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Drought risk assessment: A pilot study in drought-prone Rarh Tract under semi-arid region of India

B. Ghosh[1], M.D. Gupta[2], S. Das[3], A. Haldar[3]*, P. Dey[3], S. Chatterjee[4] and P.G.D. Chakrabarti[1]

[1]*Department of Environment and Disaster Management, Ramakrishna Mission Vivekananda Educational and Research Institute, Kolkata- 700 103, India*
[2]*Department of Agricultural Extension, Krishi Vigyan Kendra, Sonamukhi, Bankura- 722 207, India*
[3]*Department of Agricultural Extension, ICAR-Agricultural Technology Application Research Institute Kolkata, Indian Council of Agricultural Research, Kolkata-700 097, India*
[4]*Department of Statistics, Indian Statistical Institute Kolkata, Kolkata- 700 108, India*

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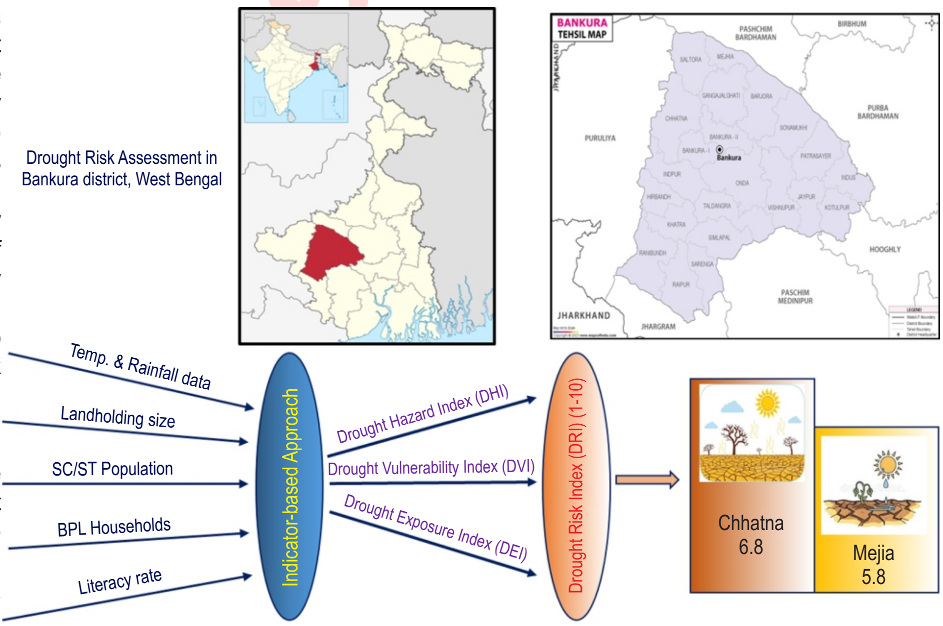
***Corresponding Author Email:** vetavijit@gmail.com ***ORCiD:** https://orcid.org/0000-0003-0770-3983

Abstract

Aim: Extreme droughts and dry spells are common in the Chota Nagpur Plateau, particularly in the Rarh tract encompassing Bankura and Purulia districts in West Bengal under semi-arid region of India. This study aims to identify and characterize block-wise drought hazard, vulnerability, and risk for effective long-term drought management in the Bankura district.

Methodology: The study employed a micro-scale, indicator-based drought risk assessment integrating three decades of climatic variability (temperature and rainfall, 1992–2022) with key socio-economic indicators (landholding size, SC/ST population share, BPL households, and literacy rate) across ten drought-prone blocks of Bankura district. Hazard, vulnerability and exposure indices were normalized on a 10-point scale and aggregated to generate a composite Drought Risk Index (DRI) for block-wise comparison and prioritization.



Results: The findings indicate pronounced spatial variability in drought risk, with higher risk concentrated in the north-western blocks. Chhatna recorded the highest DRI (6.8) whereas Mejia showed the lowest DRI (5.8), indicating comparatively lower drought risk.

Interpretation: The micro-level ranking of drought-prone blocks provide a valuable framework for developing targeted, block-wise integrated drought management strategies. This will enhance preparedness, early warning, and mitigation efforts not only in the Rarh tract, but also in similar semi-arid region across India and beyond.

Key words: Chota Nagpur plateau, Drought risk index, Rarh tract, Semi-arid region

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Introduction

Drought is widely regarded as one of the most complex, severe, and recurring hydro-climatic hazard, with far-reaching impacts on both society and the environment (Gu *et al.,* 2020; Tora *et al.,* 2021; Li *et al.,* 2022). It is broadly classified into four types: meteorological, hydrological, agricultural, and socio-economic drought (Mishra and Singh, 2010). The combined effects of reduced rainfall (meteorological drought) and declining water availability (hydrological drought) often lead to agricultural and socio-economic droughts, resulting in reduced crop yields and disruptions to human, animal, and environmental systems (Gupta *et al.,* 2014; Goswami, 2017). Over the past few decades, the frequency and intensity of drought events have increased globally, especially in the tropical and subtropical regions, due to climate change and socio-economic pressures (Li *et al.,* 2022; Wang and Sun, 2023). According to the World Health Organization (WHO, 2025), droughts affect approximately 55 million people annually, threatening livelihoods, increasing the risk of disease and displacement, and exacerbating water scarcity. Nearly 40% of the global population already suffers from water stress, and drought could displace up to 700 million people by 2030.

Developing countries are particularly vulnerable due to their agrarian economies, dependence on natural resources, and limited adaptive capacities. The social effects of drought are most pronounced in nations experiencing food insecurity and heavily dependent on subsistence farming and primary sector operations, while the economic effects are most noticeable in water-dependent industrialized nations (Wang and Sun, 2023). India, with nearly two-third of its landmass drought-prone area in arid and semi-arid regions, is among the most affected countries (Singh *et al.,* 2019). The nation experienced major famines during the 19th and 20th centuries, largely driven by prolonged droughts (Mishra *et al.,* 2019; Aadhar and Mishra, 2020). Since agriculture and groundwater recharge heavily depend on the south-west monsoon, irregular rainfall often triggers recurrent droughts (Kumar *et al.,* 2013; Asoka *et al.,* 2017; Ghosh *et al.,* 2025). Global drought risk is assessed through three key components: hazard, exposure and vulnerability (Oh *et al.,* 2023). The impact of droughts is expected to intensify in the near future due to increasing food demand driven by rapid urbanization and population growth (Chuphal *et al.,* 2024). To reduce the vulnerability of future generations to drought, it is crucial to understand historical drought patterns and long-term trends.

The Chota Nagpur Plateau, especially the Rarh region in West Bengal (including Bankura, Purulia, Jhargram, Birbhum, and parts of Midnapore) under semi-arid region of India, is highly susceptible to drought and dry spells (Roy and Hazra, 2020; Bera *et al.,* 2021). The Rarh region is a distinct physiographic tract of West Bengal, India, situated between the Ganges Delta in the east and the Chota Nagpur Plateau in the west. It is characterized by undulating topography, lateritic soils, and a network of rivers including the Damodar, Ajay and Mayurakshi. The region broadly encompasses the districts of Bankura, Birbhum, Purulia, and parts of Bardhaman. Owing to its unique geo-environmental setting and historical importance, the Rarh region holds considerable relevance for geotourism and sustainable resource management. At the same time, it is confronted with persistent developmental constraints, including agricultural distress, which underscores the need for context-specific planning and interventions. The region's undulating terrain leads to rapid surface runoff and quick soil moisture loss after rainfall events (Goswami, 2017). Consequently, despite receiving an average annual rainfall of around 1400 mm, large areas of Bankura experience dryness due to irregular precipitation patterns and hot westerly winds (Ghosh, 2018; Senapati *et al.,* 2021).

While several studies have analyzed drought trends in the western and central India, semi-arid regions of eastern India (e.g., Rarh region) are less studied using integrated risk approaches (Roy and Hazra, 2020; Senapati *et al.,* 2021). The detailed investigations focusing on the identification and characterization of drought in the Rarh tract of West Bengal remain limited. Despite the frequent occurrence of droughts in the Rarh tract of eastern India, there is a gap of research on micro-level(block-wise), integrated assessments that combine long-term climatic variability with socio-economic indicators to generate block-wise drought risk prioritization. Block-level assessment of drought hazard, exposure, and vulnerability is essential for targeted and effective long-term drought risk management. Unlike previous studies in Bankura, Western West Bengal, or the Chota Nagpur Plateau that were largely conducted at district or regional scales and often relied on short-term climatic data (Bera *et al.,* 2021; Senapati *et al.,* 2021), we tempted to conduct a novel micro-scale, indicator-based drought risk assessment by integrating long-term climatic variability with socio-economic factors to develop a policy-oriented Drought Risk Index (DRI) for block-wise prioritization, thereby enabling targeted and actionable drought preparedness and management strategies, with applicability to similar semi-arid regions in India. While understanding the complex spatio-temporal patterns of droughts is crucial for effective water resource management and developing strategies to mitigate their impacts, the present study aimed to conduct a comprehensive drought risk assessment in the Rarh region by analyzing the nature and extent of drought hazards, and evaluating the existing vulnerabilities that threaten local populations and their livelihoods.

Materials and Methods

Study area: The study was conducted in the Bankura district, located in the western part of West Bengal, India, and forming an extended part of the Chota Nagpur Plateau. Geographically, the district lies between 22°38´ to 23°38´ North latitude and 86°36´ to 87°46 East longitude, and is part of the "Rarh" region of the state. Spanning approximately 6,882 km^2, the district is traversed by seasonal rivers such as the Damodar, Dwarakeswar, Shilabati, Sali, Kangsabati, Gandheswari, Jaypanda, Bhairabbanki, Kukhra and Birai. The topography is primarily composed of plateaus and hills, with major soil types, such as, Laterite Soil, Red Soil, Alluvial

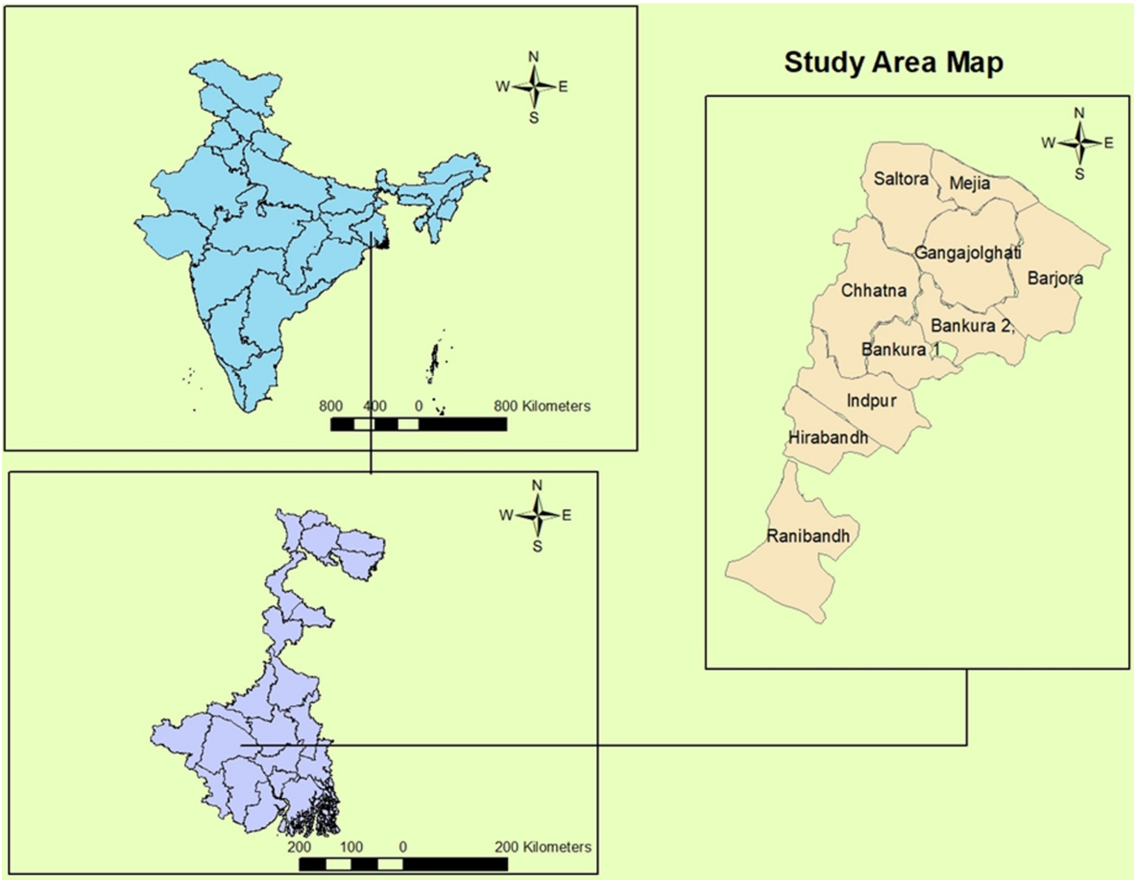

Fig. 1: Study area map (Using Qgis).

Soil (Sarkar *et al.,* 2020). Bankura is predominantly rural, with 89% of its population residing in rural areas and only 11% in urban settlements. For this study, ten drought-prone blocks were selected using purposive random sampling: Bankura I, Bankura II, Chhatna, Saltora, Mejia, Gangajalghati, Barjora, Indpur, Hirbandh and Ranibandh. Across these blocks, the highest rainfall was typically recorded in July. The years that witnessed rise in temperature also behold scarcity in rainfall, and gave rise to dry condition, which affected normal agricultural operations. The study area is illustrated in Fig. 1.

Dataset: In the present study, data were collected on three primary indicators: temperature, rainfall and net irrigated area during 1992 to 2022 from Agriculture Department, Government of West Bengal. These indicators were obtained from primary sources. Monthly rainfall (mm) and monthly maximum temperature (°C) were compiled for each block for 1992–2022 (31 years) from departmental records and aggregated to annual and long-term averages for index construction. The spatial unit was the administrative block (non-gridded). Data on land holding, schedule caste (SC)/ schedule tribes (ST) population, below poverty line (BPL) family, literacy rate were collected from ten drought-prone blocks of Bankura district. Thereafter, drought hazard index, vulnerability index and exposure index were calculated on a 10-point scale and the drought risk index was determined. Each index was assigned an equal weight of 33.3%, and based on this, a composite hazard index was developed for each of the ten Drought Prone Area Programme (DPAP) blocks in Bankura district. Equal weighting is a widely accepted practice in composite index construction, particularly in exploratory and policy-oriented risk assessments, as it ensures transparency, simplicity, and comparability across spatial units (Manteaw *et al.,* 2022). Several drought and climate risk studies have successfully employed equal weighting when indicators represent distinct but complementary dimensions of risk (hazard, exposure, and vulnerability) and when the objective is relative prioritization rather than precise prediction (Hagenlocher *et al.,* 2019). Accordingly, equal weighting was considered appropriate for the present micro-scale, block-level assessment, where the primary aim was to identify relative drought risk and support decision-making.

Drought hazard index: The drought hazard index (DHI) is a composite numerical measure used to quantify drought hazard by integrating key indicators such as magnitude, frequency, severity and duration. This index offers a comprehensive statistic to assess the relative hazard posed by drought events by accounting for their intensity, duration, and spatial extent (Wang and Sun, 2023). It was calculated by the formula:

$$\mathrm{DHI}_i = 10 \times \left[\frac{1}{3}\left(\frac{\mathrm{AMT}_i}{\mathrm{AMT}_{\max}}\right) + \frac{1}{3}\left(\frac{\mathrm{AAR}_{\min}}{\mathrm{AAR}_i}\right) + \frac{1}{3}\left(1 - \frac{\mathrm{NAI}_i}{100}\right)\right]$$

Where, DHI_i=Drought Hazard Index of block *i*, AMT*i*= Average Maximum Temperature of block *i*, AMT_{max}= Maximum possible value of average maximum temperature, AAR *i*= Average Annual Rainfall of block *i*, AAR_{min}= Minimum value of average annual rainfall, NAI_i= Net area irrigated (%) of block *i*

In the drought hazard index, the "Max Possible Value of Average Max Temp" was the highest observed block-wise long-term mean annual maximum temperature across the ten blocks during 1992–2022, used as the denominator for scaling the temperature indicator on a 0–10 scale. Comparable observed maxima/ minima from the same dataset were used as reference values for other indicators. Net irrigated area (%) was obtained from the Agriculture Department, Government of West Bengal for 1992–2022, and the block-wise mean was used in the hazard indicator.

Drought vulnerability index: Drought vulnerability refers to the degree to which a population, community, or system is susceptible to the adverse impacts of drought (Serkendiz and Tatli, 2023). It is a multidimensional concept, influenced by various socio-economic, demographic and environmental factors, and is inherently dynamic shaped by ongoing political, social, and economic changes (Rahman *et al.,* 2024). In this study, an indicator-based approach was used to assess drought vulnerability. Key indicators included landholding size (with emphasis on small and marginal farmers, sharecroppers, and landless laborers), social status (Scheduled Castes and Scheduled Tribes), economic status (Below Poverty Line population), and educational attainment (literacy level). Data on population, literacy, and SC/ST demographics were sourced from the Census of India, while landholding classifications were obtained from the District Statistical Handbook. For the computation of the vulnerability index across ten DPAP blocks of Bankura district, equal weights were assigned to each of the four indicators: landholding (25%), SC/ST population (25%), literacy (25%) and BPL population (25%).

$$\mathrm{DVI}_i = 10 \times \left[\frac{1}{3}\left(\frac{\mathrm{LHI}_i}{10}\right) + \frac{1}{3}\left(\frac{\mathrm{VPI}_i}{10}\right) + \frac{1}{3}\left(\frac{\mathrm{LI}_i}{10}\right)\right]$$

Where, DVI_i= Drought Vulnerability Index of block *i*, LHIi= Landholding Index of block *i*, VPIi= Vulnerable Population (Rural) Index of block *i*, LI_i= Literacy (Rural) Index of block *i*

a. Landholding index:

$$\mathrm{LHI}_i = 10 \times \left[\frac{1}{4}\left(\frac{B_i}{B_{\max}}\right) + \frac{1}{4}\left(\frac{100 - S_i}{S_{\max}}\right) + \frac{1}{4}\left(\frac{M_i}{M_{\max}}\right) + \frac{1}{4}\left(\frac{L_i}{L_{\max}}\right)\right]$$

Where, LHI_i= Landholding Index of block *i*, B_i= Bargadar landholding (%) of block i, S_i= Small landholding (%) of block *i*, M_i= Marginal landholding (%) of block *i*, L_i= Landless labourer landholding (%) of block *i*, B_{max}, S_{max}, M_{max}, L_{max}= Maximum possible values (%) of respective landholding categories

b. Vulnerable population (rural) index:

$$\mathrm{VPI}_i = 10 \times \left[\frac{1}{3}\left(\frac{\mathrm{SC}_i}{\mathrm{SC}_{\max}}\right) + \frac{1}{3}\left(\frac{\mathrm{ST}_i}{\mathrm{ST}_{\max}}\right) + \frac{1}{3}\left(\frac{\mathrm{BPL}_i}{\mathrm{BPL}_{\max}}\right)\right]$$

Where, VPI_i= Vulnerable Population (Rural) Index of block *I*,= Scheduled Caste population (%) in block *i*, ST_i= Scheduled Tribe population (%) in block *i*, BPL_i= Below Poverty Line population (%) in block *i*, SC_{max}, ST_{max}, BPL_{max}= Maximum possible values (%) of the respective indicators

c. Literacy (rural) index:

$$LI_i=10\times[0.5(100-MLR_i)+0.5(100-FLR_i)]$$

Where, LI_i= Literacy (Rural) Index of block *i*, MLR_i= Male literacy rate (%) of block *i*, FLRi= Female literacy rate (%) of block *i*

Drought exposure index:

$$\mathrm{DEI}_i = 10 \times \left(\frac{P_i}{P_{\max}}\right)$$

Where, DEI_i= Drought Exposure Index of block i, P_i= Total population of block i, P_{max}= Maximum value of block-level population among all blocks. Block-wise population data used for the Drought Exposure Index (DEI) was obtained from the Census 2011.

Drought risk index: Drought risk is determined by the combined influence of geographic, climatic and socio-economic factors. It refers to the potential for adverse impacts resulting from the interaction among three core components: drought hazard (the magnitude and frequency or severity of drought events), drought exposure (the population or assets at risk in a particular area), and drought vulnerability (the degree to which a system is susceptible to harm and its capacity to cope and adapt) (Rahman *et al.,* 2024). In this study, an index-based approach was adopted to assess drought risk by quantifying each component—hazard, vulnerability and exposure.

Following the internationally accepted methodology recommended by the United Nations Office for Disaster Risk Reduction (UNDRR), the components were weighted in the ratio of 5:3:2 for hazard, vulnerability and exposure respectively. The adoption of a UNDRR-consistent weighted index framework (5:3:2) ensured conceptual robustness, transparency and policy relevance, while minimizing subjectivity and maintaining comparability with international disaster risk studies. The approach was particularly suitable for micro-scale, block-level prioritization, where the objective focused on relative risk ranking to support targeted drought preparedness, mitigation, and resource allocation (Hagenlocher *et al.,* 2019). The drought risk index was calculated using the following formula:

$$DRI_i = 0.5 \times DHI_i + 0.3 \times DVI_i + 0.2 \times DEI_i$$

Where, DRI_i= Drought Risk Index of block *i*, DHI_i= Drought Hazard Index of block *i*, DVI_i= Drought Vulnerability Index of block *i*, DEI_i= Drought Exposure Index of block *i*

Results and Discussion

The present study was conducted in ten drought-prone blocks of Bankura district, an extension of the Chota Nagpur Plateau under semi-arid region of India, to assess the Drought Risk Index using an indicator-based approach. Agriculture is the main source of livelihood in the region, with major crops including Kharif-Rabi-Summer paddy, mustard, sesame, potato, maize, and gram. Recurrent droughts have reduced both irrigated and net cropped areas. The hazard is, further, aggravated by lesser annual precipitation and lower percentage area under irrigation. Drought vulnerability is embedded in multiple layers like land holding, size of SC/ ST population, size of BPL population, and literacy rate. Most farmers are smallholders, sharecroppers, or landless labourers, relying on subsistence farming with little to no marketable surplus. As a result, crop failures severely impact livelihoods, nutrition, health, and education, especially among women and children. Population exposure further amplifies the risk of drought-induced disasters in this region.

The perusal of data in Table 1 showed that the Saltora block recorded the highest DHI, followed by Chhatna and Mejia. Overall, the drought hazard was found to be relatively higher in the northern and western parts of the district compared to the eastern part. The study revealed that the DHI was relatively higher in the northern and western parts of Bankura district, with Saltora block recording the highest index (8.33), followed by Chhatna and Mejia, while Barjora had the lowest (7.14). These spatial variations were largely influenced by the geo-environmental factors and climate variability. The increasing trend of global warming and the weakening relationship between El Niño Southern Oscillation (ENSO) and the Indian monsoon in recent years contribute to these disparities (Kundu and Mondal, 2019). However, ENSO alone cannot fully explain drought patterns in this region, which are more closely linked to local factors such as soil type, geology, and topography (de Espindola *et al.,* 2017), as well as warming of the equatorial Indian ocean, weakening of the easterly jet stream, and weakening of the meridional SST gradient from the equatorial region to the south Asian coast during summer (Bhaduri *et al.,* 2016).

The north- western and western parts of the district are underlain by crystalline basement rocks and shallow fracture zones, limiting groundwater retention (Doke *et al.,* 2021; Kundu and Mondal, 2019). These areas also showed significant depletion in soil moisture and green water storage (Chowdhury and Behara, 2018). In Saltora, only 8% of the land is irrigated, intensifying agricultural drought, whereas Barjora, with 44.2% net irrigated area, benefits from multiple irrigation sources that mitigate drought hazard. Additionally, climate change-induced temperature rise and erratic rainfall have worsened water scarcity (Field *et al.,* 2018). Over a 30-year period, Saltora recorded the lowest average annual rainfall (1298 mm) among the blocks studied, these results corroborate with the previous reports of Raha and Gayen (2019, 2020), Bera *et al.* (2021), and Ghosh (2019), identifying the north-western and western Bankura as the most drought-prone, while the eastern regions remain comparatively less affected. Identifying drought vulnerability is essential for effective drought mitigation and planning, as it helps prioritize regions and populations at greatest risk (Wilhelmi and Wilhite, 2002). Vulnerability is shaped by the interactions of biophysical and socio-economic factors (Peduzzi, 2019), as well as community perspectives, local knowledge and coping capacities (Hilhorst and Bankoff, 2013). In this study, the Hirbandh block recorded the highest vulnerability index, followed by Indpur, Ranibandh and Chhatna. On average, the western region of Bankura district was found more vulnerable to drought (Table 1).

The present findings indicate that the western part of the district was more vulnerable, while the northern part experienced higher drought exposure. The highest vulnerability index (4.8) was observed in the Hirbandh block, primarily due to a high

Table 1: Drought Hazard Index, Drought Vulnerability Index, Drought Exposure Index and Drought Risk Index of Drought Prone Blocks of Bankura District

Block Name	Hazard Index (Scale of 10)	Vulnerability Index Scale of 10	Exposure Index (Scale of 10)	Risk Index Scale of 10
Bankura-1	7.83	4.3	3.6	5.9
Bankura-2	7.77	3.8	4.7	6.0
Chhatna	8.19	4.6	6.5	6.8
Saltora	8.33	4.5	4.5	6.4
Mejia	7.91	4.1	2.9	5.8
Gangajalghati	7.62	4.1	6.0	6.3
Barjora	7.14	4.0	6.7	6.1
Hirbandh	7.84	4.8	2.8	5.9
Indpur	7.64	4.6	5.2	6.2
Ranibandh	7.56	4.6	4.0	6.0

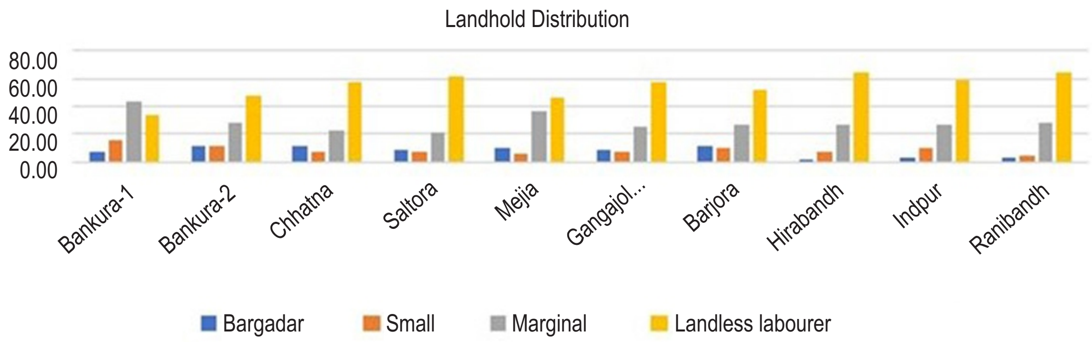

Fig. 2: Agricultural land hold distribution of drought prone block of Bankura district.

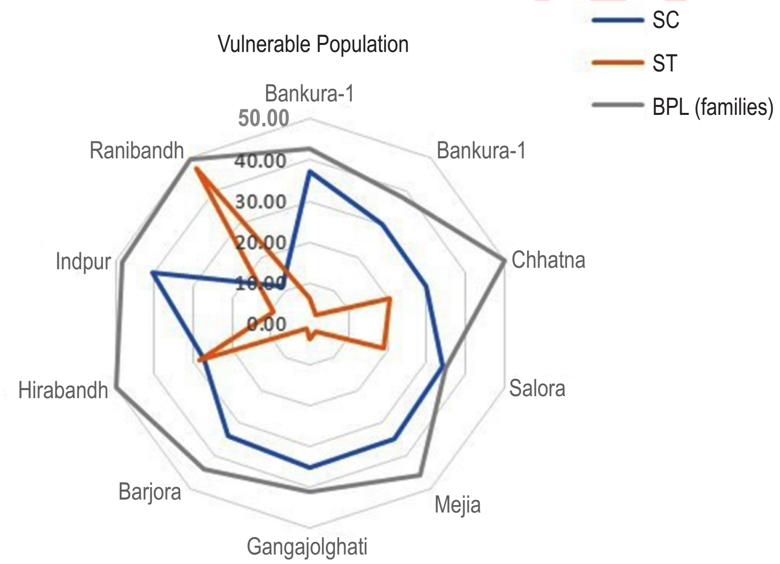

Fig. 3: Vulnerable population distribution of drought prone block of Bankura district.

proportion of BPL families (approximately 49.95%) and a landholding weighted score of 5.11. In contrast, Bankura II exhibited the lowest vulnerability index (3.8), likely owing to higher literacy rates among both men and women, and the lowest BPL population in the district. The agricultural landholding distribution across the drought-prone blocks of Bankura district is illustrated in Fig. 2. On an average, landless labourers constituted the largest category of agricultural landholders, followed by marginal farmers. The proportion of landless labourers was comparatively higher in the western part of the district. In contrast, the landholding distribution of bargadars (sharecroppers) and small farmers was more prominent in the northern regions, while marginal farmers were generally concentrated in both the northern and western parts of the district. The distribution of vulnerable populations is shown in Fig. 3. The highest proportion of SC was found in Indpur, ST in Ranibandh, and BPL population in Chhatna block. Overall, the concentration of SC, ST and BPL populations was comparatively higher in the western part of the district, indicating a greater level of social and economic vulnerability in that area.

Drought exposure index is presented in Table 1. In terms of exposure, Barjora block ranked highest, followed by Chhatna and Gangajalghati. The northern part of the district exhibited greater drought exposure compared to other parts highlighting population and land-use pressures in these areas that elevate drought-related risks.The present study is in line with the findings of Tora *et al.* (2021), indicating that in the African continent, Sahel is a severely vulnerable area with recurring natural hazards like drought, floods, etc., where the population is exposed to chronic vulnerability resulting in cramped livelihood and development endeavors, food insecurity and poverty. Disaster risk assessment involves determining the nature and extent of risk by analyzing hazards and evaluating existing vulnerability conditions that, together, may adversely affect exposed populations, property, livelihoods and the environment. In this study, the DRI for ten drought-prone blocks of Bankura district is presented in Table 1. The results revealed that Chhatna block exhibited the highest drought risk index (6.8), followed by Saltora (6.4), Gangajalghati (6.3), Indpur (6.2), Barjora (6.1), Ranibandh and Bankura II (6.0), Hirbandh and Bankura I (5.9), and Mejia (5.8). On an average, the drought risk was comparatively higher in the north-western part of the district. These findings align with those of Senapati et al. (2021), reporting that the north-western regions of Bankura were more susceptible to extreme drought, while the remaining parts of the district tend to experience mild to moderate drought conditions.

Policy interventions: Based on the findings of the present study, the following policy recommendations are proposed to mitigate drought risk and enhance resilience in the drought-prone blocks of Bankura district, particularly in the north-western part of Bankura district. Development and implementation of localized block-specific drought management plans focusing on the most vulnerable blocks (e.g., Chhatna, Saltora, Gangajalghati and Indpur). These would integrate hazard mapping, vulnerability assessment, and resource inventory. Bera *et al.* (2021) suggested that non-structural measures like government policies, public awareness and legal framework would be effectively adopted in different pockets of drought prone region in the extended part of Chota Nagpur plateau. Water resources in high-risk blocks can be effectively managed through rainwater harvesting infrastructure, integrated watershed management, and groundwater recharge initiatives (Bera *et al.,* 2021). Additionally, traditional water bodies such as, tanks, and ponds for supplemental irrigation can be rejuvenated. Micro-irrigation including drip and sprinkler methods, is essential to enhance water-use efficiency (Jain *et al.,* 2021).

Climate resilient agriculture may be adopted through the promotion of drought-tolerant crops, short-duration varieties and crop diversification in high-drought risk areas. Capacity building is required for climate- resilient farming practices including mulching, soil moisture conservation, integrated farming systems and agroforestry. Jat *et al.* (2025) reported that climate-resilient agriculture under Integrated Watershed Management (IWM) in dryland areas enhance drought resilience by conserving soil moisture, improving productivity, reducing soil erosion, and strengthening ecosystem and livelihood resilience.

Therefore, livelihood diversification, income-generating activities and skill development support are required to encourage non-farm employment and reduce over-dependence on agriculture in high-risk areas. Targeted support to the vulnerable groups may be provided through special schemes for SC/ST communities and BPL families focusing on food security, education, and health to enable social equity and community support. Kamruzzaman *et al.* (2018) reported that drought vulnerability increased with the increased percentage of illiterate people involved in agricultural practices. As agriculture is the primary livelihood option for majority of people of this region, promoting crop insurance coverage and easy credit access may become a good support to the drought vulnerable indigenous communities. Real-time drought monitoring system using remote sensing for better preparedness is required. It needs to integrate with existing weather forecasting services and disseminate early warnings to the farmers. Masupha *et al.* (2025) indicated that agricultural drought early warning system enables effective, adaptive, and informed decision-making for stakeholders. Awareness and educational programs would help to build local capacities on drought preparedness and drought adaptation practices including crop planning, water management and sustainable farming. The innovation-driven policy should be undertaken to use soil moisture sensors for controlled-irrigation, drones, IoT-linked nutrient and pest management. It is necessary to invest in rural broadband and mobile connectivity to enable real-time access to cloud-based tools, and GPS-based farm advisory services, supporting timely and informed agricultural decision-making and food security planning (Hu *et al.,* 2023).

Block-level drought management cells in high-risk blocks may help to coordinate and implement drought mitigation programs. Convergence of schemes through ensuring coordination across state and central schemes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Integrated Watershed Management Programme (IWMP), Rashtriya Krishi Vikas Yojana (RKVY), and Jal Shakti Abhiyan may also be a good option in this regard. District-level drought research units to study localized impacts and provide regular feedback into policy formulation and adaptation planning are essential.

The present study highlights that drought risk is significantly higher in the north-western part of Bankura district, with Chhatna block showing the highest risk index. Using an indicator-based approach combining physical, meteorological, and socio-economic factors, the assessment reveals deep-rooted vulnerabilities among marginal and tribal communities, particularly due to high levels of poverty, landlessness and low literacy. The findings underscore the urgent need for integrated drought management strategies, including early warning systems, vulnerability reduction, and community-based resilience building. This research offers valuable insights not only for Bankura, but also for other drought-prone regions with similar agro-ecological conditions across India and beyond.

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Authors' contribution: B. Ghosh: Writing–original draft, Methodology, Investigation; **M.D. Gupta:** Formal analysis, Data

curation, Validation, Methodology, Investigation; **S. Das:** Writing – revision and editing, Visualization; **A. Haldar:** Conceptualization, Visualization, Supervision; **P.G.D. Chakrabarti:** Validation, Methodology, Data curation; **S. Chatterjee:** Visualization, Methodology, Data curation; **P. Dey:** Visualization, Supervision.

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