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Multi Dimensional Relative Vulnerability Assessment of Santhal Pargana, Jharkhand, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The concept of vulnerability is multifaceted, encompassing a range of socio-economic, environmental, and climatic elements that necessitate comprehensive analysis to fully grasp its implications for affected populations. The study employs a Fuzzy-AHP methodology to conduct a multi-dimensional relative vulnerability (Meteorological, Agricultural and Socio-economic) assessment in Santhal Pargana, located in Jharkhand. Notably, rainfall data from 1900 to 2020 revealed a downward trend. The findings of study indicate that Sahibganj exhibits the lowest vulnerability, while the Godda faces the highest risk. To validate the model's accuracy, we calculated the Area Under Curve (AUC), which yielded a value of 84.3, demonstrating the robustness of our assessment approach.

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Keywords: Rainfall trend; FUZZY-AHP; relative vulnerability; Santhal Pargana.

1. INTRODUCTION

India, with its diverse agro-climatic zones and large agrarian population, faces significant challenges in the context of climate change and agricultural vulnerability. The country has experienced a notable increase in average temperature, with the India Meteorological Department (IMD) reporting a rise of about 0.7°C over the past century (Krishnan et al. 2020).

Santhal Pargana, a division in the northeastern part of Jharkhand state, presents a microcosm of the broader challenges facing India's rural and tribal regions. This area, predominantly inhabited by the Santhal tribe and other indigenous communities, is characterized by its unique cultural heritage, rich biodiversity, and challenging socio-economic conditions. The meteorological scenario in Santhal Pargana reflects the broader trends observed across India, with some region-specific variations. Local climate data indicate a gradual increase in average temperatures and greater unpredictability in rainfall patterns over the past few decades. The region, which primarily relies on the southwest monsoon for agricultural activities, has experienced more frequent instances of delayed monsoon onset, prolonged dry spells, and intense rainfall events. Agriculture in Santhal Pargana is predominantly rain-fed and subsistence-oriented, making it highly vulnerable to climatic variations. The main crops cultivated include rice, maize, and various pulses. Traditional agricultural practices, while well-adapted to historical climate patterns, are increasingly challenged by the changing environmental conditions. Crop yields in the region have shown greater fluctuations in recent years, with some studies suggesting a decline in productivity for certain staple crops. The socio-economic landscape of Santhal Pargana is characterized by high poverty rates, low literacy levels, and limited access to modern agricultural technologies and market linkages. According to state government reports, a significant proportion of the population in this region lives below the poverty line, with tribal communities being particularly vulnerable. The heavy reliance on agriculture and forest resources for livelihoods makes the local economy highly sensitive to environmental changes.

Numerous studies have explored vulnerability by considering multiple dimensions and employing various methodologies. For instance, Goto et al. (2022) developed the Social Vulnerability Index (SoVI) using socioeconomic and demographic factors. Muleia et al. (2023) assessed climate change vulnerability in Mozambique, incorporating socio-economic, demographic, and health indicators. Williams et al. (2018) examined agricultural vulnerability in South Africa, combining biophysical and socio-economic factors. Pandey (2021) used a composite index approach to assess social and ecological vulnerability in Nepal. Derbile et al. (2022) employed a comprehensive evaluation method to analyze agricultural vulnerability in Ghana. Furlan et al. (2021) developed a multi-dimensional vulnerability assessment framework in the Italian coast, integrating meteorological, agricultural, and socio-economic factors. Sahoo & Bhaskaran (2018) used spatial multi-criteria analysis to assess coastal vulnerability in Odisha. Yang & Pan (2021) have tried to measure the rural vulnerability of China. Williams et al. (2020) used a livelihood vulnerability index to examine climate variability impacts on smallholder farming communities in Ghana. Lastly, Sathyan et al. (2018) have tried to measure a Climate vulnerability in rainfed farming. Kumar et al. (2024) have been analyzed a district wise climate vulnerability pattern in Madhya Pradesh, India based on the indicators of agricultural and socio-economy. Keeping the above in view, an attempt has been made to examine the relative vulnerability of Santhal Pargana, Jharkhand by considering meteorological, agricultural, and socio-economic factors.

1.1 Study Area

Santhal Pargana, a division in the northeastern part of Jharkhand, India. It consists of 6 districts. They are Sahibganj, Godda, Pakur, Dumka, Deoghar, Jamtara (Fig. 1). It experiences a subtropical climate characterized by hot summers and mild winters. The region typically sees temperatures ranging from about 10°C in winter to over 40°C in summer, with monsoon rains occurring between June and September. This climate pattern significantly influences agricultural practices in the area. The soil composition in Santhal Pargana varies, but it predominantly consists of red and laterite soils, which are generally less fertile and require careful management for productive agriculture. Some areas also feature alluvial soils near river basins, offering better cultivation prospects. Demographically, Santhal Pargana is known for its diverse population, with a significant presence of tribal communities, particularly the Santhals, after whom the region is named. The area has a predominantly rural population, with agriculture and forest-based activities being the primary sources of livelihood. The region faces challenges related to literacy, healthcare access, and economic development, which are common to many rural areas in Jharkhand. Despite these challenges, Santhal Pargana's unique cultural heritage and natural resources present opportunities for sustainable development and cultural preservation.

2. MATERIALS AND METHODS

2.1 Identification of Rainfall Trend by Mann-Kendall Test

The Mann-Kendall test compares each data point with subsequent values chronologically, tallying the instances of increases (+1), decreases (-1), and no changes (0). A positive Sen's slope suggests an increasing rainfall trend, while a negative value indicates a decreasing pattern, providing researchers with a reliable measure of precipitation changes over time.

2.2 Vulnerability Parameters

Table 1 outlines a comprehensive set of vulnerability parameters used in a research study, categorized into three main domains: Meteorological, Agricultural, and Socio-economic. It consists of 19 factors. This set of parameters suggests a multifaceted approach to assessing vulnerability, likely aimed at understanding the complex interplay between climate, agriculture, and socio-economic factors in the region.

2.3 Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

The fuzzy comparison matrices are synthesized using the extent analysis method, which involves calculating fuzzy synthetic extent values and the degree of possibility of dominance. The weights of criteria and alternatives are then derived by defuzzifying and normalizing these values. Finally, the global priorities are computed by aggregating the weights across the hierarchy, enabling decision-makers to rank alternatives and make informed choices while accounting for imprecision in human judgments.

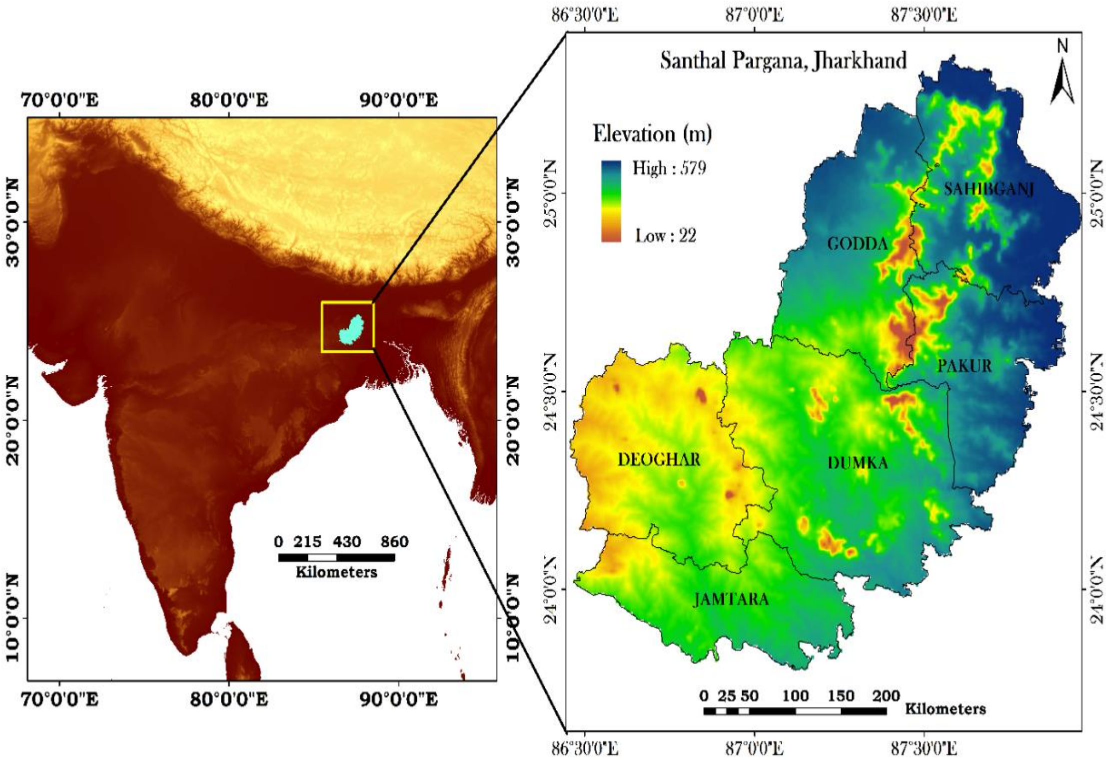

Fig. 1. Study area map

Table 1. Selected Parameters with their sources

Vulnerability	Parameters	Source
Meteorological	Rainfall	Indian Meteorological Department
	Temperature	Indian Meteorological Department
	Sen's slope of monsoon rainfall	Calculated
	Sen's slope of annual rainfall	Calculated
	No. of successive extreme drought year	Climate of Jharkhand, IMD
	No. of Excessive Rainfall Year	Climate of Jharkhand, IMD
Agricultural	Cultivable area	Agriculture contingency plan
	Net sown area	Agriculture contingency plan
	Net irrigated area	Agriculture contingency plan
	Cropping intensity	Agriculture contingency plan
	Forest area	Agriculture contingency plan
Socio-economic	Population density	Census of India 2011
	Health Index	Deogharia 2021
	Education Index	Deogharia 2021
	Income Index	Deogharia 2021
	ST Population	Census of India 2011
	Main worker (ST)	Census of India 2011
	Marginal worker (ST)	Census of India 2011
	Non worker (ST)	Census of India 2011

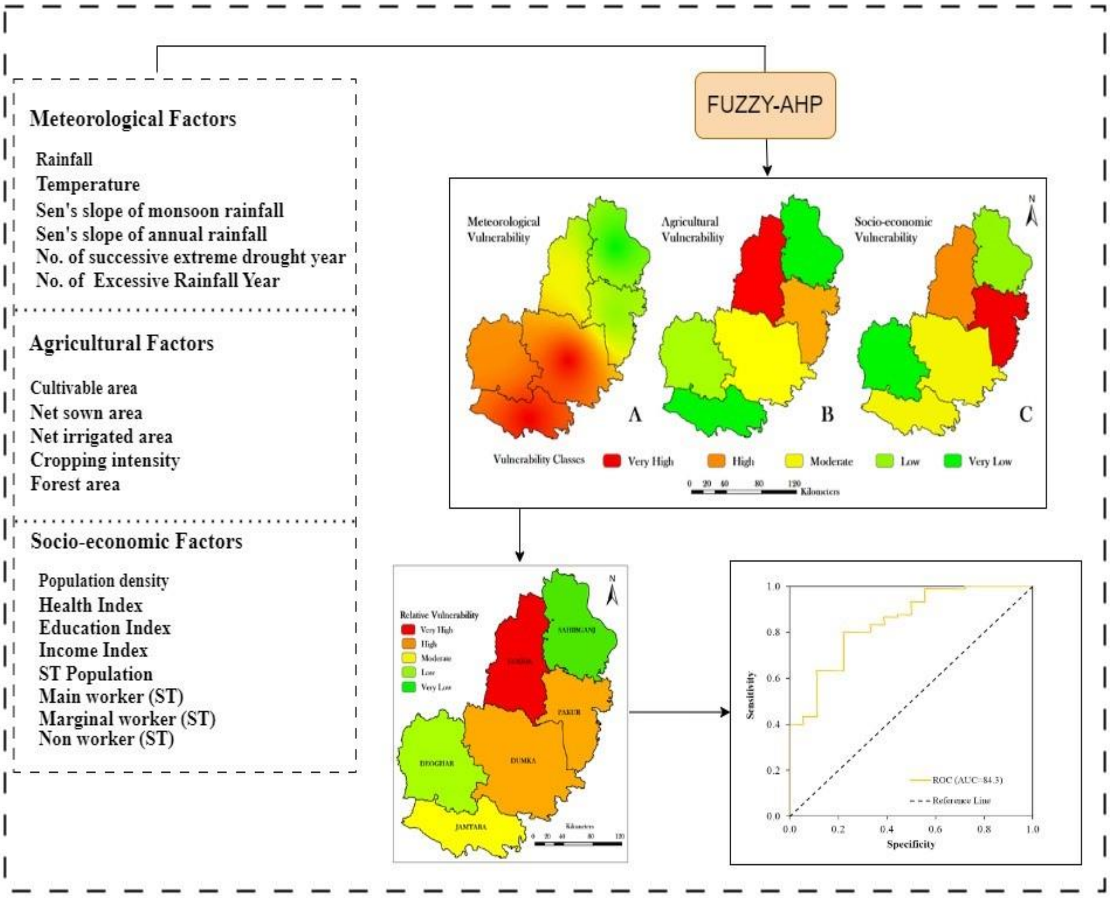

Fig. 2. Methodological framework

2.4 Area Under Curve (AUC)

The Area Under the Curve (AUC) methodology involves plotting the Receiver Operating Characteristic (ROC) curve and calculating the area beneath it (Richardson et al. 2024). It is created by graphing the true positive rate against the false positive rate at various classification thresholds. To compute the AUC, we integrate the ROC curve from 0 to 1 using numerical methods such as the trapezoidal rule. The resulting value, ranging from 0 to 1, quantifies the model's ability to distinguish between classes. A higher AUC indicates better classification performance, with 1.0 representing perfect discrimination and 0.5 equivalent to random guessing. This metric is particularly useful for evaluating binary classifiers and comparing different models' performance.

3. RESULTS AND DISCUSSION

3.1 Trend of Annual Rainfall Assessed by Mann-Kendall Test

The analysis of long-term rainfall trends from 1900 to 2020 across six districts in Table 2 (Fig. 3) revealed a consistent pattern of declining precipitation, as indicated by negative Sen's slope values throughout the region. Jamtara district exhibited the most dramatic decrease with a Sen's slope of -2.85, signifying a substantial reduction in rainfall over the 120year. This was followed by the Godda and Dumka districts, which showed moderate declines with slopes of -0.316 and -0.264, respectively. Deoghar displayed a similar trend with a slope of -0.26, while Pakur and Sahibganj demonstrated relatively milder, yet still noteworthy, decreases with slopes of -0.203 and -0.148, respectively. The findings of the study collectively suggest a significant shift in the precipitation patterns across the region, with potential implications for water resources, agriculture, and local ecosystems.

3.2 Data Layers

Data layers under different dimensions have been prepared in the ArcGIS environment and presented in Figs. 4, 5, and 6.

3.3 Meteorological, Agricultural and Socio-economic Vulnerability

Sahibganj is classified as having very low vulnerability, while Pakur falls into the low vulnerability category. Godda is identified as having moderate vulnerability. Deoghar is categorized as highly vulnerable. Finally, Dumka and Jamtara are grouped together in the very high vulnerability class (Fig. 7A).

Sahibganj and Jamtara are identified as having very low agricultural vulnerability, suggesting they may have more resilient agricultural systems or favorable conditions. Deoghar is classified as having low vulnerability, while Dumka falls into the moderate category. Pakur is designated as highly vulnerable, indicating it may face significant challenges in its agricultural sector. Finally, Godda is classified as having very high agricultural vulnerability, implying it could be the most susceptible to agricultural risks or stresses among the listed districts (Fig. 7B)

Deoghar is classified as having very low vulnerability, while Sahibganj is categorized as low. Dumka and Jamtara fall into the moderate vulnerability class. Godda is classified as having high vulnerability, and Pakur is identified as the most vulnerable district with a very high classification (Fig. 7C). It provides a snapshot of the relative socio-economic conditions across these districts, potentially highlighting areas that may require more focused attention or resources to address underlying vulnerabilities.

3.4 Relative Vulnerability

Sahibganj is identified as having very low vulnerability, while Deoghar falls into the low vulnerability category. Jamtara is classified as moderately vulnerable. Two districts, Pakur and Dumka, are designated as highly vulnerable. Finally, Godda stands out as the only district in the very high vulnerability class.

3.5 Validation

A value of 84.3% suggests that the model correctly ranks a randomly chosen vulnerable entity higher than a randomly chosen non-vulnerable entity 84.3% of the time. This high AUC value demonstrates the model's robust discriminatory power in assessing relative vulnerability. It implies that the model effectively captures the factors contributing to vulnerability and can reliably identify at-risk entities. This performance metric supports the model's validity and potential utility in vulnerability assessment and risk management applications.

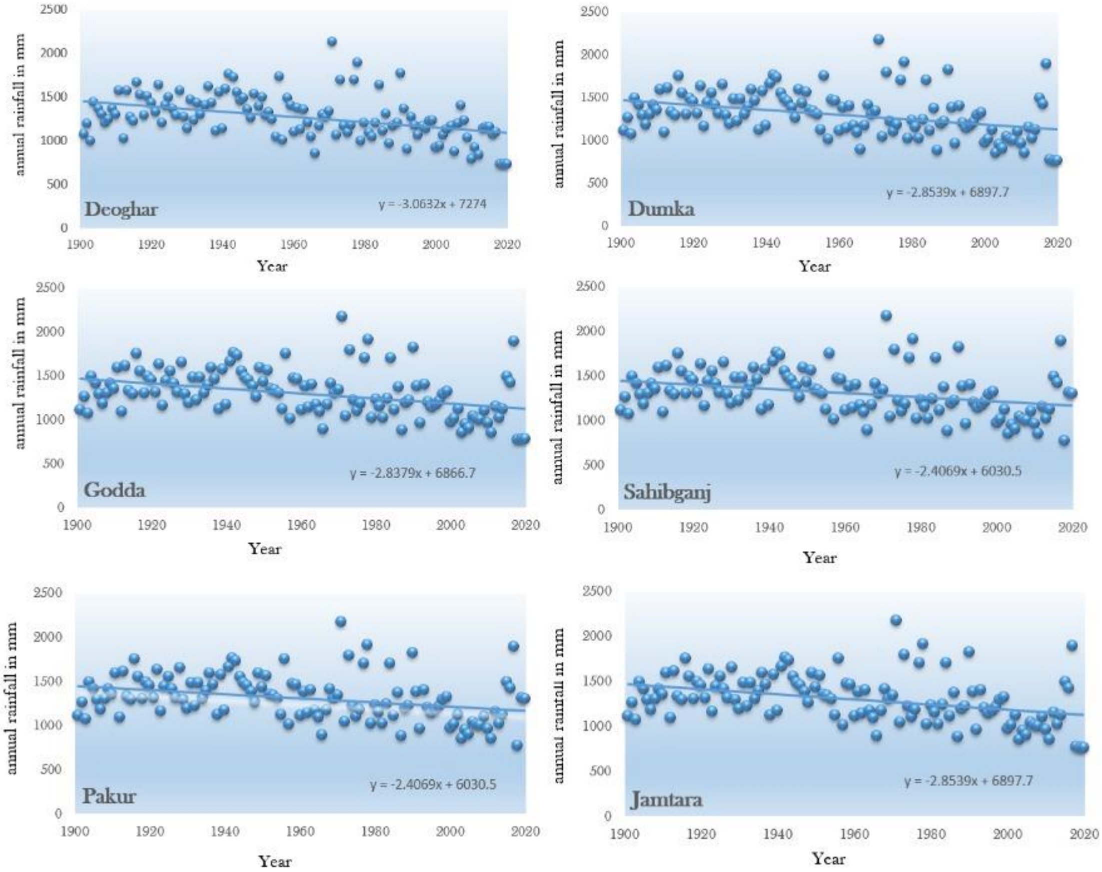

Fig. 3. Trend of rainfall in different districts of Santhal pargana

Meteorological Factors:

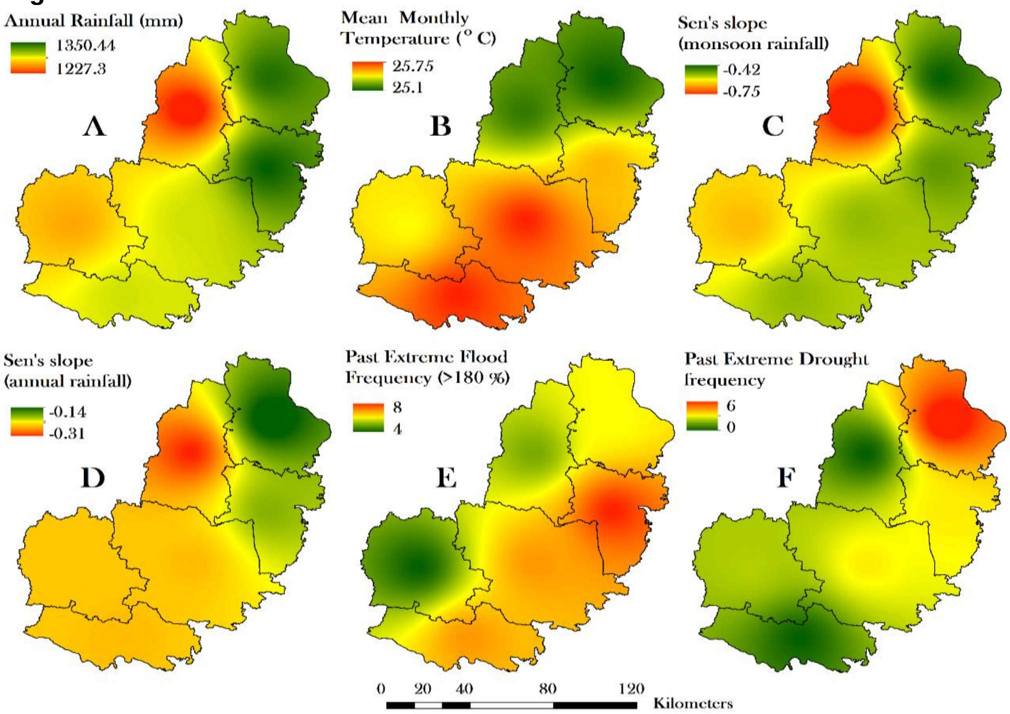

Fig. 4. Meteorological vulnerability factors

Agricultural Factors:

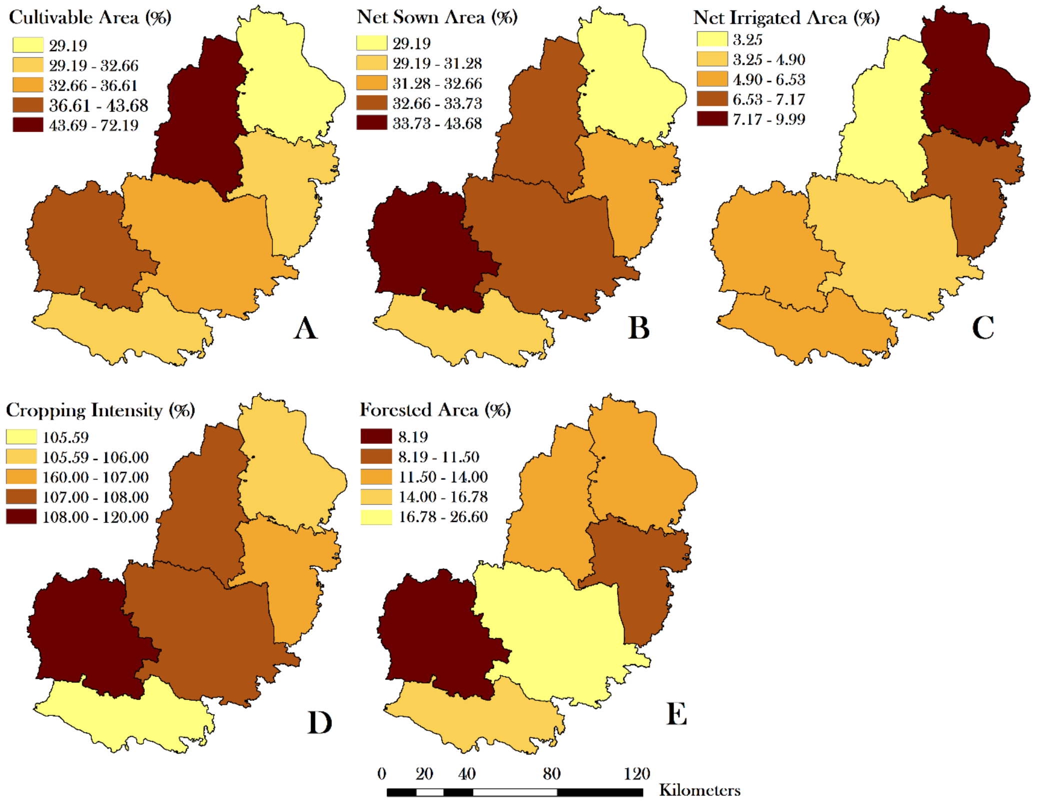

Fig. 5. Agricultural vulnerability factors

Socio-economic Factors:

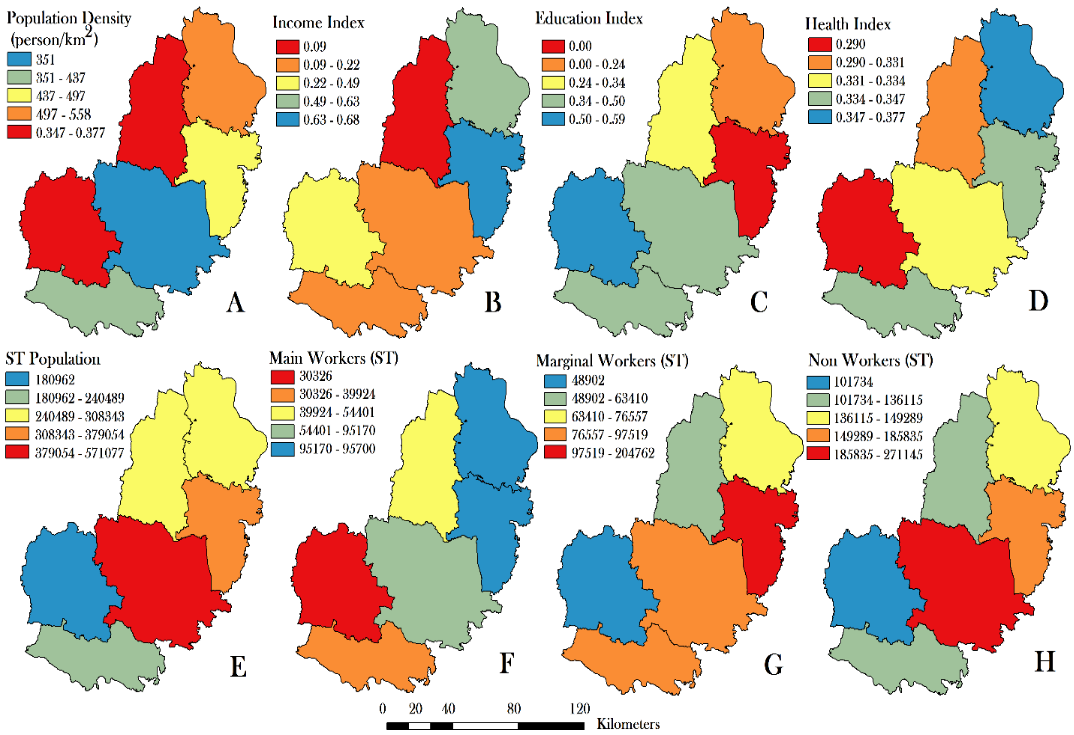

Fig. 6. Socio-economic vulnerability factors

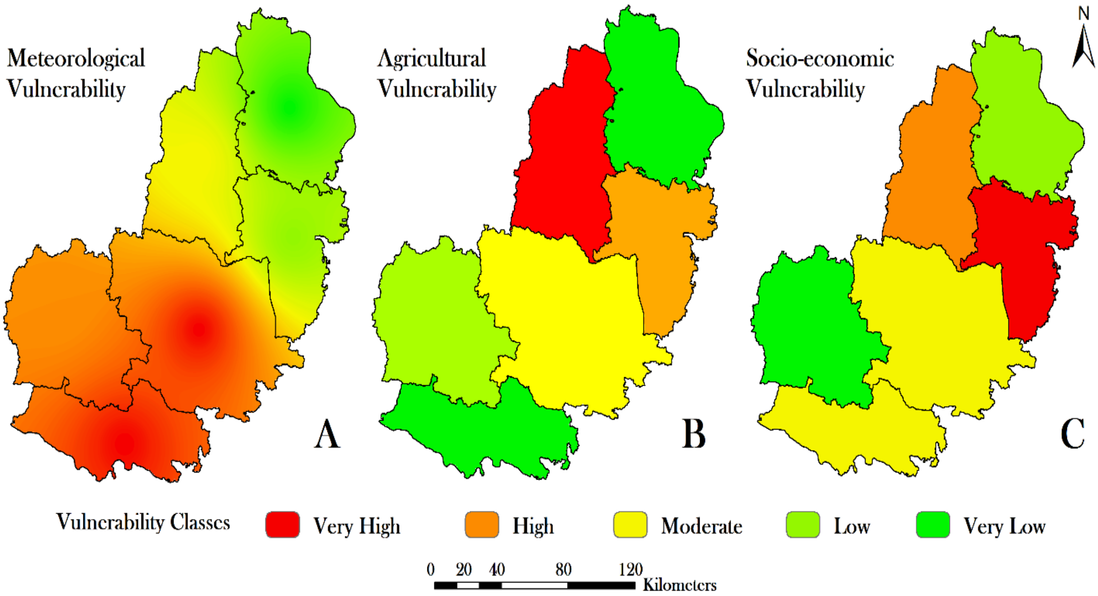

Fig. 7. Meteorological, agricultural and socio-economic vulnerability maps

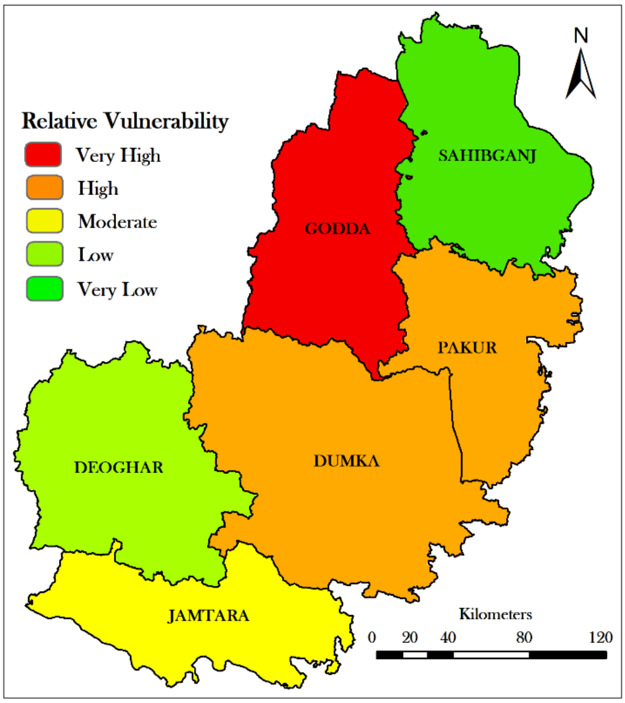

Fig. 8. Relative vulnerability map

Table 2. Value of Sen's slope

Rainfall data from 1900 to 2020			
Districts	**Sen's slope**	**Districts**	**Sen's slope**
Sahibganj	-0.148	Deoghar	-0.26
Godda	-0.316	Dumka	-0.264
Pakur	-0.203	Jamtara	-2.85

4. CONCLUSION

This study presents a thorough evaluation of vulnerabilities in Santhal Pargana, offering crucial information to guide targeted interventions and inform policy decisions. Analysis of study indicated notable disparities in vulnerability among the region's six districts. Notably, Godda emerged as an area of urgent concern, exhibiting extremely high vulnerability levels followed by Pakur. In contrast, Sahibganj demonstrated considerably lower vulnerability, suggesting greater resilience followed by Deoghar. A concerning trend of decreasing rainfall over the last hundred years highlights the necessity for region-wide adaptation strategies. The reliability of our findings is supported by a high Area Under Curve (AUC) value of 84.3%, validating the effectiveness of our chosen Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) methodology for assessing vulnerability. To build upon this work, we recommend that future studies explore temporal changes and incorporate a wider range of socio-economic and environmental factors to deepen our comprehension of vulnerability patterns in Santhal Pargana.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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