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Effect of rainfall variability on rainfed agriculture of the middle catchment of Mahanadi River Basin

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ABSTRACT

Rainfed agriculture in the Kantamal catchment of the middle Mahanadi River Basin is highly sensitive to rainfall variability. Approximately 95% of the catchment area lies in Odisha, covering parts of Kalahandi, Nuapada, Bolangir, Kandhamal, Nabarangpur, Boudh and Sonepur districts, while the remaining 5% lies in Chhattisgarh, covering parts of Gariaband district. The present study carried out in 2024 examined the seasonal trend in rainfall using the Innovative Trend Analysis (ITA) technique and effect of changing rainfall patterns in major cropping systems of the basin. The Sen's slope analysis revealed that annual, monsoon, pre-monsoon and post-monsoon rainfall are decreasing @4.2, 3.5, 0.8 and 1.2 mm/year, respectively. These correspond to reductions of approximately 3.0%, 3.0%, 8.0% and 11.4% per decade from the long-term normal rainfall. The decline in post-monsoon rainfall is proportionally higher than other seasons, indicating increasing vulnerability of winter (*rabi*) crops due to reduced residual soil moisture in the catchment. The study also revealed that important farming operations such as seedbed preparation and nursery raising of rice were affected by decline in pre-monsoon rainfall, rice crop may suffer with water stress at the critical period of irrigation like the active tillering, panicle initiation and flowering stages due to the decrease in monsoon rainfall. Further, due to decrease in post-monsoon rainfall, the low volume and high value crops like pulses and oilseeds may suffer due to moisture stress which will impact agricultural productivity and rural livelihood of the catchment. The findings suggests for implementation of water conservation measures (e.g. check dams, farm ponds and dams), rainwater harvesting structures, irrigation infrastructures, advanced on farm water management techniques (e.g. micro irrigation and alternate wetting and drying) and agricultural policies to face the climate change induced rainfall variability in the catchment.

Keywords: Agricultural productivity, Climate change, Livelihoods, Rainfall variability, Trend analysis

Rainfall is crucial for shaping agriculture, especially in rainfed areas where crop growth depends entirely on seasonal precipitation. In the middle catchment of the Mahanadi River Basin, covering parts of Odisha and Chhattisgarh, agriculture is mostly rainfed. Farmers rely on monsoon rainfall to grow rainy (*kharif*) crops like rice, while *rabi* crops, including pulses (greengram, blackgram), sesame and mustard are grown depending on the residual soil moisture and post-monsoon rainfall. Variability in rainfall both in amount and timing can severely affect agricultural productivity and livelihoods. Erratic rainfall patterns and frequent droughts lead to crop failures, reduced yields and increased risk for rainfed agriculture (Abebaw 2025, Singh and Prabhakar 2025).

Climate change has impacted variability in weather parameters. Global temperatures have already risen by 1.1°C since pre-industrial times, with projections suggesting an increase of 1.5°C by the 2030s (IPCC 2021). In India, climate change is becoming more evident through more frequent extreme weather events, shifts in monsoon patterns and increasing temperatures. Research shows that India's mean temperature has risen by 0.6°C from 1901 to 2018 (IMD 2020). This broader climate shift has led to increasingly erratic rainfall patterns, resulting in severe droughts and profound agro-ecological crises such as critical groundwater depletion in vulnerable dryland regions (Gupta *et al.* 2021, Das *et al.* 2022). Since agriculture is the mainstay of India's rural economy, farmers in rainfed regions are vulnerable to such shifts, which directly affect crop yields and income stability.

Study of trend in rainfall and its seasonal variability is critical for understanding how climate change has affected the rainfed agriculture. Analysing these trends helps to identify long-term climate patterns, which is essential for developing resilient agricultural practices. Various methods, such as the Mann-Kendall test and Sen's slope estimator, are

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widely used for this type of hydro-climatic trend analysis (Desai *et al.* 2019, Padhiary *et al.* 2018). Innovative Trend Analysis (ITA) is especially useful for identifying trends in highly variable and non-linear data, making it ideal for assessing climate impacts on rainfall. In rainfed regions like the Kantamal catchment, where rainfall variability directly influences farming, trend analysis is key to shaping strategies for climate adaptation. Hence the study aims to quantify the seasonal trends in rainfall from 1901–2021 using the Innovative Trend Analysis (ITA) technique and assess the implications of these trends on the major cropping systems and agricultural operations in the Kantamal catchment.

MATERIALS AND METHODS

Study area: Kantamal catchment was selected as the study area as it is the main catchment of the Mahanadi basin in Odisha having highest percentage rainfed agriculture. It covers an area of 20,023 km². The region experiences three distinct rainfall periods such as, pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January) which are critical for different stages of agricultural operations. The normal annual rainfall of the study area is found to be 1443 mm out of which 86% occurs in monsoon and rest 14% during non-monsoon season. The average maximum and minimum temperature of the study area was found to be 33.2°C and 23.1°C, respectively. The major crops cultivated in the Kantamal catchment of the Mahanadi River basin during the *kharif* season are rice (*Oryza sativa*), maize (*Zea mays*) and finger millet (*Eleusine coracana*), covering approximately 55–65%, 8–12% and 5–8% of the gross cropped area, respectively. During the *rabi* season, greengram (*Vigna radiata*), blackgram (*Vigna mungo*), sesame (*Sesamum indicum*) and mustard (*Brassica juncea*) are cultivated, occupying about 10–15%, 5–8%, 3–5% and 4–7% of the cropped area, respectively. Kantamal catchment drained by Tel tributary, is the major rainfed area of Mahanadi basin of the state of Odisha. It covers eight districts and 48 blocks of Odisha and one district and two blocks of Chhattisgarh. Kalahandi, Bolangir, Nuapada, Kandhamal, Nabarangpur, Rayagada, Boudh and Sonepur districts of Odisha and Gariaband district of Chhattisgarh come under this catchment. More than 95% area of the basin spreads over the state of Odisha and the rest in Chhattisgarh.

Data collection and analysis: For this study, 0.25° × 0.25° gridded daily rainfall data (1901–2021) obtained from the India Meteorological Department (IMD) were used. The Kantamal catchment boundary was overlaid on the IMD grid in a GIS platform and all grid cells whose centroids fell within the catchment area were selected. Based on this spatial intersection, 27 grid stations were identified within the catchment for rainfall variability study conducted in 2024. The collected data were processed to identify seasonal trend in rainfall using ITA technique.

Statistical analysis: To understand the fundamental distribution and natural variability of the seasonal and annual rainfall data across the catchment, descriptive statistics were computed prior to conducting the trend analysis. The evaluated parameters included the mean ($\bar{x}$), standard deviation (SD), coefficient of variation (CV), coefficient of skewness (CS) and coefficient of kurtosis (CK). These parameters were calculated using the following standard mathematical frameworks (Equation 1 to Equation 4):

$$\mathrm{SD} = \sqrt{\left\{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2\right\}} \tag{1}$$

$$\mathrm{CV}\ (\%) = \left(\frac{\mathrm{SD}}{\bar{x}}\right) \times 100 \tag{2}$$

$$\mathrm{CS} = \frac{1}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{\mathrm{SD}}\right)^3 \tag{3}$$

$$\mathrm{CK} = \frac{n(n+1)}{(n-1)(n-2)(n-3)}\sum_{(i=1)}^{\{n\}}\left(\frac{x_i - \bar{x}}{\mathrm{SD}}\right)^4 - \frac{3(n-1)^2}{(n-2)(n-3)} \tag{4}$$

Where n represents the total number of observations and X_t represents the specific rainfall value for a given period. The CV was utilized to measure the dispersion of the data relative to its mean. Following the classification by Hare (2003) and Gebremichael *et al.* (2014), rainfall variability was categorised based on the CV as low (CV<20%), medium (20–30%) and high (> 30%). The CS and CK were utilised to assess the asymmetry and the "tailedness" of the rainfall distribution, respectively.

Innovative trend analysis: The Innovative Trend Analysis method, introduced by Şen (2012), provides a robust and non-parametric approach for detecting trends in time series data, particularly in hydrological studies such as rainfall analysis. Unlike traditional trend detection methods like the Mann-Kendall test or Spearman's rho, which can be limited by assumptions of serial independence and sensitivity to outliers, ITA effectively overcomes these challenges. It offers the potential to identify both monotonic and sub-trends within the data, making it suitable for complex datasets that exhibit non-normal distributions, autocorrelation, or outliers, which are often found in climate and hydrological studies.

The ITA method begins by dividing the data into two equal parts. The first half of the data is sorted in ascending order, while the second half remains unsorted. The two halves are then plotted against each other on a scatter plot, with the sorted data on the x-axis and the unsorted data on the y-axis. The trend is interpreted by comparing the data points to a 45º reference line (also known as the 1:1 line). Points above the 45º line indicate an increasing trend, while those below suggests a decreasing trend. If the points cluster along the 45º line, it implies the absence of a trend. This visual method makes ITA particularly intuitive for identifying complex patterns within the dataset. To quantify the trend, the slope of the ITA is calculated using the Equation 5:

$$\mathrm{B} = \frac{1}{n}\sum_{t=1}^{n}(x_j - x_k) \tag{5}$$

Where, B is the ITA slope; n is the number of data pairs and x_j and x_k represent the values of the sorted and unsorted sub-series, respectively. A positive slope indicates an increasing trend, while a negative slope indicates a decreasing trend.

The significance of the trend is evaluated using a confidence interval, which is based on the standard deviation of the slope. The confidence limit is given by Equation 6:

$$CL_{(1-\alpha)} = 0 \pm \frac{S_{ITA}}{\sigma_s} \qquad (6)$$

Where σ_s is the standard deviation of the slope; S_{ITA} is the slope's standard deviation and α is the chosen significance level (typically 95%). If the evaluated slope exceeds the critical value, the null hypothesis of no trend is rejected, confirming the presence of a statistically significant trend.

To compute the standard deviation of the slope, the Equation 7 is used:

$$\sigma_s = \frac{2}{n(n-1)}\sigma(1-\rho_{y1y2}) \qquad (7)$$

Where σ is the standard deviation of the series and ρ_{y1y2} is the cross-correlation coefficient between the ascending sorted two halves of the data series.

In this study, ITA was applied to pre-monsoon, monsoon and post-monsoon rainfall data from the Kantamal catchment of the Mahanadi River Basin. By using ITA, it was possible to detect significant seasonal variations in rainfall patterns. For instance, the study revealed a significant decline in pre-monsoon and post-monsoon rainfall, which has direct implications for agricultural practices such as summer plowing and *rabi* crop moisture availability. The ability of ITA to capture such localized trends provides valuable insights for water resource management and climate adaptation strategies in rainfed agricultural regions.

The crop calendar for the Kantamal catchment in the Mahanadi Basin shows a clear seasonal pattern dominated by *kharif* crops during the monsoon and *rabi* crops in winter (Fig. 2). Rice, maize and finger millet are mainly grown from June to October/November, aligning with the south-west monsoon and high rainfall period. Pulses like greengram and blackgram are cultivated in two windows, i.e. January–March and November–December seasons in residual moisture conditions. Mustard is primarily a *rabi* crop mostly sown in November and some patches its harvest continues up to March, while sesame is cultivated in both pre-monsoon (January–March) and post-monsoon (October–December) windows. Overall, the calendar reflects efficient use of monsoon rainfall and residual soil moisture to support multiple cropping systems in the region which is going to be affected by climate change and shift of rainfall trend in the catchment area.

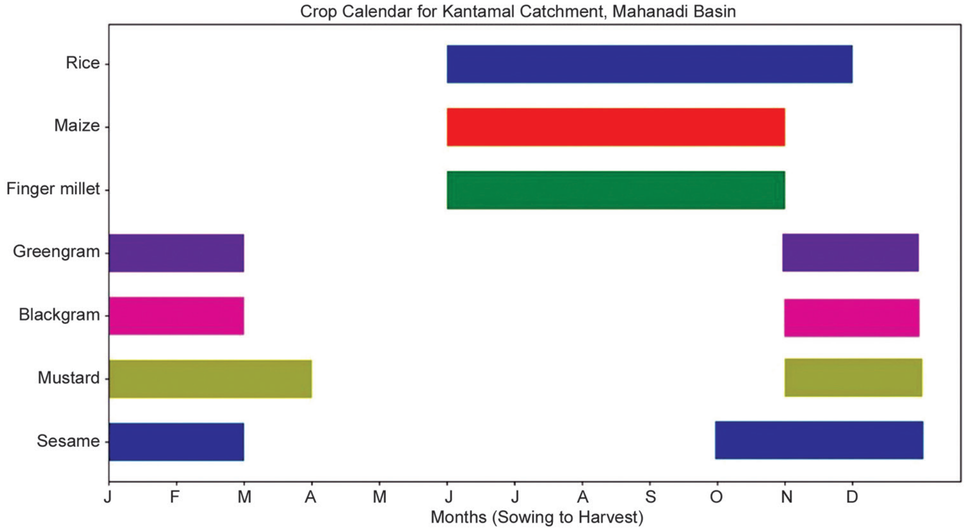

Fig. 1 Crop calendar of Kantamal catchment.

RESULTS AND DISCUSSION

Descriptive statistics: Table 1 presents a comprehensive overview of the descriptive statistical parameters related to seasonal and annual rainfall recorded across 27 meteorological stations in India from 1901 to 2021. The analysis revealed that the highest mean rainfall for the pre-monsoon season was observed at station 16, measuring 179.32 mm, while station 1 recorded the peak mean rainfall for the monsoon season at 1428.77 mm. In the post-monsoon season, station 16 again exhibited the highest mean at 238.7 mm and station 1 had the highest annual mean rainfall at 1634.35 mm. Conversely, the lowest mean rainfall figures were recorded at station 22 (67.49 mm) for pre-monsoon, station 12 (113.3 mm) for monsoon, station 7 (82.28 mm) for post-monsoon and station 8 (1229.06 mm) for annual rainfall. The findings indicate that variability was high during both pre-monsoon and post-monsoon seasons across all stations, as well as in annual and monsoon rainfall. Specifically, station 1 showed high variability in annual rainfall, while stations 1, 4 and 12 exhibited high variability during the monsoon season. The remaining stations displayed low to medium variability. Furthermore, the skewness (CS) values for pre-monsoon and post-monsoon seasons suggest that rainfall data is positively skewed across all stations. In contrast, during the monsoon season, two stations and three stations for annual rainfall exhibited slight negative skewness, with all other stations demonstrating a positively skewed distribution in both monsoon and annual rainfall.

Rainfall trend analysis: The Innovative Trend Analysis of rainfall pattern in the Kantamal catchment has highlighted significant seasonal variations that carry implications for water resource management and agricultural planning. The annual, monsoon, pre-monsoon and post-monsoon rainfall trends generated from ITA for the 27 grid stations of the catchment are detailed in Table 2 and the spatial distribution of these rainfall trends is presented in Fig. 2. Rainfall analysis indicated a complex pattern of rainfall trends across

Table 1 Statistical analysis of annual and seasonal rainfall

Post-monsoon	CK	0.7	1.1	1.7	4.0	3.7	0.6	1.9	6.7	7.6	7.4	2.6	0.7	0.3	0.8	9.5	6.3	3.8	3.3	1.0	0.4	2.8	8.5	7.5	4.1	3.8	4.2	2.4
	CS	1.0	1.2	1.3	1.7	1.6	1.0	1.4	2.0	2.1	2.1	1.3	0.9	0.9	1.0	2.3	1.9	1.6	1.4	0.9	0.8	1.3	2.1	2.1	1.6	1.5	1.5	1.3
	CV	75.6	83.4	86.3	84.2	80.6	71.8	88.4	97.1	86.8	84.5	75.7	64.6	66.9	67.2	91.5	83.7	86.6	77.7	67.0	66.1	70.7	88.0	85.7	81.3	80.2	71.4	67.5
	SD	79.7	76.2	73.5	82.1	90.4	87.1	73.2	82.5	86.9	90.7	85.7	95.9	141.6	160.3	80.7	82.4	90.2	86.1	89.1	113.7	145.4	72.4	81.9	85.8	80.7	78.1	92.7
	Mean	105.4	91.4	85.2	97.5	112.3	121.3	82.8	85.0	100.1	107.3	113.3	148.5	211.5	238.7	88.2	98.4	104.1	110.8	132.9	172.1	205.7	82.3	95.6	105.5	100.6	109.4	137.4
Monsoon	CK	2.2	0.1	0.5	3.8	1.4	-0.1	0.1	1.0	0.4	0.6	0.1	2.6	1.3	4.1	0.0	1.1	1.1	0.9	0.2	1.8	2.2	0.2	1.9	1.1	0.6	0.3	0.8
	CS	1.6	0.1	0.2	1.5	0.7	0.3	0.0	-0.4	0.3	0.2	0.2	1.3	0.8	1.4	0.2	0.6	0.5	0.7	0.4	1.0	0.9	0.3	0.9	0.7	0.4	0.3	0.3
	CV	44.8	21.5	25.5	32.1	26.4	24.0	22.4	26.9	25.4	25.8	23.9	75.7	19.8	20.2	24.8	24.8	26.5	24.1	21.6	22.5	21.2	21.8	22.9	23.0	22.3	20.9	21.4
	SD	640.1	235.8	279.7	403.5	315.6	278.1	242.3	286.3	296.0	304.0	284.0	85.7	205.6	196.4	270.1	285.4	315.4	291.8	258.0	252.0	222.1	246.2	258.9	273.2	269.8	262.7	259.9
	Mean	1428.8	1097.4	1095.6	1255.8	1194.1	1159.0	1080.5	1063.2	1167.2	1180.0	1187.8	113.3	1037.9	974.3	1088.0	1149.8	1190.6	1210.9	1193.7	1122.3	1047.1	1129.0	1129.9	1185.3	1209.5	1254.7	1216.3
Pre-monsoon	CK	4.2	-0.1	0.9	6.6	3.0	1.2	0.8	5.4	5.6	3.0	3.8	3.1	4.4	3.6	0.8	17.3	24.6	3.8	5.4	5.3	3.6	0.9	0.6	4.5	0.3	1.5	4.3
	CS	1.5	0.7	1.0	1.9	1.4	1.0	1.1	1.9	2.0	1.5	1.5	1.3	1.5	1.4	1.2	3.1	3.8	1.6	1.8	1.7	1.5	1.3	1.1	1.6	0.9	1.2	1.5
	CV	68.6	65.6	73.7	71.3	65.6	65.0	75.6	91.6	77.4	70.6	69.3	57.3	54.1	55.1	81.6	85.4	90.8	70.2	62.6	61.1	59.0	87.6	72.1	69.4	65.3	60.0	59.7
	SD	68.7	59.7	62.9	68.3	67.3	71.5	60.6	74.1	73.5	68.4	71.3	74.8	91.9	98.8	63.9	76.3	86.8	68.6	73.4	85.7	95.3	59.1	57.0	64.1	62.8	62.2	73.3
	Mean	100.2	90.9	85.3	95.8	102.6	110.0	80.2	80.9	95.1	96.9	103.0	130.5	169.9	179.3	78.3	89.4	95.6	97.6	117.3	140.2	161.4	67.5	79.1	92.3	96.2	103.6	122.6
Annual	CK	1.9	0.0	0.2	3.7	2.1	0.0	0.1	1.8	0.8	1.5	0.2	0.3	2.4	4.1	-0.2	0.4	1.0	0.9	0.2	2.7	2.6	-0.2	0.7	0.8	0.4	0.6	1.5
	CS	1.5	0.0	0.1	1.4	0.8	0.1	-0.1	-0.3	0.3	0.4	0.1	0.4	1.0	1.2	0.0	0.4	0.5	0.7	0.4	0.8	0.7	0.2	0.6	0.6	0.4	0.3	0.4
	CV	39.9	20.2	24.1	29.1	24.1	20.8	22.0	27.2	24.0	23.7	21.8	18.5	18.6	19.7	24.4	24.0	25.2	22.1	19.7	20.1	20.6	22.2	22.3	21.5	20.7	19.5	19.8
	SD	652.9	258.1	305.3	421.2	340.0	289.2	274.1	333.8	326.9	327.8	305.4	262.9	264.0	274.4	306.5	320.7	350.7	313.5	284.2	287.9	291.8	284.3	290.4	297.9	291.2	286.3	292.7
	Mean	1634.3	1279.7	1266.1	1449.0	1409.0	1390.3	1243.5	1229.1	1362.4	1384.2	1404.1	1420.2	1419.3	1392.3	1254.5	1337.6	1390.4	1419.4	1443.9	1434.5	1414.2	1278.8	1304.5	1383.2	1406.2	1467.6	1476.4
Co-ordinates		82.75,19.50	82.25,19.75	82.50,19.75	82.75,19.75	83.00,19.75	83.25,19.75	82.25,20.00	82.50,20.00	82.75,20.00	83.00,20.00	83.25,20.00	83.50,20.00	83.75,20.00	84.00,20.00	82.50,20.25	82.75,20.25	83.00,20.25	83.25,20.25	83.50,20.25	83.75,20.25	84.00,20.25	82.50,20.50	82.75,20.50	83.00,20.50	83.25,20.50	83.50,20.50	83.75,20.50
Station Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

SD, Standard deviation; CV, Coefficient of variation; CS, Coefficient of skewness; CK, Coefficient of kurtosis.

different seasons. The annual and monsoon trends have shown a decrease in rainfall and in most of the cases the trend is not significant. However, at only one point in the southern parts of the catchment has shown significant increase in rainfall, as shown in Fig. 2. Ray *et al.* (2026a, 2026b) also observed a similar declining trend in monsoon rainfall in the Mahanadi Basin, attributing the reduction to shifting monsoon dynamics influenced by changing climate patterns. Likewise, a study by Roxy *et al.* (2015) noted a general weakening of monsoon systems in eastern India, resulting in irregular and diminished rainfall.

Quantitative assessment of the percentage deviations from the long-term normal rainfall indicates that annual and monsoon precipitation are both decreasing at a rate of approximately 3.0% per decade, which corresponds to an absolute reduction of 4.2 mm/year and 3.5 mm/year, respectively. The deviations are even more severe during the non-monsoon months. Pre-monsoon rainfall showed an 8.0% reduction per decade (0.8 mm/year) while post-monsoon rainfall exhibits the highest proportional decline at 11.4% per decade (1.2 mm/year). The duration of rainfall deficits and the length of dry spells have noticeably extended across the catchment. The proportionally higher decline in post-monsoon rainfall severely prolongs the dry spell length during the winter months, rapidly depleting residual soil moisture and shrinking the viable growing window for *rabi* crops. Similarly the extended deficit duration in the pre-monsoon season directly delays seedbed preparation and nursery raising for the *kharif* cycle.

During the pre-monsoon season there was decrease in rainfall in most of the grid stations and at three grid stations significant decrease was recorded, predominantly in the western part of the catchment. Pal *et al.* (2021) examined long-term rainfall trends across various regions in India and reported a notable decline in pre-monsoon rainfall, especially in eastern and central India. The study attributed this reduction to weakening convective activity and increased temperatures, which reduce moisture availability during the pre-monsoon season. Similarly, Singh *et al.* (2020) analyzed regional rainfall trends across the mid-Mahanadi River Basin and found a significant decrease in pre-monsoon and non-monsoon precipitation, a shift negatively correlated with rising air temperatures that has led to prolonged dry spells and severe moisture stress in the region. A study by Das and Ghosh (2019) on the impact of climate change on rainfall patterns in Odisha found similar results, showing a clear decline in pre-monsoon rainfall in various catchments, including areas around the Kantamal region. The decline was linked to changes in the regional wind patterns and a reduction in the intensity of local thunderstorms, a key contributor to pre-monsoon rainfall. This aligns with the findings in the Kantamal catchment, where the western part is most affected by the reduced pre-monsoon rainfall, possibly due to these broader climatic changes.

In the post-monsoon season all grid stations have recorded decrease in rainfall and at 11 grid stations significant decrease was observed. The overall decrease in post-monsoon rainfall is about 40.74% over the catchment. This decrease may be resulted due to the shifting in monsoon pattern. Research conducted in the neighboring river basins of the Subarnarekha and Brahmani also observed seasonal shifts in rainfall trends, with significant declines in post-monsoon precipitation, similar to the findings in the Kantamal catchment. Dalai and Jena (2025) highlighted that shifting climatic patterns and changing water availability during the winter months have severe implications for water resource management, projecting significant groundwater depletion during the dry-season (*rabi*) cropping cycle if not properly managed. The observed 40.74% decrease in post-monsoon rainfall across the Kantamal catchment echoes the findings of Rao *et al.* (2020), who also noted significant reduction in post-monsoon rainfall over the Nagavali and Vamsadhara Basins in eastern India. Similarly, Singh *et al.* (2018) documented a marked long-term reduction in post-monsoon and winter precipitation across the contributing upper catchments of the Indo-Gangetic Plains, further emphasizing the broader regional pattern of diminishing dry-season rainfall. Such trends suggest a broader pattern of seasonal rainfall variability across these crucial river basins, which could be tied to larger climatic shifts at the regional scale.

Agricultural implications of rainfall variability: The analysis of rainfall trends in the Kantamal catchment, using the Innovative Trend Analysis method, revealed significant seasonal variations. Pre-monsoon rainfall has shown a declining trend, particularly in the western part of the catchment. This reduction poses a significant challenge for the timely preparation of seedbeds and summer ploughing, which are essential for the successful establishment of *kharif* rice. A delay in these activities could lead to reduced crop vigour and lower yields, directly impacting food security and farm incomes in the region (Cui *et al.* 2017, Girma *et al.* 2020).

Monsoon rainfall, which is critical for rice cultivation, has also shown a general, though non-significant, decreasing trend across much of the catchment. This variability in monsoon rainfall can lead to periods of both water scarcity and excess, complicating crop water management. In particular, areas that receive lower-than-average monsoon rainfall are likely to experience moisture stress, resulting in reduced rice yields. Farmers in such areas may need to adopt more resilient agricultural practices, such as alternate wetting and drying (AWD) or the use of short-duration rice varieties or drought tolerant rice varieties (Şen 2012).

Post-monsoon rainfall, which provides residual moisture for *rabi* crops, has shown a significant decline in several grid stations across the catchment. This trend is particularly concerning for the cultivation of pulses, sesame and mustard, as these major *rabi* crops depend on post-monsoon soil moisture to meet their crop water requirement. The reduction in post-monsoon rainfall could exacerbate soil moisture deficits, increasing the risk of crop failure and threatening the livelihoods of farmers who rely on *rabi* farming for income generation. The significant decrease

Table 2 ITA slope and trend of rainfall in Kantamal catchment

Co-ordinates	Annual		Pre-monsoon		Monsoon		Post-monsoon	
	Trend	Slope	Trend	Slope	Trend	Slope	Trend	Slope
82.75,19.50	SI	6.31	NSD	-0.01	SI	6.75	SD	-0.43
82.25,19.75	NSD	-1.70	NSD	-0.01	NSD	-1.40	NSD	-0.29
82.50,19.75	NSD	-1.69	NSD	-0.10	NSD	-1.16	SD	-0.43
82.75,19.75	NSI	1.42	NSD	-0.06	NSI	1.94	SD	-0.45
83.00,19.75	NSD	-0.82	NSI	0.06	NSD	-0.69	NSD	-0.18
83.25,19.75	NSD	-1.76	NSI	0.04	NSD	-1.52	NSD	-0.28
82.25,20.00	NSD	-2.38	NSD	-0.21	NSD	-1.77	SD	-0.39
82.50,20.00	NSD	-2.39	NSD	-0.14	NSD	-1.91	SD	-0.33
82.75,20.00	NSD	-1.48	NSD	-0.08	NSD	-1.07	NSD	-0.33
83.00,20.00	NSD	-1.88	NSD	-0.19	NSD	-1.42	NSD	-0.26
83.25,20.00	NSD	-1.19	NSD	-0.09	NSD	-0.89	NSD	-0.21
83.50,20.00	NSD	-1.21	NSD	-0.01	NSD	-0.70	NSD	-0.50
83.75,20.00	NSD	-0.65	NSD	0.02	NSI	0.22	SD	-0.89
84.00,20.00	NSD	-0.40	NSD	0.01	NSI	0.57	SD	-0.98
82.50,20.25	NSD	-3.37	SD	-0.32	NSD	-2.68	SD	-0.38
82.75,20.25	NSD	-2.08	NSD	-0.18	NSD	-1.62	NSD	-0.28
83.00,20.25	NSD	-1.71	NSD	-0.23	NSD	-1.15	NSD	-0.32
83.25,20.25	NSD	-0.71	NSD	-0.25	NSD	-0.22	NSD	-0.24
83.50,20.25	NSD	-0.75	NSD	-0.16	NSD	-0.16	NSD	-0.42
83.75,20.25	NSD	-1.25	SD	-0.57	NSI	0.36	SD	-1.05
84.00,20.25	NSD	-0.79	NSD	-0.39	NSI	0.70	SD	-1.09
82.50,20.50	NSD	-3.48	SD	-0.45	NSD	-2.66	SD	-0.37
82.75,20.50	NSD	-2.67	NSD	-0.34	NSD	-2.15	NSD	-0.17
83.00,20.50	NSD	-1.36	NSD	-0.18	NSD	-1.09	NSD	-0.09
83.25,20.50	NSD	-1.57	NSD	-0.14	NSD	-1.16	NSD	-0.28
83.50,20.50	NSD	-1.87	NSD	-0.02	NSD	-1.67	NSD	-0.17
83.75,20.50	NSD	-1.61	NSI	0.00	NSD	-1.56	NSD	-0.05

SD, Significant decrease; NSD, Non-significant decrease; SI, Significant increase; NSI, Non-significant increase.

in post-monsoon rainfall observed is about 40.74% in the catchment highlighting the urgent need for the development of supplementary irrigation infrastructure to support *rabi* crops under these changing climatic conditions (Pour *et al.* 2020).

The crop water requirement of catchment, water available from rainfall and water deficit to be met from irrigation is presented in Table 3. It indicates that although *kharif* crops in the Kantamal catchment of the Mahanadi River Basin received rainfall exceeding their total crop water requirement, much of this apparent surplus is lost as runoff due to intense and concentrated monsoon rainfall. This creates intra-seasonal moisture stress despite adequate seasonal totals. In contrast, *rabi* crops such as greengram, blackgram, mustard and sesame experience severe water deficits (≈250–320 mm) because rainfall during this season is very limited and meets only a small fraction of crop demand. The declining rainfall trend in the region is again making the agriculture activities in the catchment more vulnerable. These results clearly showed that the problem of the region is not low annual rainfall but poor temporal distribution and lack of water storage facilities. Therefore, rainwater harvesting is essential to capture excess monsoon runoff and store it for use during critical crop growth stages and the

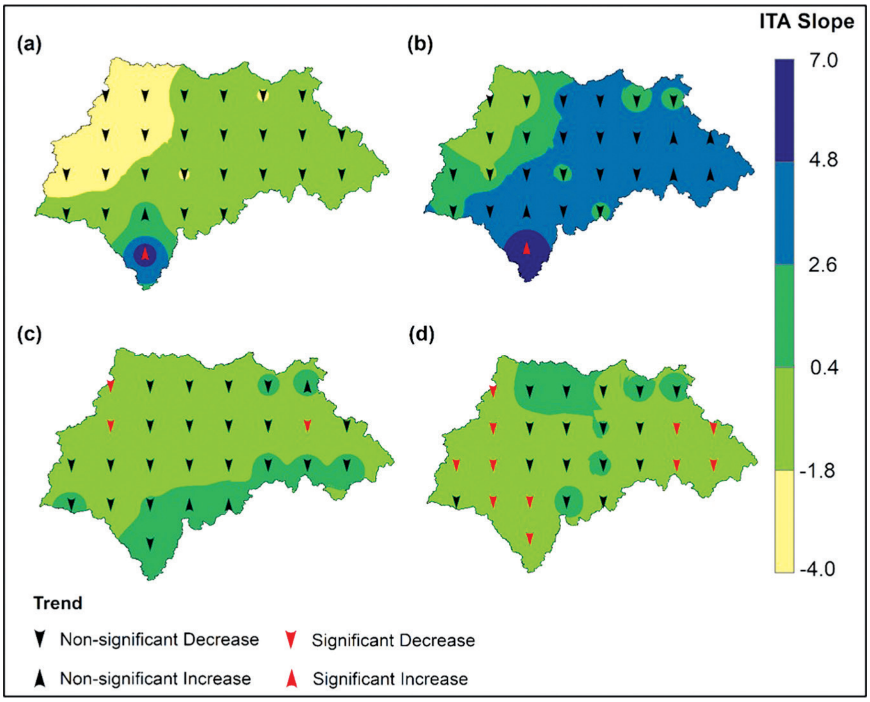

Fig. 2 Slope of innovative trend test of rainfall time series (a) annual, (b) monsoon, (c) pre-monsoon, (d) post-monsoon.

rabi season, thereby stabilizing yields, increasing cropping intensity and improving overall watershed sustainability (Panda *et al.* 2021).

Effect on rural economy: The rural economy in the middle catchment of the Mahanadi River Basin is closely tied to agricultural productivity, with more than 85% of households relying on rainfed farming for their livelihoods. Farmers of the catchment is more vulnerable to climate variability due to the dominance of small and marginal farmers who rely primarily on rainfed agriculture and mono-cropping systems. The decline in both pre-monsoon and post-monsoon rainfall, as highlighted by recent trend analysis poses a severe threat to the sustainability of rainfed agriculture in the catchment. Reduced yields during both *kharif* and *rabi* season could lead to food insecurity, lower farm incomes and increased vulnerability to poverty. Furthermore, the potential for crop failures due to inadequate moisture during critical growing periods may prompt increased out-migration from rural areas as farmers seek alternative livelihoods in urban centers (Tiwari and Joshi 2015).

To mitigate the adverse effects of rainfall variability on the rural economy, there is an urgent need for policy interventions that promote climate-resilient agricultural practices. These interventions may include the promotion of drought-resistant crop varieties, the expansion of irrigation infrastructure may be medium or minor irrigation projects and the adoption of water-efficient farming techniques, such as AWD in rice and supplemental irrigation from farm ponds, check dams, minor irrigation projects etc. or from exploration of groundwater source for *rabi* crops. Investments in rural infrastructure, particularly in the development of on-farm water management systems are critical for ensuring the long-term sustainability of agriculture in this rainfed region of the middle catchment of Mahanadi River Basin (Singh *et al.* 2020).

Uneven and deficit rainfall in the Kantamal catchment of the Mahanadi River Basin resulted in estimated yield losses of approximately ₹15,000–35,000/ha/year for major *rabi* crops such as pulses and oilseeds. At the regional scale, this translates into substantial aggregate income losses for farmers across western Odisha and adjoining Chhattisgarh, reducing farm profitability, limiting cropping intensity and weakening rural purchasing power. The recurring per-hectare economic loss significantly constrains the agricultural contribution to both states' economies, particularly in predominantly rainfed districts where small and marginal farmers form the majority of the agricultural workforce.

Rainfall variability in the middle catchment of the Mahanadi River Basin has significant implications for rainfed agriculture and the rural economy. The observed

Table 3 Crop water requirement available rainfall and water deficit of major crops of Kantamal catchment

Crop	Initial CWR (mm)	Development CWR (mm)	Mid-season CWR (mm)	Late-season CWR (mm)	Total CWR (mm)	Available rainfall (mm)	Water deficit (mm)
Rice (*Kharif*)	120.0	280.0	410.0	230.0	1040.0	1200.0	-160.0
Maize (*Kharif*)	80.0	130.0	250.0	140.0	600.0	850.0	-250.0
Finger Millet (*Kharif*)	70.0	130.0	200.0	90.0	490.0	800.5	-310.5
Greengram (*Rabi*)	50.0	80.0	120.0	70.0	320.0	52.5	267.5
Blackgram (*Rabi*)	50.0	80.0	110.0	60.0	300.0	52.5	247.5
Mustard (*Rabi*)	60.0	100.0	160.0	80.0	400.0	80.0	320.0
Sesame (*Rabi*)	60.0	80.0	160.0	80.0	380.0	83.5	296.5

CWR, Crop water requirement.

decline in pre-monsoon and post-monsoon rainfall trends poses a major challenge for farmers, particularly those relying on rice during the *kharif* season and pulses and oilseeds during the *rabi* season. To ensure sustainable agricultural production and rural livelihoods, there is an urgent need for the implementation of climate-resilient farming practices, including the development of supplemental irrigation infrastructure and the promotion of drought-tolerant crop varieties. Policymakers must prioritise these interventions to mitigate the risks posed by changing rainfall patterns and ensure the long-term viability of rainfed agriculture in the region.

REFERENCES

Abebaw S E. 2025. A global review of the impacts of climate change and variability on agricultural productivity and farmers' adaptation strategies. *Food Science and Nutrition* **13**(5): e70260. https://doi.org/10.1002/fsn3.70260

Cui L, Wang L, Lai Z, Tian Q, Liu W and Li J. 2017. Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during 1960–2015. *Journal of Atmospheric and Solar-Terrestrial Physics* **164**: 48–59. https://doi.org/10.1016/j.jastp.2017.08.001

Dalai A and Jena S K. 2025. Impact assessment of climate change on the future conjunctive water use. *The Indian Journal of Agricultural Sciences* **95**(10): 1190–97. https://doi.org/10.56093/ijas.v95i10.158696

Das D M, Nayak D, Sahoo B C, Raul S K, Panigrahi B and Choudhary K K. 2022. Identification of potential groundwater zones in rice-fallow areas within the Mahanadi river basin, India, using GIS and the analytical hierarchy process. *Environmental Earth Sciences* **81**(15): 395.

Das U and Ghosh S. 2019. Contrasting resilience of agriculture to climate change in coastal and non-coastal districts of Odisha. *The Indian Journal of Agricultural Sciences* **89**(5): 769–74. https://doi.org/10.56093/ijas.v89i5.89655

Desai S, Singh D K, Islam A, Sarangi A and Khanna M. 2019. Trend analysis of climatic variables in Betwa river basin. *The Indian Journal of Agricultural Sciences* **89**(6): 1033–38. https://doi.org/10.56093/ijas.v89i6.90830

Gebremichael A, Quraishi S and Mamo G. 2014. Analysis of seasonal rainfall variability for agricultural water resource management in southern region, Ethiopia. *Journal of Natural Science Research* **4**(11): 56–79.

Girma A, Qin T, Wang H, Yan D, Gedefaw M, Abiyu A and Batsuren D. 2020. Study on recent trends of climate variability using innovative trend analysis: The case of the upper Huai River Basin. *Polish Journal of Environmental Studies* **29**(3): 2199–2210. https://doi.org/10.15244/pjoes/103448

Gupta S K, Rao D U M, Nain M S and Kumar S. 2021. Exploring agro-ecological bases of contemporary water management innovations (CWMIs) and their outscaling. *The Indian Journal of Agricultural Sciences* **91**(2): 263–68. https://doi.org/10.56093/ijas.v91i2.111629

Hare W. 2003. Assessment of knowledge on impacts of climate change contribution to the specification of Art. 2 of the UNFCCC. WBGU, Berlin.

Indian Meteorological Department (IMD). 2020. *State of the Climate Report*. Government of India.

Intergovernmental Panel on Climate Change (IPCC). 2021. *Sixth Assessment Report*. https://www.ipcc.ch

Padhiary J, Das D M, Patra K C and Sahoo B C. 2018. Trend analysis of rainfall and temperature using the Mann–Kendall test in Jaraikela catchment of Brahmani river basin. *International Journal of Agriculture Sciences* **10**(19): 7309–13.

Pal L, Ojha C S P and Dimri A P. 2021. Characterizing rainfall occurrence in India: Natural variability and recent trends. *Journal of Hydrology* **603**(B): 126979. https://doi.org/10.1016/j.jhydrol.2021.126979

Panda C, Das D M, Sahoo B C, Panigrahi B and Singh K K. 2021. Spatio-temporal modeling of surface runoff in ungauged sub-catchments of Subarnarekha river basin using SWAT. *Mausam* **72**(3): 597–606.

Pour S H, Wahab A K A, Shahid S and Ismail Z B. 2020. Changes in reference evapotranspiration and its driving factors in peninsular Malaysia. *Atmospheric Research* **246**: 105096. https://doi.org/10.1016/j.atmosres.2020.105096

Rao G V, Reddy K V, Srinivasan R, Sridhar V, Umamahesh N V and Pratap D. 2020. Spatio-temporal analysis of rainfall extremes in the flood-prone Nagavali and Vamsadhara Basins in eastern India. *Weather and Climate Extremes* **29**: 100265. https://doi.org/10.1016/j.wace.2020.100265

Ray S L, Sahu A P, Paul J C, Das D M, Raul S K and Jena P P. 2026a. Assessment of spatio-temporal trend in hydro-climatic variables and their agricultural implications in the Mahanadi River Basin using innovative trend analysis technique. *Plant Science Today* **13**(sp1): 01–09. https://doi.org/10.14719/pst.10914

Ray S L, Sahu A P, Paul J C, Raul S K, Jena P P, Palmate S and Dash S S. 2026b. Flow regime shifts in eastern India under changing climate: A causality and trend perspective. *Earth Systems and Environment*, 1–25. https://doi.org/10.1007/s41748-025-00996-2

Roxy M K, Ritika K, Terray P, Murtugudde R, Ashok K and Goswami B N. 2015. Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. *Nature Communications* **6**(1): 7423. https://doi.org/10.1038/ncomms8423

Şen Z. 2012. Innovative Trend Analysis Methodology. *Journal of Hydrologic Engineering* **17**(9): 1042–46. https://doi.org/10.1061/(asce)he.1943-5584.0000556

Singh G, Panda R K and Nair A. 2020. Regional scale trend and variability of rainfall pattern over agro-climatic zones in the mid-Mahanadi river basin of eastern India. *Journal of Hydro-Environment Research* **29**: 5–19. https://doi.org/10.1016/j.jher.2019.11.001

Singh R K, Dubey R K, Ruchika, Singh R, Kewate B and Dubey S K. 2018. Climatic variability over the 20th century and future drift during wheat (*Triticum aestivum*) growing period in Uttarakhand region, India. *The Indian Journal of Agricultural Sciences* **88**(8): 1287–95. https://doi.org/10.56093/ijas.v88i8.82576

Singh V K and Prabhakar M. 2025. Challenges and opportunities in rainfed agriculture. *Indian Farming* **75**(01): 05–08.

Tiwari P C and Joshi B. 2015. Climate Change and Rural Out-migration in Himalaya. *Change and Adaptation in Socio-Ecological Systems* **2**(1): 08–25.