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Long-Term Seasonal and Annual Rainfall Trend Analysis of Giridih District, Jharkhand, India

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Abstract: District Giridih is primarily rain dependent on its 95 per cent net cultivable land under summer-monsoon crops. It is classified as a mono-cropping area as it lacks irrigation facilities, essential for winter crops. In the last few years, the district experienced water stress due to the shortage of monsoon rainfall. We study long term seasonal and annual rainfall trend analyses for the Giridih district of Jharkhand in India using linear regression modelling. The last 100 years of data were taken for the study and were divided into two-time phases of 50 years each to analyse the changing pattern of rainfall trends. We found a decreasing trend in monsoon rainfall from 1 mm y^{-1} to 3 mm y^{-1} between the initial (1921-1971) and final (1972-2021) phase of the study period. Similarly, the return period of droughts (rainfall deficit years) has also reduced from 11 years to 5 years. The study has shown that the rainfall pattern has changed, with the winter months showing a decrease and the pre-monsoon months an increase in their relative contributions to the annual rainfalls. The study may help in the formulation of water resource conservation-oriented decision-making to cope-up with the rainfall uncertainties and meet the future water demand.

Key words: Giridih, climate change, trend analysis, Linear Regression Modelling.

Introduction

The Intergovernmental Panel on Climate Change, in their sixth Assessment Report (AR6) highlighted that as compared with the climate of any decade before 1850, each of the last four decades has been successively warmer than it. Moreover, the report also predicted that during the 21st century, global warming of 1.5°C and 2°C will be exceeded much earlier than expected. Such temperature changes very likely have influenced the long-term rainfall patterns and will have a compounding blow on the existing water stress around the globe (Barnett et al., 2005). Climatic variation is an evident phenomenon noticeable worldwide with changes in variables like rainfall, temperature, pressure, humidity and other climatic indicators (Bates et al., 2008; IPCC, 2015). Indian sub-continent is known for its unique monsoon cycle which has its predictability of occurrence and intensity based on the event of Inter Tropical Convergence Zone (specifically Jet streams) and Southern Oscillation (specifically El Nino- ENSO) causing a year to have monsoon with a deficient, an abundant or normal precipitation and even leading to rainfall anomalies (IMD). The year with El Nino event leads to a fall in normal rainfall which is a reflection of warmer surface conditions in the tropical eastern Pacific Ocean leading to changes to wind directions, and vice versa La Nina is the colder circulations. There

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exists a higher dependency on agriculture employment, the consistently growing population and water resource depletion is amplified by strong variability and deficiency leading to dry spells in the developing countries located in tropical and sub-tropical zones (Ramos et al., 2012).

Earlier studies have proven that any change in the intensity and trend of the southwest monsoon will have major implications on the availability of water resources, agricultural production and the economy of India (Gosain et al., 2006; Jain and Kumar, 2012; Lal, 2001; Sonali and Kumar, 2013). These monsoon variabilities and weather-related anomalies have been crucial factors of India's policy formulations specifically in the agriculture sector that demands huge revenue for risk covering and farmers' welfare. The agriculture sector contributes to 15% of GDP and a failure of crops in any season affects the economy drastically. Trend analysis of long-term climate data has been done to assess climate variability (Guhathakurta and Rajeevan, 2008; Kishore et al., 2016; Suryavanshi et al., 2014). Among the states in India, Jharkhand has sub-tropical climatic influences. Previous studies from Jharkhand state have exhibited a significant decrease in monsoon rainfall, whereas December registered a significant increase in rainfall (Guhathakurta and Rajeevan, 2008; Rajeevan et al., 2006). The farmers of the state grow both summer-monsoon crops and winter crops called Kharif crops and Rabi crops, respectively. Variability of summer and winter rainfall will increase the dependency on irrigation infrastructure and, eventually, the financial burden on the farmers. In Jharkhand, 18 and 10 out of its 24 districts were declared drought-affected by the state government in 2018 and 2019, respectively. In the year 2018, only 16.27 lakh hectares of land were sown with paddy. As per the information from the agriculture department, 40 percent of this was destroyed due to rain deficiency. Giridih was one of the drought-affected districts in both years. Giridih was identified as one of the districts with a high priority for the development and management of degraded land, according to the JSAC report (2010). The district is characterised by limited irrigation infrastructure and a heavy reliance on agriculture. This points out the critical need for localised climatic data to inform planning and development initiatives. In this study, we aim to analyse the rainfall trend of the Giridih district. Such insights could lay the groundwork for sustainable water resource management strategies in resource-rich yet underdeveloped districts like Giridih. Our results may help with sustainable development and water resources management in the Giridih district.

Study Area

Giridih district lies in the central part of the North Chotanagpur Division, between 24°11' North latitude and 86°18' East longitude, in Jharkhand state with an area of about 4854.33 sq. km (Figure 1). The district represents an undulating terrain with an

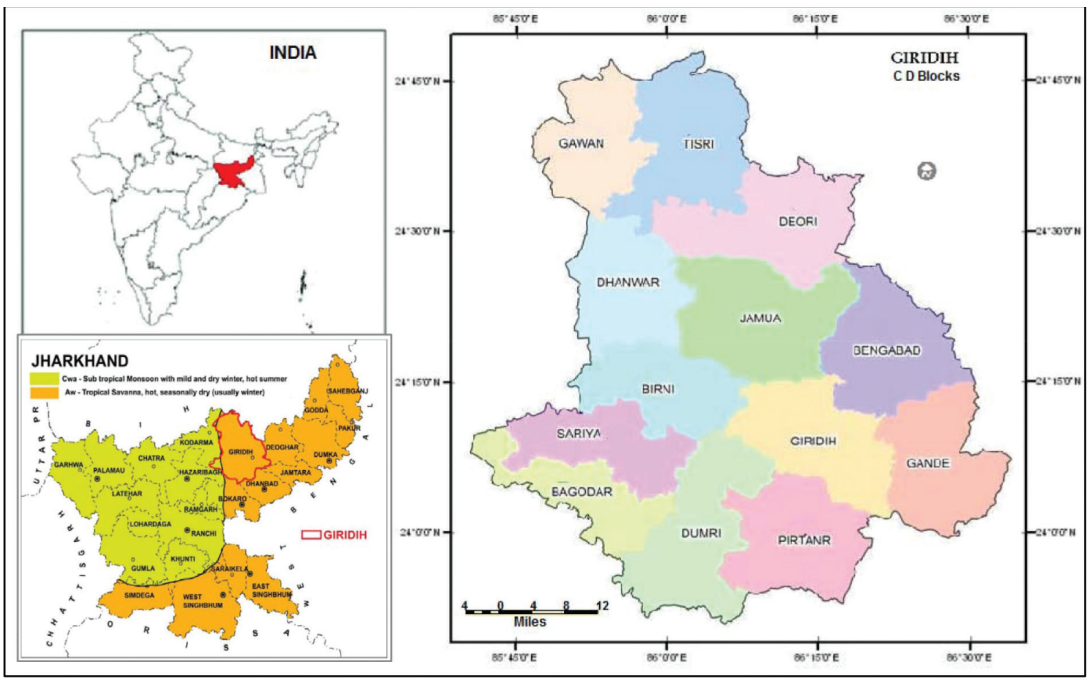

Figure 1: Location of Giridih in climatic belt of Jharkhand.

average elevation between 250 m and 600 m above mean sea level, comprising of central plateau, lower plateau and the trough basin of river Damodar. The area is majorly drained by rivers like Barakar, Sakri and Usri. The district has a subtropical climate with three distinct seasons namely winter, summer and rainy season (advancing and retreating monsoon). In summers maximum temperature can reach up to 47°C while the minimum can be as low as 10°C in winters. The district receives 1231.3 mm of rain annually most of which falls in the rainy season. Between 1951 and 2000, the highest annual rainfall was recorded in 1984 when it amounted to 154% of the normal, and in year 1966, the lowest rainfall amounted to only 48% of the normal (IMD, 2011). Red loamy soil, which is mostly found in the region, is deep in the low-fertile valleys and often shallow on ridges and plateaus. Out of 14.4 lakh hectares of cultivable land in the district, only 0.12 lakh hectares of land is irrigated through sources like dug wells, ponds, and tanks. The District has 31.80 % of area out of total Net cultivated areas that are rainfed. The government of Jharkhand under IWMP guidelines identified Giridih under very high priority water shed zone (WSMIS-JRD, 2010). The district's entire population according to the 2011 Census of India makes up 8 % of the state of Jharkhand's total population. Geologically, the district is dominated by Archean formation sedimentary rocks as well as broad coverage of intrusion of granite formation. Giridih has a massive quantity of virtuous quality of mica. The region is abundant in mineral resources with multiple large-sized coal fields formed under the influence of the Hercynian movement, leading to the creation of Damodar valley in this particular geographical zone (WSMIS-JRD, 2010).

Material and Methodology

Data

A trend analysis of the yearly and seasonal rainfall was conducted in order to examine the temporal variations in the Giridih district's rainfall pattern. Monthly rainfall for 100 years (1921–2021) was acquired from the India Meteorological Department (IMD) and holds a high degree of reliability and credibility, despite spanning a century. The 100 years of data were divided into two time phases of 50 years each to analyse the changing pattern of rainfall trends: the initial phase (1921-1971) and final phase (1972-2021). The year was divided into four seasons for the purpose of seasonal analysis: season 1 represented by the winter months of January and February; Season 2 by the pre-monsoon months of March to May; season 3 by the monsoon months of June to September; and season 4 by the post-monsoon months of October to December.

Methods

The long-term annual and seasonal normals (X_n) were calculated from 30 years of rainfall data (1981-2010) using the given equation:

$$X_n = \frac{1}{n}\sum_{1=i}^{n} X_i$$

Further deviation of rainfall in mm (DI) and deviation of rainfall in per cent (D_i) from normal was calculated using:

$$DI = X_i - X_n$$

$$D_i = \frac{DI}{X_n} \times 100$$

A linear regression model was used to evaluate the annual and seasonal DI trends. This parametric model is one of the most used techniques for identifying patterns in a set of data (Kaur and Kaur, 2019). We used linear regression modelling to predict the value of the dependent variable using the value of the independent or the explanatory variable. Given X the explanatory variable, then Y the dependent variable can be expressed mathematically by the following equation:

$$Y = aX + b$$

where a represents the slope of the line. The value of y when $x = 0$ is called the intercept b. For a set of n observations with p independent variables (with linear regression one)., the F values (observed) were calculated as follows to check the significance of the coefficient of determination represented as R^2:

$$F = \frac{R^2}{1-R^2} \cdot \frac{n-p-1}{p}$$

At the 5% level of significance, the computed value of F was compared to the tabular value of $F(p, n\text{-}p\text{-}1)$. Additionally, while linear regression methodology was employed for trend analysis, its suitability was verified through robust statistical validation, ensuring its adequacy for the research objectives.

Results and Discussion

Long-Term Rainfall Trends

The district's average annual rainfall (normal) for the period spanning 1981 to 2010 is 1231 mm, with a standard deviation of 309 mm. The deviation of rainfall from normal for the last 100 years in Giridih district, under annual and seasonal time frames is shown in Figure 2. The significance level of the rainfall trend was studied at 0.05 as the value of α. The seasonal time frame is divided into season 1 (JF), season 2 (MAM), season 3 (JJAS), and season 4 (OND). Annually, the rainfall is showing a declining trend (not significant) at approx 0.6 mm/y. Season 1 shows a significant decline in winter rainfall at 0.43 mm/y, while season 2 shows a significant increase in rainfall at 0.51 mm/y. Season 3, representing summer monsoon months, and Season 4 have recorded a decrease (not significant) in rainfall at 0.46 mm/y and 0.21 mm/y, respectively. Since the 1950s, there has been a declining long-term trend in rainfall.

The rainfall variability, metrological referred to as an anomaly, is defined as the deviation of the amount of annual rainfall received from the mean (Houghton et al., 2001). The anomaly in rainfall is clearly visible in the study area leading to changes in the crop yield and productivity. In the recent year, in 2018, paddy (summer-monsoon crop) was sown with the onset of monsoon on 16.27 lakh hectares of land and by harvesting time (September – October) 40 % was damaged due to rainfall deficiency. There has been a deficiency in rainfall in all four seasons in 2018 as presented in Figure 2. Paddy is the major crop of the

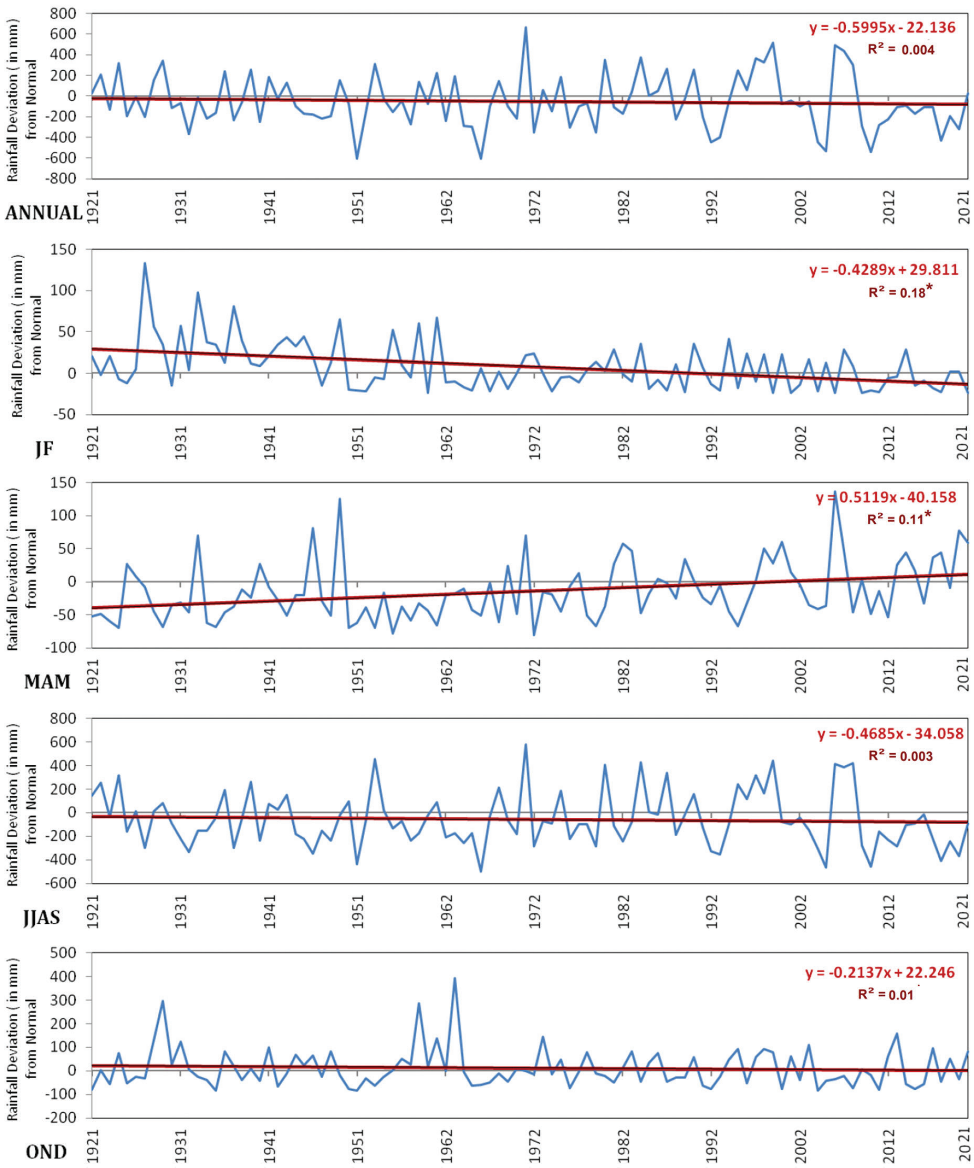

Figure 2: Annual and seasonal rainfall trend since 1921 (* signifies significance at $\alpha = 0.05$).

summer-monsoon season and covers an area of 68.3 ('000 ha) followed by Maize with a coverage of 16.0 ('000 ha) and pigeon peas with 3.6 ('000 ha) are rainfed. During the winter crop growing season Maize rank first with 189 ('000ha) followed by wheat with 3.6 ('000ha) irrigated area.

So, summer-monsoon crops in the district are fully dependent on rainfall and affected by the variability. The amount of rainfall received and the variability have converted the area into an area prone to regular drought conditions.

Phase-Wise Rainfall Trends

Phase-wise trend analysis provides a clear scenario of the variability of rainfall by marked years more precisely as Figure 3 shows the changing pattern of rainfall trends during two-time phases: the initial phase (1921-1971) and the final phase (1972-2021). Annual

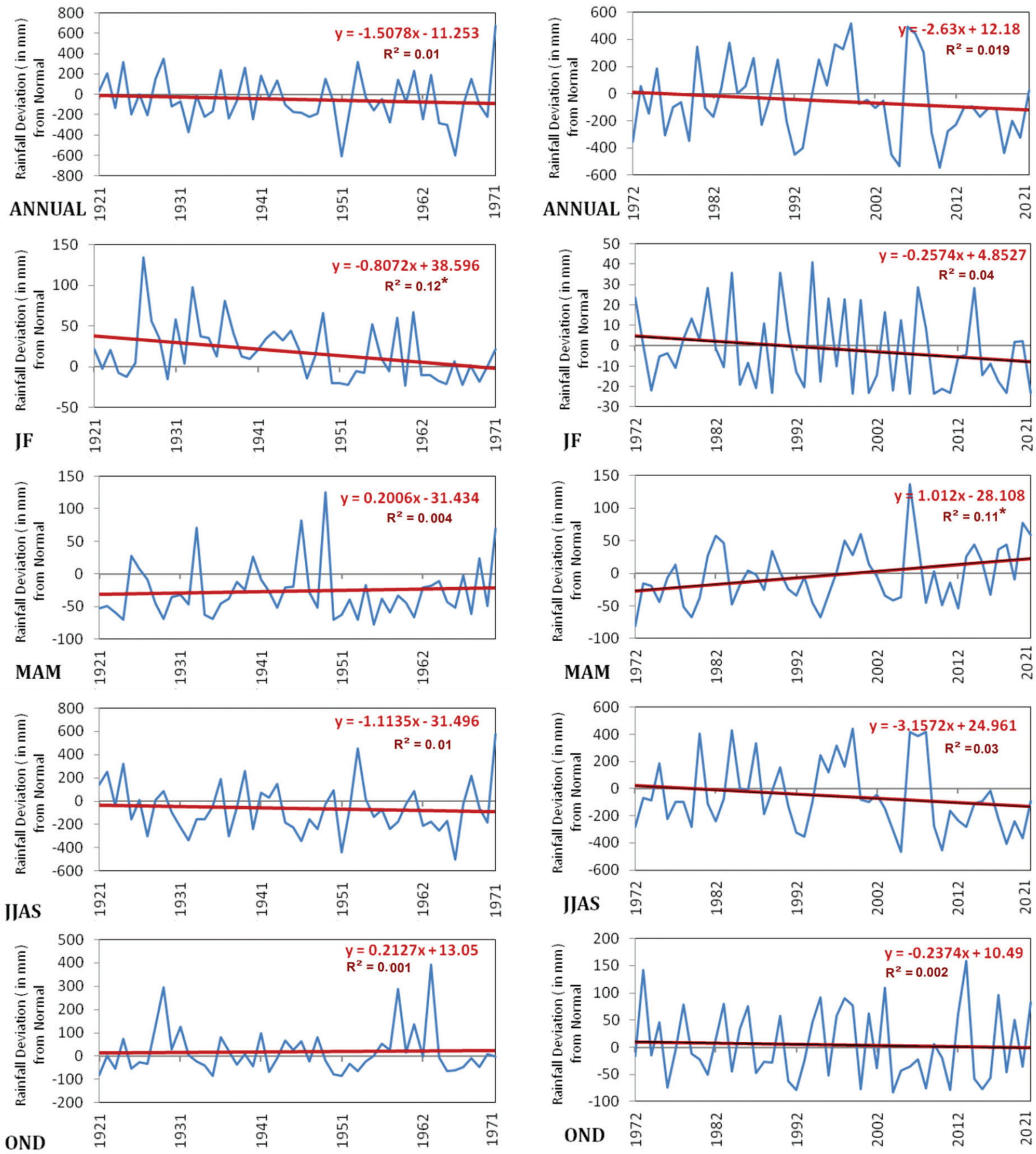

Figure 3: Annual and seasonal rainfall trend comparison between initial and final phases (* signifies significance at $\alpha = 0.05$).

rainfall in both phases shows a declining trend (not significant), but the rate of decline has accelerated in the final phase by approx. 1mm/y. In the initial phase, the annual decline in rainfall was 1.5 mm/y and in the final phase it was 2.63 mm/y.

Season 1 shows a declining trend (significant) at 0.8 mm/y in the initial phase, while the final phase shows a decline (not significant) but at a reduced rate (0.3 mm/y). Interestingly season 2 has recorded a significant increase in rainfall trend from 0.2 mm/y in the initial phase to 1.01 mm/y in the final phase. Similarly, in season 3, the rate of decline (not significant) in monsoon rainfall has also increased from 1.1 mm/y in the initial phase to 3.16 mm/y in the final phase. Not much variation in the trend of rainfall was observed for season 4. So, the second phase of the annual trend, seasons 2 and 3 have a higher significance level and variability compared to its initial phase. The initial phase of season 1 is quite remarkable. Season 3 (JJAS) has been a crucial month as most of the rainfall is received in this advancing phase of monsoon and crucial for the agriculture sector and hydrological planning and related event mitigations.

Frequency of Rainfall Deficit and Excess Periods

The decadal change reflects the percentage change from normal determined by deviation from the actual rainfall of that year. As established the monsoon variability has a direct linkage to the amount of rainfall received in the year (Naidu et al., 1999).

Figure 4 displays the rainfall deficit (where the deficit is defined as less than 25% of average rainfall) and excess years (over 25% of average rainfall) for the Giridih district's annual and season 3 (JJAS) months over the previous 100 years. As per the annual rainfall, there were 13 rainfall deficit years, while there were 12 rainfall excess years. However, considering the season 3 (Indian summer monsoon rainfall) months, there were 18 rainfall stress years and 13 rainfall excess years. This means that in 5 years other seasons have received more than their normals and were able to reduce the rainfall shortage of season 3. Moreover, the frequency of rainfall deficit years has increased in the final phase when compared to the initial phase. As per annual rainfall, in the initial phase, there were only three rainfall deficit years, while in the final phase, there were ten. This

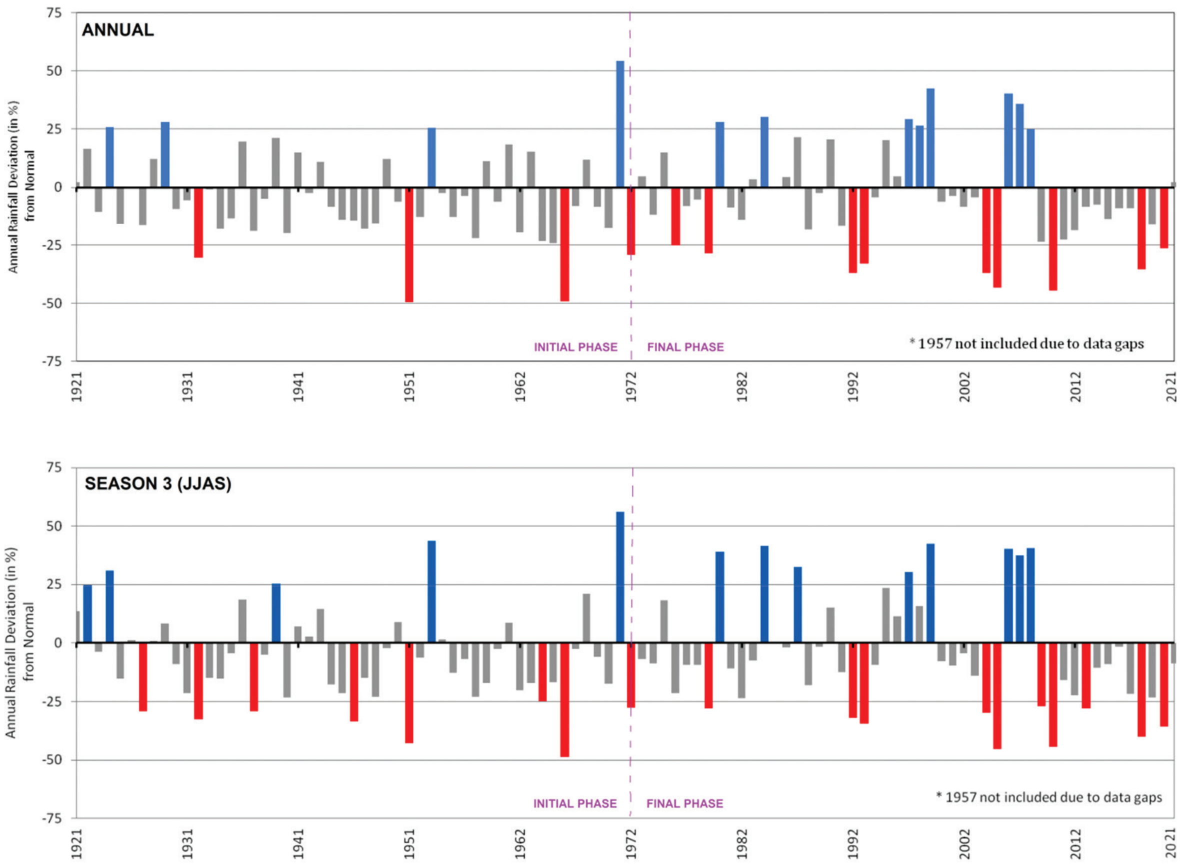

Figure 4: Frequency of rainfall deficit and excess years of Giridih district since 1921.

clearly implies reducing trend in the return period of the rainfall deficit years has reduced in recent decades. It can also be observed that the frequency of rainfall deficit for three consecutive years has become frequent in recent decades. 1992-93, 2004-05 and 2009-2010 were the three consecutive rainfall deficit years under season 3. Regarding the rainfall excess situation, in the initial phase, there were only four rainfall excess years, while in the final phase there were eight. This again implies a reducing trend in the return period of the rainfall excess years also reduced in recent decades.

Implications of Rainfall Variability on Agriculture

Previous long term rainfall studies (Kumar et al., 2016; Sharma and Singh, 2017) conducted in the study area with data till 2002, have shown a decreasing mode of monsoon season and yearly rainfall at a rate of approx. 2 mm/year, with no significant rainfall trend during winter months. The present study, which extends till 2021, has shown that the last two decades are comparatively drier than before, bringing the overall rainfall deficit trend to 3mm/year with more numbers of dry episodes in the final phase (1972-2021). This implies that there has been a rise in rainfall unpredictability and uncertainty in recent decades. The impacts are already visible in the district's agriculture sector. Although Jharkhand is entirely experiencing a reduction in gross cropped area (Figure 5), the situation of Giridih is no good with only 150.8 thousand hectares in 2013 (Agriculture Contingency Plan for District: Giridih 2013). As per the Directorate of Economics and Statistics (Government of Jharkhand) in Giridih district, the net sown area has decreased from 77.59 thousand hectares in 2004-05 to 42.22 thousand hectares in 2019-20. The total irrigated area has increased from 8.6 thousand hectares (District Census Report, 2001) to 12.5 thousand hectares (Agriculture Contingency Plan for District: Giridih 2013) between 2001 and 2013, but has declined to 10.3 thousand hectares in 2019-2020 (District Statistical Handbook, Giridih 2021).

The cropping intensity of Giridih is 109 per cent (Agriculture Contingency Plan for District: Giridih 2013), which is less than the cropping intensity of Jharkhand state i.e. 140% (Economic Survey, Jharkhand_2020-21). Owing to the decrease in monsoon rainfall and the absence of irrigation facilities, the summer-monsoon crops of rain-fed regions are going to be hugely affected. Furthermore, rainfall determines a region's hydrological response, which has long-term effects on surface and groundwater storage. Thus, an increase in rainfall deficit situations will have a massive impact on the farming communities. As per the Multidimensional Poverty Index (Alkire et al., 2018), 55 per cent of Giridih's population are in multidimensional

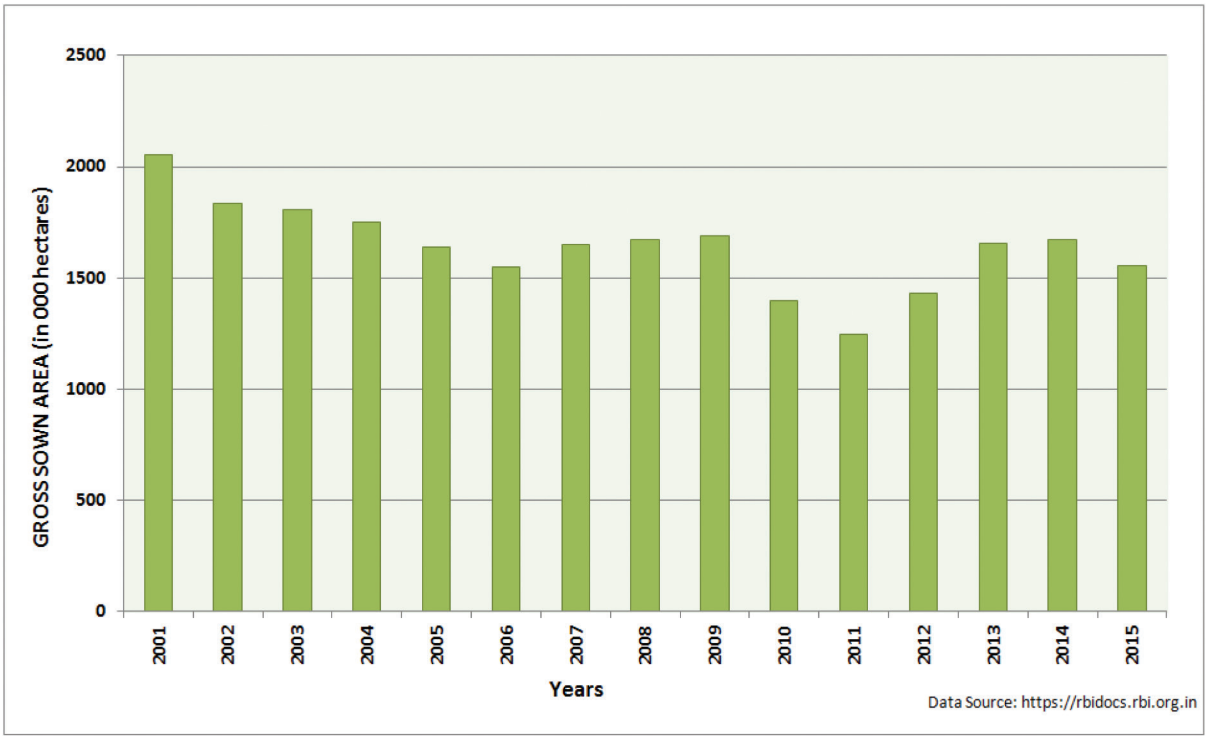

Figure 5: Gross sown area of Jharkhand since 2000-01.

poverty. Petare et al. (2018) have found that Jharkhand households engaged in rainfed agriculture had low food grain production during drought years. Thus these households relied heavily on the subsidised rice provided through the Public Distribution System by the state government during the drought period of two consecutive years 2009 and 2010. The dip in the gross sown area during 2010-11 in Figure 2 clearly indicates the impact of the droughts. Lack of livelihood sustenance options in agriculture has forced many young populations to either migrate to surrounding states or end up working in mica or coal mines (cini-India, 2018). Therefore, there is a need to relook at the efficacy of the existing water storage and managing mechanisms of the district, and also to make modifications in the cropping pattern to adapt to the changing rainfall patterns.

Conclusion

Understanding rainfall trends is crucial for the development and management of water resources in any area. We examined the long-term annual and seasonal rainfall trends for the Giridih district in Jharkhand, India to understand the hydrological responses to climate change. The study found a decreasing trend of 3.15 mm/year rainfall during the monsoon months (season 3) in recent decades, which is higher than the decreasing trend recorded in the initial phase (1921-1971). The growth of summer-monsoon crops may be affected by the observed decreasing rainfall trend resulting in low crop production. As winter rainfall is also showing a decreasing trend, the winter crops may need more irrigation facilities to sustain crop production in these regions. Several investigations in this field have found that the variabilities and anomalies of monsoon rainfall have not only affected the Indian subcontinent but also Southeast Asia leading to extended drought conditions leading not only to crop failures but land degradation too (Naidu et al., 1999). In this Holocene paleoclimate scenario, the years 1961-1990 have been identified as the 'baseline' of these frequent anomalies in rainfall by the World Metrological Organization (WMO). The rainfall patterns observed in the latter part of the 20th century are essential for planning and mitigating actions. Therefore, revisiting the traditional irrigation facilities and monitoring El Nino (ENSO) are highly needed in this district to cope with future stress situations and mitigate land degradation.

The study primarily focusses on decision-making related to conserving water resources at the local level. However, it's important to recognise that the issue of climate variability and community preparedness is interconnected with broader policy contexts and socio-political dynamics of the region. The present study should act as a base for a more comprehensive understanding of water resource management challenges and opportunities by analysing these highly interconnected and complex factors more holistically. By considering the broader policy landscape and socio-political dynamics, decision-making frameworks can be improved to better address the complex and interconnected issues involved.

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