsoon season across most of the agro-climatic zones.
6. Annual trend is found to be increasing in the zone 1 and 5 at 99% significance level.
7. High SI index in all agro-climatic zones indicates that the rainfall distribution has become asymmetric with a loss in seasonality.

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