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Rainfall Variability and Emerging Climate Stress in Santhal Pargana, Jharkhand: Insights from Grid-Based IMD Rainfall Records

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Abstract: *Rainfall plays a critical role in shaping agricultural production and water security in eastern India, particularly in drought-prone tribal regions like Santhal Pargana in Jharkhand. This study analyses the changing annual rainfall pattern of Santhal Pargana using IMD gridded rainfall data for 35 years (1989–2023). Daily rainfall data were converted into monthly and annual values, and statistical tools such as linear trendline analysis and year-wise comparison of rainfall were applied. Spatial maps and grid station analysis were used to identify rainfall distribution patterns and climate stress zones. The results show that long-term rainfall in Santhal Pargana exhibits a gradual decline and moderate-to-high year-to-year variability. A comparison of the 2023 annual rainfall with the long-term mean shows that most grid stations experienced a significant rainfall deficit. Only a few localized pockets recorded above-normal rainfall. The spatial pattern highlights that dry zones are expanding toward the central parts of the region. Trendline slopes for representative stations, including GS-6 and GS-23, show a continuous yet slow reduction in annual rainfall, indicating weakening monsoon support over time. These findings confirm that rainfall variability and deficits are increasing, leading to greater climate stress on agriculture, groundwater recharge, and rural livelihoods. The study suggests the need for improved water harvesting structures, drought-tolerant crops, and climate-adaptive agricultural planning. Continuous monitoring of rainfall trends and local-level climate strategies will be essential to ensure sustainable development in Santhal Pargana.*

Keywords: *Rainfall trend, Climate stress, Rainfall variability, Rainfall Deviation Index (RDI), Spatio-temporal analysis, IMD gridded data*

1. Introduction

Rainfall plays a vital role in water security, agriculture, and rural livelihoods in India. The monsoon delivers most of the annual rainfall to eastern India, and any change in its behaviour directly affects crop production, groundwater recharge, and ecosystem health. In recent decades, several parts of the country have experienced uncertain rainfall, more dry spells, and increasing climate stress. This change is seen strongly in semi-arid and drought-prone areas where rainfall is the main source of water and irrigation support is low.

Jharkhand is one of the vulnerable states in eastern India. Agriculture in this region is mostly rain-fed and highly sensitive to rainfall variation. Studies have shown that rainfall in Jharkhand shows both spatial and temporal variability, with repeated droughts and disturbed monsoon behaviour (Das et al., 2020; Prasad et al., 2021). Many districts in the state experience below-normal rainfall and irregular distribution, which increases risk for farmers and groundwater systems. Changes in rainfall trend also influence surface water bodies and forest communities, which are important for the local tribal population.

Santhal Pargana, located in the northeastern part of Jharkhand, remains one of the least studied areas in terms of long-term rainfall change. Previous studies in Jharkhand have mainly focused on district-level averages and seasonal fluctuations (Kumar et al., 2010; Saha & Sarkar, 2019). Only a few grid-based studies are available, and detailed analysis of annual rainfall change is limited for this region. Recent work indicates that rainfall deviation is common, and spatial differences are strong within Santhal Pargana, showing high climate stress on agriculture and water availability

Rainfall pattern assessment at the grid level is useful to understand local rain behaviour and drought risk more clearly. Long-term trend analysis helps identify whether rainfall is decreasing or increasing and whether the region is facing more dry years than before. Simple statistical tools like trend lines, rainfall variability, and deviation measures provide useful insights for climate-related planning and adaptation in rural areas.

Therefore, this study examines the changing annual rainfall pattern in Santhal Pargana using IMD gridded data for a 35-year period (1989–2023). The main aim is to analyse the direction of rainfall change, the level of variability, and the existence of deficit years, which together indicate increasing climate stress. The findings will support regional water management, drought preparedness, and agricultural planning in this sensitive and tribal-dominated region.

2. The Study Area

Santhal Pargana is located in the northeastern part of Jharkhand. The region covers six districts: Dumka, Deoghar, Godda, Pakur, Sahibganj, and Jamtara. It spreads over a large plateau and hill area, forming part of the eastern extension of the Chotanagpur Plateau. The terrain includes undulating uplands, ridges, and narrow river valleys. Major rivers like Mayurakshi, Ajoy, Bansloi, and Gumani drain the area and are mainly rain-fed.

The climate of Santhal Pargana is tropical monsoon type. Most of the annual rainfall arrives during June to September. The rainfall amount generally ranges between 1,000 mm and 1,400 mm, but it shows high variability across the region. Long dry spells and delayed monsoon onset are common. These conditions make the area drought-prone and sensitive to monsoon behaviour.

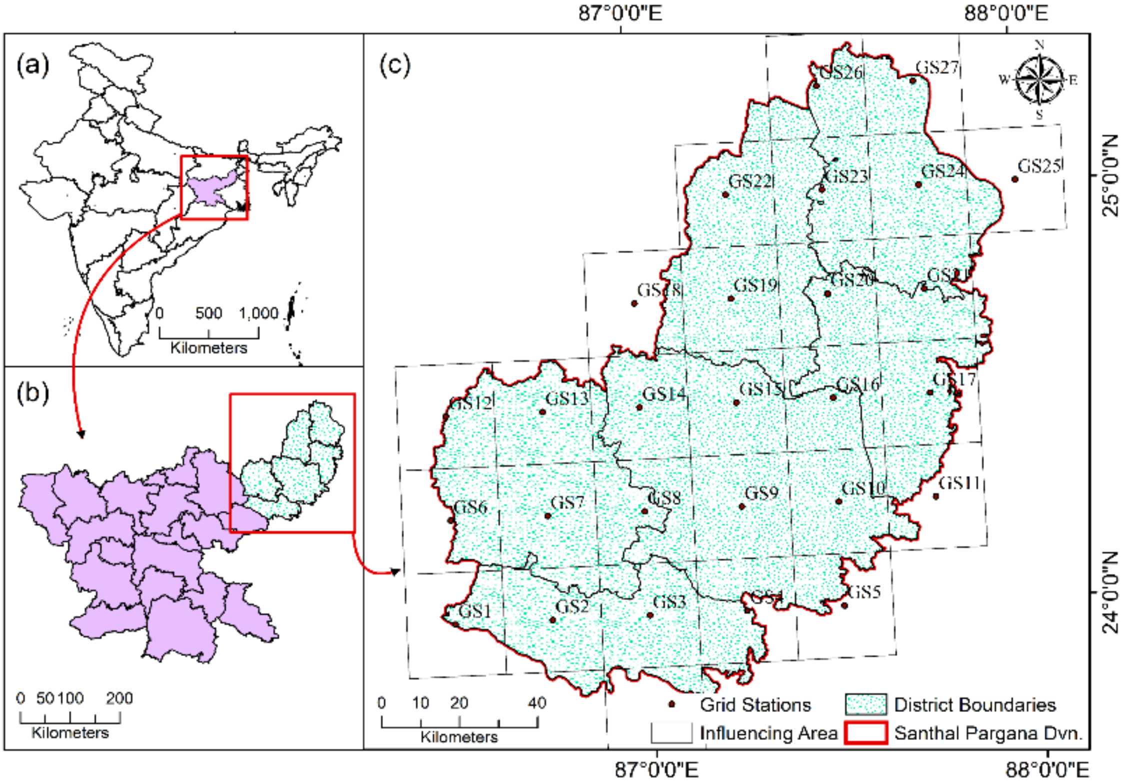

Fig. 1: Location Map of the Study Area: a) India, b) Jharkhand and c) Santhal Pargana

The population of this region is dominated by tribal communities, especially the Santhal group. Agriculture is the main livelihood activity and depends heavily on monsoon rainfall. Irrigation facilities are limited, and groundwater plays a crucial role for domestic use and small-scale cultivation. Rainfall shortage or distribution failure leads to reduced crop yield, water scarcity, and strong livelihood stress.

Because of its physical, climatic, and socio-economic conditions, Santhal Pargana is highly vulnerable to climate-related risks. Understanding rainfall behaviour here is important for sustainable agricultural planning, groundwater conservation, and overall development. This study area therefore provides a useful setting for analysing rainfall change and climate stress in eastern India.

3. Data Source and Methodology

3.1 Data Source

The study uses gridded daily rainfall data from the India Meteorological Department (IMD). The dataset covers a period of 35 years (1989–2023) and provides complete rainfall records for the Santhal Pargana region of Jharkhand. The IMD data are widely used in India for rainfall analysis due to their reliability and quality control.

From this dataset, annual rainfall totals were computed. The yearly values were then used to study the long-term rainfall pattern of the region.

3.2 Delineation of Grid Stations using Thiessen Polygons

To delineate the relevant IMD grid stations within the study area, the Thiessen Polygon method was employed in a GIS environment (Thiessen, 1911; Sinha & Srivastava, 1993). This technique ensures that each grid station represents the rainfall of its surrounding polygonal area, with boundaries equidistant from adjacent stations. The application of this method yielded a total of 27 grid stations (Figure 1), which were subsequently used for rainfall analysis.

3.3 Annual Rainfall Derivation

The IMD gridded dataset provides rainfall values on a daily scale. For this study, the daily values were first summed month-wise to obtain the monthly rainfall totals for each grid station. After that, all twelve-monthly totals were added to get the annual rainfall for each year from 1989 to 2023.

$$MR_{m,i} = \sum_{d=1}^{D_m} R_d$$

Where, $MR_{m,i} =$ Monthly rainfall of month m in year i, $D_m = Number\ of\ days\ in\ month\ m,\ R_d = Rainfall\ of\ day\ d$

Annual rainfall was then calculated as:

$$AR_i = \sum_{m=1}^{12} MR_{m,i}$$

Where, $AR_i = Annual\ rainfall\ of\ year\ i.$

Long term mean annual rainfall was then computed as:

$$\overline{AR} = \frac{1}{n}\sum_{i=1}^{n} AR_i$$

Where, n= Total number of years (35).

This monthly to annual conversion process helped reduce daily noise in the data and provided a clear picture of year-to-year rainfall behaviour in the study area.

3.4 Trend Analysis

To understand the direction and strength of rainfall change, a linear trend line was fitted using the least square method:

$$AR_i = a + bt$$

Where, $a =$ Intercept, b= Slope (rainfall rate of change per year) and t= Time (year). A positive slope shows increasing rainfall, and a negative slope indicates declining rainfall. The coefficient of determination (R^2) was used to explain the fit of the trend line.

3.5 Rainfall Deviation Index

The Rainfall Deviation Index (RDI) was used to quantify rainfall variability and departures from normal conditions (Pandey & Ramasastri, 2001; Gadgil & Gadgil, 2006). It was computed for each grid station using the formula:

$$RDI = \frac{P_i - \bar{P}}{\bar{P}} \times 100$$

Where, P_i= Rainfall in year i and $\bar{P}$= Long-Term mean rainfall for 1989-2023. A positive RDI indicates wetter-than-average conditions, while negative values signify rainfall deficits.

3.6 Mean RDI (1989–2023):

To capture long-term variability, Mean RDI was computed by averaging annual deviations over 35 years (Dhar & Nandargi, 2003). For each grid station, the Mean RDI was calculated by averaging annual RDI values from the year 1989 to 2023. This provided an understanding of the long-term spatial patterns of rainfall deviation across the basin. The mean RDI for each station was calculated using the following formula:

$$D_i = \frac{1}{n}\sum_{t=1}^{n}|RDI_{it}|$$

Where D_i = The average deviation of the station i, n = number of years (35) and RDI_{it} = RDI of the station i at year t.

3.7 Spatial Mapping in GIS

The results of the analysis were spatially interpolated using the Inverse Distance Weighting (IDW) method and mapped in GIS platform. Spatial interpolation was carried out using the Inverse Distance Weighting (IDW) technique, a widely adopted method for climatic and hydrological mapping in India (Burrough & McDonnell, 1998; Kumar & Murthy, 2014). This visual representation captured the spatial heterogeneity of rainfall deviation across the study region, enabling comparison between long-term trends and recent anomalies.

4. Result and Discussion

4.1 Mean Annual rainfall (1989–2023)

The mean annual rainfall pattern of Santhal Pargana for the long-term period (1989–2023) shows that the region receives a moderate amount of monsoonal rainfall, but its distribution is not uniform. The spatial pattern indicates that the northern and northeastern parts generally experience higher annual rainfall, while the central and southwestern parts receive relatively lower rainfall. This long-term spatial contrast (Figure 2b, Table 1) suggests that the region has a natural rainfall gradient, which affects agricultural potential and groundwater recharge differently across locations. The mean annual rainfall values also show visible fluctuations when examined year by year, indicating that the monsoon does not behave consistently. This long-term variability is a clear sign of climate-induced stress, and any further decline in rainfall may deepen the challenges already present in this drought-prone and tribal-dominated area.

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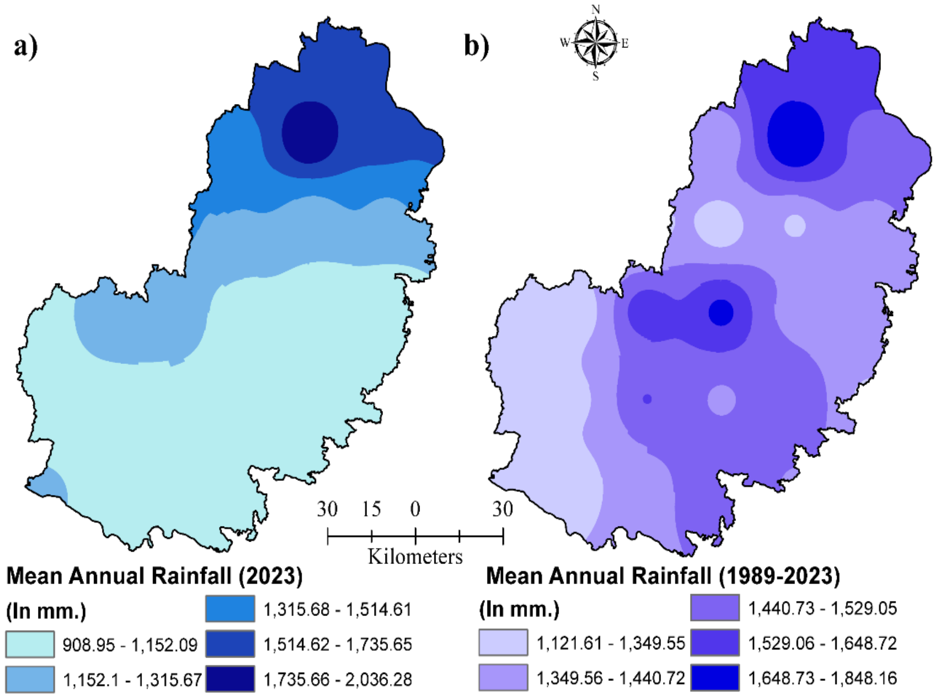

Fig. 2: Mean Annual rainfall a) of the year 2023 and b) of the years 1989-2023

The annual rainfall trends for GS-6 and GS-23 provide clear evidence of declining rainfall over the 35 years (Figure 3). In GS-6, the slope value of –9.6591 mm/year shows that rainfall is reducing slowly each year. Although the R^2 value (0.1025) is low, the negative slope suggests that monsoon support is weakening with time in this grid. GS-23 also indicates a steeper negative slope of –18.366 mm/year, which means the decline rate here is almost double that of GS-6. The R^2 value (0.1087) again indicates high year-to-year variation, but the downward pattern remains visible. These graphs confirm that rainfall decline is a real and emerging concern, especially in locations where historically higher rainfall ensured better agricultural and groundwater security. The gradual but consistent reduction in rainfall highlights the need for climate-adaptive water management strategies across Santhal Pargana.

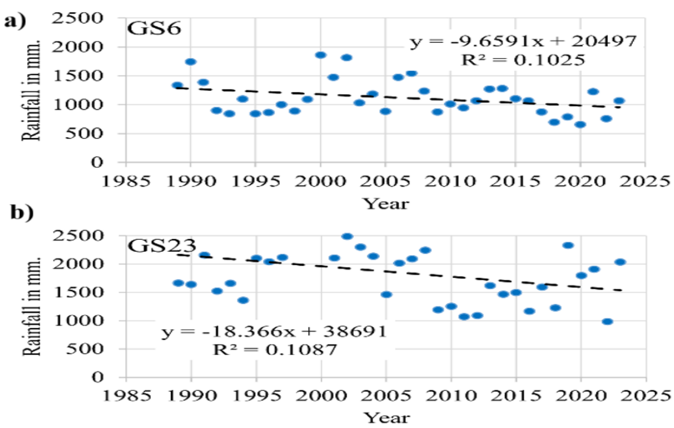

Fig. 3: Representative Mean Annual trends for selected grid stations in Santhal Pargana (1989-2023): a) Grid Station 2 and b) Grid Station 15

4.2 Annual rainfall of 2023

The annual rainfall condition in 2023 reflects a significant deviation from long-term normal behaviour in many parts of Santhal Pargana. Most grid stations recorded rainfall values that were well below their long-term mean, showing that 2023 was a dry year for a large part of the region (Figure 2, Table 1). This deficit is especially strong in central and western locations, where several stations such as GS-11, GS-12, and GS-15 showed sharp drops from their normal rainfall levels. Only a few pockets in the northern and eastern zones received comparatively higher rainfall, indicating small localized surplus zones. This pattern confirms that rainfall shortage in 2023 was not uniform but widespread enough to affect agriculture, drinking water availability, and groundwater recharge. The noticeable drop in rainfall in a single year also shows the region's high sensitivity to monsoon variations, further supporting the evidence of rising climate stress in Santhal Pargana.

Table 1: Annual rainfall (2023) and Mean Annual rainfall (1989-2023)

Grid Station	Annual Rainfall (2023)	Mean Annual Rainfall (1989-2023)	Grid Station	Annual Rainfall (2023)	Mean Annual Rainfall (1989-2023)
GS-1	1187.39	1335.47	GS-15	1043.20	1688.99
GS-2	1146.88	1292.54	GS-16	974.46	1418.38
GS-3	1078.45	1423.63	GS-17	1007.72	1356.79
GS-4	1083.47	1502.47	GS-18	1364.29	1290.51
GS-5	1065.96	1434.39	GS-19	1305.34	1282.37
GS-6	1066.16	*1120.29	GS-20	1170.87	1333.44
GS-7	1138.54	1328.81	GS-21	1267.14	1410.35
GS-8	1134.25	1531.40	GS-22	1443.51	1388.10
GS-9	1061.39	1426.74	GS-23	*2036.28	*1848.16
GS-10	1055.12	1505.13	GS-24	1604.52	1498.34
GS-11	954.52	1325.29	GS-25	1613.41	1529.34
GS-12	*908.89	1213.90	GS-26	1616.04	1615.08
GS-13	1221.65	1288.59	GS-27	1725.34	1606.80
GS-14	1224.49	1598.96	*Source: Computed by the Authors*		

*Highest and Lowest Rainfall # Rainfall in mm.

4.3 Mean Rainfall Deviation Index (1989–2023)

The long-term Mean RDI analysis (1989–2023) provides insights into the spatial variability of rainfall across the Santhal Pargana division. The values ranged from 14.31 (minimum) to 28.25 (maximum), with grid number 2 showing the lowest deviation and grid number 15 showing the highest deviation (Table 2). Areas with relatively higher Mean RDI values indicate greater rainfall variability and less stability in rainfall distribution, while areas with lower Mean RDI reflect more consistent rainfall over time. The spatial distribution, as presented in Figure 5a, highlights clear regional contrasts, with central and western parts exhibiting higher deviations compared to the southern and eastern sectors.

Table 2: Mean Rainfall Deviation Index (1989-2023)

Grid Station	Mean RDI	Grid Station	Mean RDI	Grid Station	Mean RDI
GS-1	15.55	GS-10	22.21	GS-19	18.76
*GS-2	14.31	GS-11	17.27	GS-20	18.33
GS-3	16.81	GS-12	20.71	GS-21	15.30
GS-4	16.93	GS-13	16.47	GS-22	15.96
GS-5	19.71	GS-14	23.70	GS-23	24.78
GS-6	21.81	*GS-15	28.25	GS-24	16.62
GS-7	17.07	GS-16	27.93	GS-25	18.32
GS-8	22.83	GS-17	18.15	GS-26	19.35
GS-9	23.28	GS-18	20.42	GS-27	15.97

*Highest and Lowest Deviations *Source: Computed by the Authors*

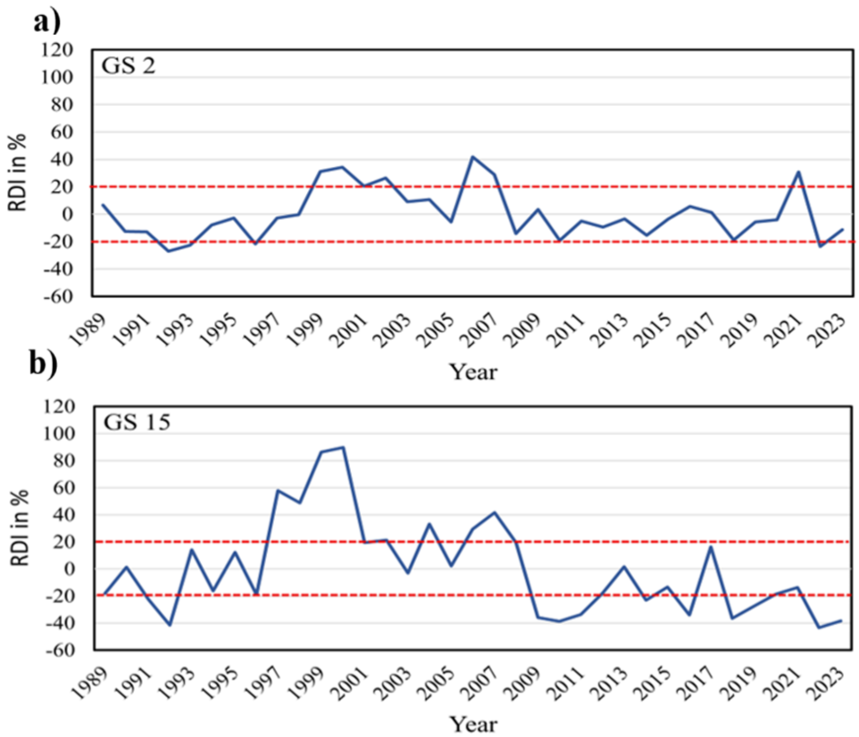

Fig. 4: Representative RDI trends for selected grid stations in the study area: a) GS-2 showing the lowest rainfall variability and b) GS-15 showing the highest rainfall variability

4.4 RDI of 2023

The RDI values for 2023 (Table 3) reveal a marked rainfall deficit across most of the Santhal Pargana region, with deviations ranging from –38.24 (GS-15) to +10.18 (GS-23). Out of the 27 grid stations, the majority recorded negative RDI, highlighting the prevalence of drier-than-normal conditions during the year. Only a few stations, such as GS-18, GS-22, GS-23, GS-24, GS-25, GS-26, and GS-27, exhibited positive RDI, indicating localized rainfall surpluses

Table 3: Rainfall Deviation Index (2023)

Grid Station	RDI	Grid Station	RDI	Grid Station	RDI
GS-1	-11.09	GS-10	-29.90	GS-19	1.79
*GS-2	-11.27	GS-11	-27.98	GS-20	-12.19
GS-3	-24.25	GS-12	-25.13	GS-21	-10.15
GS-4	-27.89	GS-13	-5.20	GS-22	3.99
GS-5	-25.69	GS-14	-23.42	*GS-23	10.18*
GS-6	-4.83	*GS-15	-38.24*	GS-24	7.09
GS-7	-14.32	GS-16	-31.30	GS-25	5.50
GS-8	-25.93	GS-17	-25.73	GS-26	0.06
GS-9	-25.61	GS-18	5.72	GS-27	7.38

*Highest and Lowest Deviations *Source: Computed by the Authors*

Spatially, the deficit is more severe in the central and north-western grids, particularly GS-15, GS-16, GS-10, and GS-11, which show the sharpest departures from long-term rainfall conditions. Conversely, positive anomalies in the southern and eastern grids suggest small pockets of localized wet conditions, though they are insufficient to offset the overall dry year.

These results (Table 3; Figure 5b) clearly establish that 2023 was a year of significant rainfall scarcity, intensifying existing rainfall variability patterns identified through long-term Mean RDI analysis. The contrasting grid-wise results also emphasize the spatial heterogeneity of drought conditions, which has implications for agriculture and water resource planning.

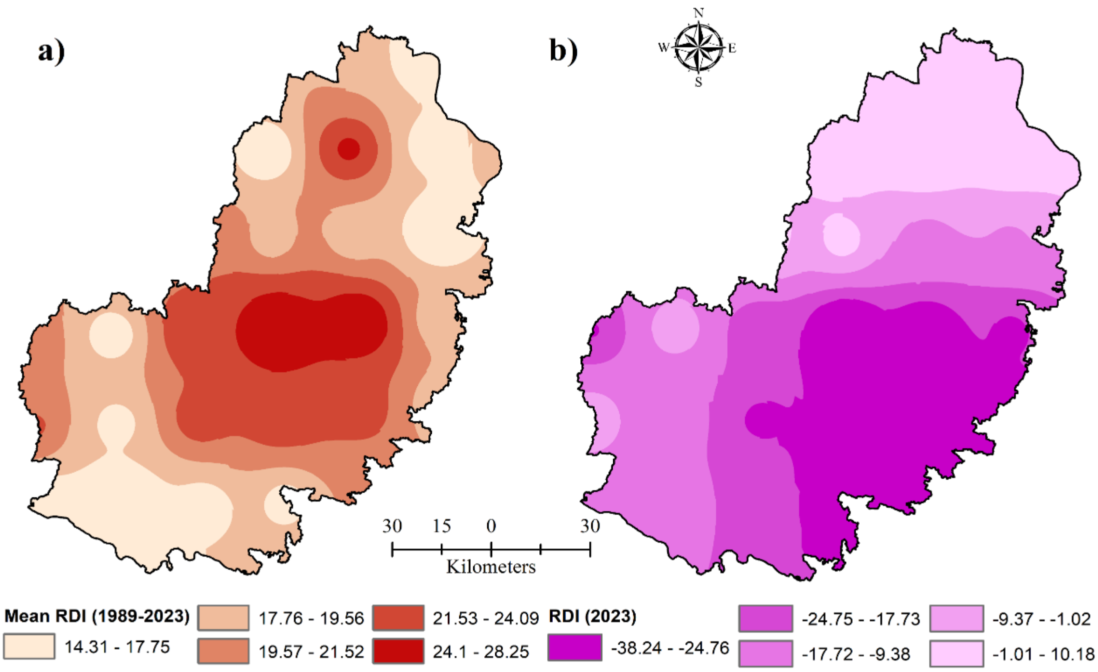

Fig. 5: Spatial variability of rainfall index: a) Mean Rainfall Deviation Index (1989-2023) and b) Rainfall Deviation Index of 2023

4.5 Analysis

The results clearly show that the rainfall pattern in Santhal Pargana is shifting toward a more stressed and uncertain condition. The long-term assessment (1989–2023) indicates that the northern and northeastern parts of the region generally receive higher rainfall, while the central and southwestern belts remain comparatively dry. This natural rainfall imbalance has always created uneven water availability, but recent changes suggest that the gap between wetter and drier areas is increasing.

The rainfall data of 2023 show a significant departure from the normal rainfall behaviour. Many stations recorded rainfall far below the long-term average level. For example, GS-11, GS-12, and GS-15 experienced a major drop in rainfall, signalling severe deficit conditions in key agricultural areas. Only a few stations such as GS-23 show surplus conditions, but these are limited pockets and cannot balance the wider pattern of rainfall shortage across the region.

The rainfall trend graphs for GS-6 and GS-23 show a slow but continuous decline in rainfall over time. Although the yearly values fluctuate widely, the slope of the trend line is negative for both stations, supporting the observation that monsoon rainfall is gradually weakening. This changing rainfall behaviour increases the risk of crop loss and groundwater scarcity, especially for rural and tribal communities dependent on rain-fed agriculture.

Overall, the analysis confirms that rainfall in Santhal Pargana has become more variable and unreliable, with a tendency toward lower annual rainfall. This presents a growing climate stress that needs immediate attention for sustainable water and agricultural planning in the region.

5. Recommendations

The findings of this study highlight the urgent need to adopt adaptive water and agricultural measures in Santhal Pargana. As rainfall variability and deficit years are becoming more common, local planning should focus on improving water security and building climate resilience. First, rainwater harvesting structures such as check dams, ponds, and percolation tanks must be strengthened, especially in central and western areas where rainfall is scarce. Second, the adoption of drought-tolerant crop varieties and short-duration paddy can help farmers reduce the risk of crop failure during weak monsoon years. Third, there should be proper promotion of micro-irrigation methods, such as drip and sprinkler systems, to increase water-use efficiency and reduce dependence on monsoon rainfall.

Groundwater monitoring and recharge efforts must also be improved, as declining rainfall affects both domestic supply and irrigation demands. Local communities, especially tribal farmers, should be supported through awareness programmes, seasonal crop advisories, and early warning systems. Strengthening the capacity of government institutions and village-level committees will improve disaster management and water governance. A long-term climate adaptation plan is needed to make this drought-prone region more resilient to changing rainfall behaviour.

6. Conclusion

This study assessed the changing annual rainfall pattern in Santhal Pargana using 35 years of IMD gridded data. The results confirm that rainfall in the region is becoming less reliable, with a slow but noticeable declining trend in many locations. The year 2023 saw widespread rainfall deficits, highlighting the region's growing exposure to climate stress. Spatial analysis also reveals that dry zones are expanding, placing pressure on agriculture, groundwater recharge, and daily water needs in rural and tribal communities.

The study shows that Santhal Pargana is highly vulnerable due to its heavy dependence on monsoon rainfall and limited irrigation facilities. Therefore, focus should be placed on rainwater harvesting, groundwater recharge, drought-tolerant crops, and climate-smart farming practices to protect livelihoods and improve resilience.

However, this study has some limitations. It is based solely on annual rainfall, without accounting for other climate variables, such as seasonal rainfall, temperature, or evapotranspiration, which also influence water availability. Advanced statistical tests and extreme rainfall indices were not included due to data constraints. Future studies should combine rainfall trends with groundwater data, agricultural performance, and socio-economic indicators to provide a more comprehensive understanding of climate impacts.

Despite these limitations, the findings strongly indicate that rainfall behaviour in Santhal Pargana is changing and poses a serious challenge to sustainable development in the region. Continuous monitoring and adaptive water management strategies are necessary to support long-term resilience and safeguard the well-being of the communities living in this drought-prone area.

References

Burrough, P. A., & McDonnell, R. A. (1998). Principles of Geographical Information Systems. Oxford University Press.

Das, A., Chakraborty, A., & Roy, S. S. (2020). Long-term variability and trends of rainfall over Jharkhand, India. Theoretical and Applied Climatology, 142(1–2), 323–337. https://doi.org/10.1007/s00704-020-03277-2

Dhar, O. N., & Nandargi, S. (2003). Rainfall variability over the Indian region and its impact on agriculture. Indian Journal of Agricultural Meteorology, 5(2), 7–20.

Gadgil, S., & Gadgil, S. (2006). The Indian monsoon, GDP and agriculture. Economic and Political Weekly, 41(47), 4887–4895.

Guhathakurta, P., & Rajeevan, M. (2008). Trends in the rainfall pattern over India. International Journal of Climatology, 28(11), 1453–1469. https://doi.org/10.1002/joc.1640

IMD (2021). Rainfall Statistics of India. India Meteorological Department, New Delhi.

Kumar, V., & Murthy, C. S. (2014). Rainfall variability mapping using GIS and geostatistical techniques for Jharkhand. Journal of the Indian Society of Remote Sensing, 42(4), 777–787.

Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. Hydrological Sciences Journal, 55(4), 484–496. https://doi.org/10.1080/02626667.2010.481373

Mishra, V., & Sahu, N. (2014). Drought and drought management in India: A review. Weather and Climate Extremes, 3, 167–179. https://doi.org/10.1016/j.wace.2014.03.002

Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S., & Mukhopadhyay, B. (2014). Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall dataset over India. Mausam, 65(1), 1–18.

Pandey, R. P., & Ramasastri, K. S. (2001). Relationship between the common climatic parameters and drought index in India. Hydrological Processes, 15(6), 1019–1032.

Prasad, S., Kumar, A., & Jha, R. (2021). Rainfall variability and trend analysis for Jharkhand using standardized indices. Journal of Earth System Science, 130(2), 123. https://doi.org/10.1007/s12040-021-01628-2

Ranjan, R., Saha, A., & Sharma, R. (2019). Spatial and temporal variability of rainfall in Jharkhand. Climate Dynamics, 53(9), 5971–5987. https://doi.org/10.1007/s00382-019-04854-5

Roxy, M. K., Ghosh, S., Pathak, A., Athulya, R., Mujumdar, M., Murtugudde, R., & Rajeevan, M. (2017). A threefold rise in widespread extreme rain events over central India. Nature Communications, 8, 708. https://doi.org/10.1038/s41467-017-00744-9

Saha, R., & Sarkar, D. (2019). Climate variability and agriculture in Jharkhand. Journal of Agrometeorology, 21(2), 200–208.

Singh, R. P., & Sinha, R. (2010). Geomorphology and drainage characteristics of eastern Chotanagpur Plateau. Indian Journal of Geography and Environment, 11, 45–56.

Singh, R., Gupta, A., & Tiwari, P. (2013). Rainfall characteristics and variability over Jharkhand. Indian Journal of Soil Conservation, 41(2), 120–126.

Sinha, A., & Saha, A. (2010). Climate change and rainfall variability in Jharkhand. Indian Journal of Environmental Protection, 30(7), 553–561.

Sinha, R., & Jain, V. (1998). Flood hazards of north Bihar rivers, Indo-Gangetic plains. Proceedings of the Indian National Science Academy, 64, 157–168.

Sinha, R., & Srivastava, V. (1993). Rainfall variability analysis in Bihar using Thiessen polygon method. The Geographer, 40(2), 77–86.

Thiessen, A. H. (1911). Precipitation averages for large areas. Monthly Weather Review, 39(7), 1082–1084.

Tirkey, A., Jha, M. K., & Mishra, A. (2018). Rainfall variability and its impact on agriculture in Jharkhand. Current Science, 115(3), 470–476.

Tiwari, P. C., Singh, R. B., & Joshi, S. (2018). Agricultural risk, vulnerability and adaptation to climate change in eastern India. Environmental Development, 28, 25–39. https://doi.org/10.1016/j.envdev.2018.09.002