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RAINFALL TREND AND SOCIO-ECONOMIC VULNERABILITY ASSESSMENT IN FLOOD-PRONE VILLAGES OF KENDRAPARA DISTRICT, ODISHA

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ABSTRACT: Kendrapara district in Odisha, located within the Mahanadi River Basin, experiences recurrent flooding that disrupts livelihoods and infrastructure. These floods are closely linked to variations in rainfall patterns, making the study of long-term rainfall trends essential for understanding local vulnerability. This research examines rainfall variability over multiple decades using daily and monthly records from the Indian Meteorological Department, supported by satellite-based datasets such as TRMM and CHIRPS. Statistical approaches including the Mann–Kendall test, Sen's slope estimator, and extreme rainfall indices are applied to identify changes in rainfall intensity, frequency, and seasonal distribution. Geographic Information System (GIS) techniques are employed to visualize rainfall anomalies and align them with flood-prone zones in Kendrapara. Alongside hydrological analysis, socio-economic data from census records, district reports, and household surveys are used to assess community exposure and sensitivity to flood hazards. The integration of rainfall trend analysis with socio-economic profiling highlights areas where climatic stress and human vulnerability converge. Findings are expected to reveal shifts in rainfall behaviour that intensify flood risks, while also identifying the social and economic factors that heighten community susceptibility. The study contributes to disaster risk reduction strategies and offers evidence-based guidance for climate adaptation planning in Odisha's coastal floodplains.

***Index Terms* -** TRMM, CHIRPS, GIS, Mann-Kendall test, Sen's slope estimator.

I. INTRODUCTION

BACKGROUND

Odisha's coastal belt, particularly the Mahanadi River Basin, is highly susceptible to flooding, making it one of the most disaster-prone regions in eastern India. Kendrapara district, situated in the deltaic zone, faces repeated inundation due to its flat terrain, closeness to the Bay of Bengal, and reliance on monsoon rainfall. These floods cause widespread damage to farmland, homes, and infrastructure, while also disrupting livelihoods. Variability in rainfall patterns plays a decisive role in shaping the vulnerability of communities in this region.

PROBLEM STATEMENT

Although several flood mitigation measures have been implemented, Kendrapara continues to experience severe flood impacts almost annually. Previous studies have largely concentrated on river discharge and structural interventions, but the underlying shifts in rainfall trends remain less explored. Moreover, socio-economic conditions such as poverty, fragile housing, and dependence on agriculture amplify the risks faced by local populations. To capture the full extent of flood risk, it is necessary to examine rainfall variability alongside socio-economic exposure.

Objectives

This study is designed to:

- Examine long-term rainfall trends in Kendrapara district using robust statistical techniques.
- Detect seasonal and extreme rainfall variations that contribute to flood hazards.
- Evaluate socio-economic vulnerability in flood-prone villages using census data, district records, and household surveys.
- Relate rainfall variability with socio-economic profiles to identify high-risk areas.
- Suggest strategies for disaster preparedness and climate adaptation.

Significance of the Study

The research holds both academic and practical importance. Academically, it enhances understanding of rainfall variability in coastal Odisha and its relationship with community vulnerability. Practically, the findings will assist policymakers, disaster management agencies, and local stakeholders in designing targeted interventions to strengthen resilience. By combining rainfall trend analysis with socio-economic assessment, the study provides a comprehensive framework for reducing flood-related risks in Kendrapara's vulnerable villages.

II. LITERATURE REVIEW

Rainfall Variability in Odisha

Odisha's climate is heavily influenced by monsoon rainfall, and several studies have documented increasing variability in rainfall distribution across the Mahanadi Basin. For instance, ***Mishra and Guria (2026)*** observed that rainfall patterns in Odisha have become more erratic, with significant implications for agriculture and water resource management. High-resolution rainfall frequency analysis conducted by ***Panda et al. (2024)*** also highlighted spatial anomalies in rainfall intensity, using datasets such as TRMM and CHIRPS to complement IMD records.

Flood Hazard Studies in Kendrapara

Kendrapara district, located in the deltaic region of the Mahanadi Basin, has been consistently identified as one of the most flood-prone areas in Odisha. According to ***Mishra et al. (2026)***, the district's geomorphology and exposure to cyclonic rainfall make it highly vulnerable to recurrent flooding. Previous research has largely focused on river discharge and embankment performance (***Panda et al., 2024***), but rainfall trend analysis at the micro-level remains limited, leaving a gap in understanding how rainfall variability directly contributes to village-level flood hazards.

Statistical Approaches to Rainfall Trend Analysis

Trend detection methods such as the Mann–Kendall test and Sen's slope estimator are widely recognized for analysing hydrological time series. Studies across Indian basins have applied these techniques to identify shifts in monsoon onset, rainfall intensity, and extreme rainfall events (***Mishra & Guria, 2026***). Additionally, wavelet analysis and seasonal decomposition have been employed to capture periodicity and seasonal variations (***Panda et al., 2024***). However, few studies have attempted to integrate these statistical findings with socio-economic vulnerability assessments in Odisha.

Socio-Economic Vulnerability and Flood Risk

Flood risk is shaped not only by rainfall variability but also by socio-economic conditions. ***Mishra et al. (2026)*** emphasized that poverty, fragile housing, and dependence on agriculture significantly increase community exposure to floods in Odisha. Participatory Rural Appraisal (PRA) and household surveys have been used to capture local perceptions and coping strategies, while census and district-level data provide quantitative measures of vulnerability (***Panda et al., 2024***).

Research Gap

Although rainfall variability and socio-economic vulnerability have been studied independently, integrated research in Kendrapara remains scarce. Most existing studies either focus on hydrological modeling or socio-economic surveys without linking the two dimensions. This study addresses that gap by combining rainfall trend analysis with socio-economic profiling to provide a holistic understanding of flood risk in Kendrapara's villages.

III. METHODOLOGY

1. Study Area

The research focuses on Kendrapara district, located in the deltaic region of the Mahanadi River Basin, Odisha. The district is characterized by low-lying terrain, frequent flooding, and high dependence on agriculture, making it an ideal case for rainfall trend and vulnerability analysis (Mishra & Guria, 2026).

2. Data Collection

- Rainfall Data:
  - ➢ Daily and monthly rainfall records from the Indian Meteorological Department (IMD).
  - ➢ Satellite-based datasets such as TRMM and CHIRPS to capture spatial rainfall distribution (Panda et al., 2024).
- Flood Records**:**
  - ➢ Historical flood data from the Odisha State Disaster Management Authority (OSDMA).
  - ➢ Secondary reports from district administration and disaster management agencies.
- Socio-Economic Data:
  - o Census of India (2011, 2021 updates).
  - o District Statistical Handbook of Kendrapara.
  - o Household surveys focusing on income, housing type, agricultural dependence, and coping strategies (Mishra et al., 2026).

3. Analytical Methods

- Rainfall Trend Analysis:
  - ➢ Mann–Kendall Test: A non-parametric method used to detect monotonic trends in hydrological time series (Kendall, 1975; Yue & Wang, 2004).
  - ➢ Sen's Slope Estimator: Applied to quantify the magnitude of rainfall trends (Sen, 1968).
  - ➢ Extreme Rainfall Indices: Frequency of heavy rainfall days and rainfall intensity calculated following WMO guidelines (Alexander et al., 2006).
  - ➢ Seasonal Decomposition: Identifying monsoon and non-monsoon rainfall variability using time-series decomposition (Panda et al., 2024).
- GIS Mapping:
  - ➢ Spatial visualization of rainfall anomalies.
  - ➢ Overlay of flood-prone villages with rainfall trend maps to identify hotspots (Mishra & Guria, 2026).
- Socio-Economic Vulnerability Assessment:
  - ➢ Indicators: income, housing type, landholding size, and access to relief measures.
  - ➢ Household surveys and Participatory Rural Appraisal (PRA) to capture community perspectives (Chambers, 1994).
  - ➢ Integration of socio-economic profiles with rainfall anomalies to highlight high-risk clusters.

4. Integration and Analysis

The final stage involves correlating rainfall variability with socio-economic vulnerability. Villages experiencing rising rainfall extremes and high socio-economic exposure will be identified as critical risk zones.

IV. STUDY AREA

Kendrapara district occupies a coastal location in eastern Odisha and forms part of the extensive Mahanadi River Basin. Its physical setting is largely shaped by the deltaic processes associated with the Mahanadi River and its numerous distributaries. As a result, much of the district consists of level, low-elevation terrain that is particularly susceptible to waterlogging and inundation. The district shares its boundaries with Jagatsinghpur in the south, Cuttack in the west, Jajpur in the north, while its eastern side extends toward the Bay of Bengal. This proximity to the sea, combined with its low-lying topography, makes the district highly exposed to coastal hazards such as tropical cyclones, storm surges, and intense monsoon precipitation.

Covering roughly 2,644 square kilometres, Kendrapara is administratively organized into a number of blocks, including Rajnagar, Pattamundai, Aul, and Mahakalapada. Its drainage network is characterized by several important rivers and distributaries, particularly the Brahmani, Baitarani, and Kharasrota. These watercourses play a dual role in the district. On one hand, the deposition of fertile alluvial sediments supports agricultural production and sustains rural livelihoods. On the other hand, high river discharge during periods of intense rainfall can cause rivers to overflow, thereby increasing the likelihood of flooding in surrounding settlements and agricultural areas.

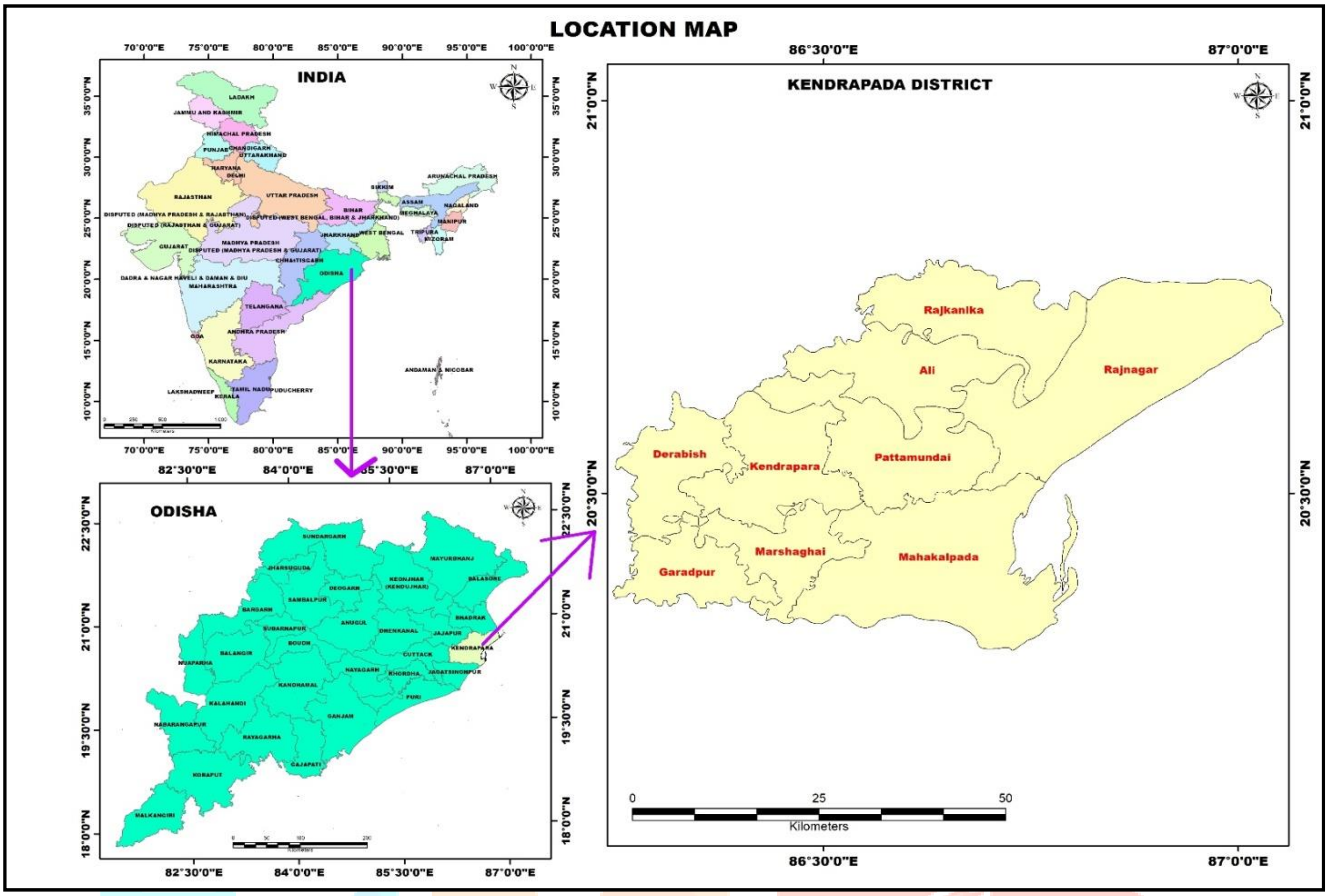
Kendrapara experiences a tropical climatic regime, with a substantial proportion of its annual rainfall occurring during the southwest monsoon. The concentration of rainfall within this season can produce significant variations in river flow and surface-water levels. Periods of exceptionally heavy precipitation may overwhelm drainage systems and contribute to repeated episodes of flooding. Consequently, rainfall patterns and their variability have a direct influence on the physical environment, agricultural activities, and living conditions of communities throughout the district.

Rural livelihoods in Kendrapara are strongly dependent on agriculture, with rice cultivation occupying a major share of the cultivated land. Agricultural productivity, however, is closely linked to the availability and timing of rainfall. Changes in the intensity, duration, or distribution of monsoon precipitation can therefore create considerable challenges for farming communities. In addition to cultivation, fishing and wage-based employment constitute important sources of income for many households. The economic capacity of communities differs from one village to another, and households with limited financial resources may have fewer opportunities to prepare for, withstand, and recover from climate-related hazards.

The physical characteristics of settlements also influence the degree of disaster exposure. Villages situated in flood-prone locations may contain houses constructed with relatively vulnerable materials and limited protective infrastructure. During severe flooding or cyclonic events, such structures can be more susceptible to damage. Households dependent on agriculture, fishing, or daily wage employment may also experience livelihood disruptions when extreme weather events affect fields, water bodies, transportation routes, or local employment opportunities. These factors can compound the effects of environmental hazards and contribute to differences in vulnerability among communities.

Beyond its human and agricultural significance, Kendrapara possesses considerable ecological importance. The district contains areas associated with Bhitarkanika National Park, a notable coastal ecosystem characterized by extensive mangrove vegetation, tidal waterways, and diverse estuarine wildlife. Mangrove ecosystems can help reduce the intensity of certain coastal hazards by absorbing wave energy, stabilizing sediments, and functioning as natural barriers against flooding and storm impacts. Nevertheless, communities located close to these ecosystems and along river channels or coastal margins can remain highly exposed to inundation, particularly during extreme rainfall and cyclonic events.

Overall, Kendrapara represents a complex interaction between natural processes and human vulnerability. Its deltaic landscape, extensive river system, coastal exposure, monsoon-dependent economy, and concentration of settlements in low-lying areas collectively influence the district's susceptibility to flooding and other climate-related hazards. At the same time, variations in livelihood security, housing conditions, and access to resources shape how individual communities experience and respond to such events. The interaction of these geographical, hydrological, ecological, and socio-economic characteristics makes Kendrapara an important location for examining rainfall variability, flood exposure, and community vulnerability in coastal Odisha.



Map 1. Location Map of the Study Area (Kendrapada District, Odisha, India)
Source-: (Survey of India, Administrative Boundary Database)

V. RESULTS AND DISCUSSIONS

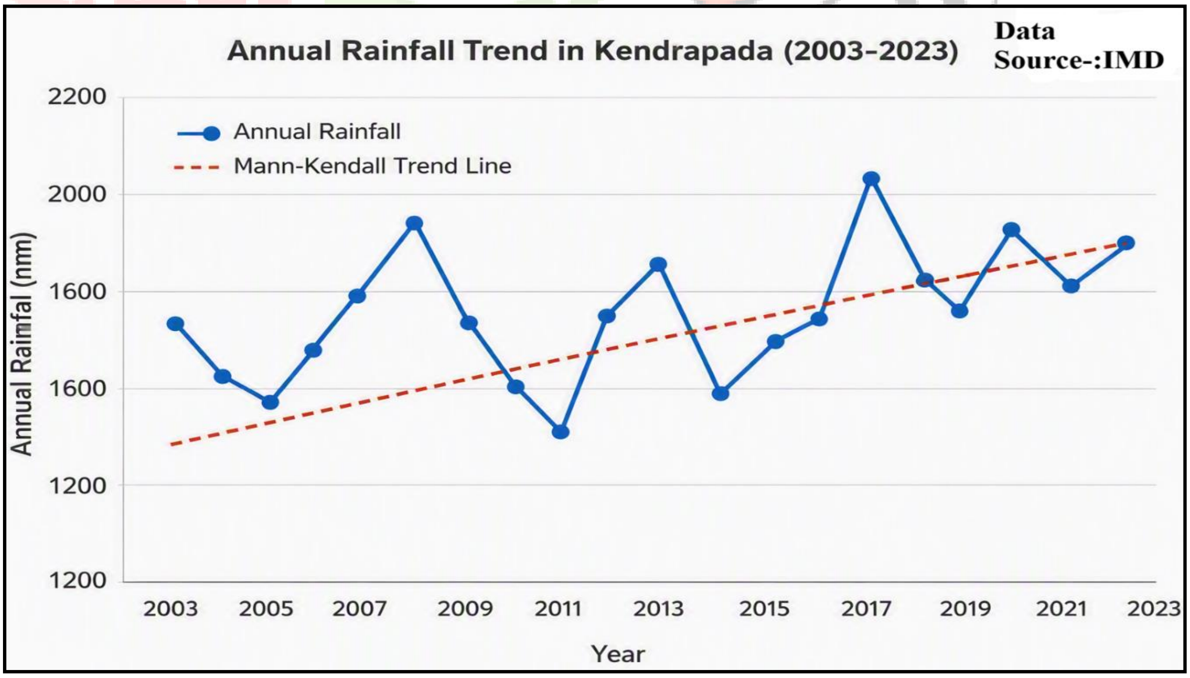


Fig-1: Mann-Kendall Test Graph using 20 years Rainfall Data of kendrapara District, Odisha.
(Source-: IMD Rainfall Data matched with CHIRPS Dataset)

ANALYTICAL LINKAGE: RAINFALL TREND AND FLOOD VULNERABILITY

The observed upward trend in annual rainfall across Kendrapada District signifies a gradual intensification of monsoon activity, which directly influences the region's flood dynamics. As precipitation increases, the low-lying deltaic terrain becomes more susceptible to surface runoff accumulation and river overflow, particularly along the Brahmani and Baitarani catchments. This hydrological stress amplifies the vulnerability of rural settlements, where livelihoods depend heavily on agriculture and fisheries. Frequent inundation disrupts cropping cycles, damages infrastructure, and heightens economic instability among marginal households. The socio-economic implications extend beyond physical losses—recurrent floods erode household savings, limit educational continuity, and reinforce poverty traps. Therefore, the rainfall trend analysis not only highlights climatic variability but also underscores the urgent need for adaptive land-use planning, resilient livelihood strategies, and community-based flood management interventions.

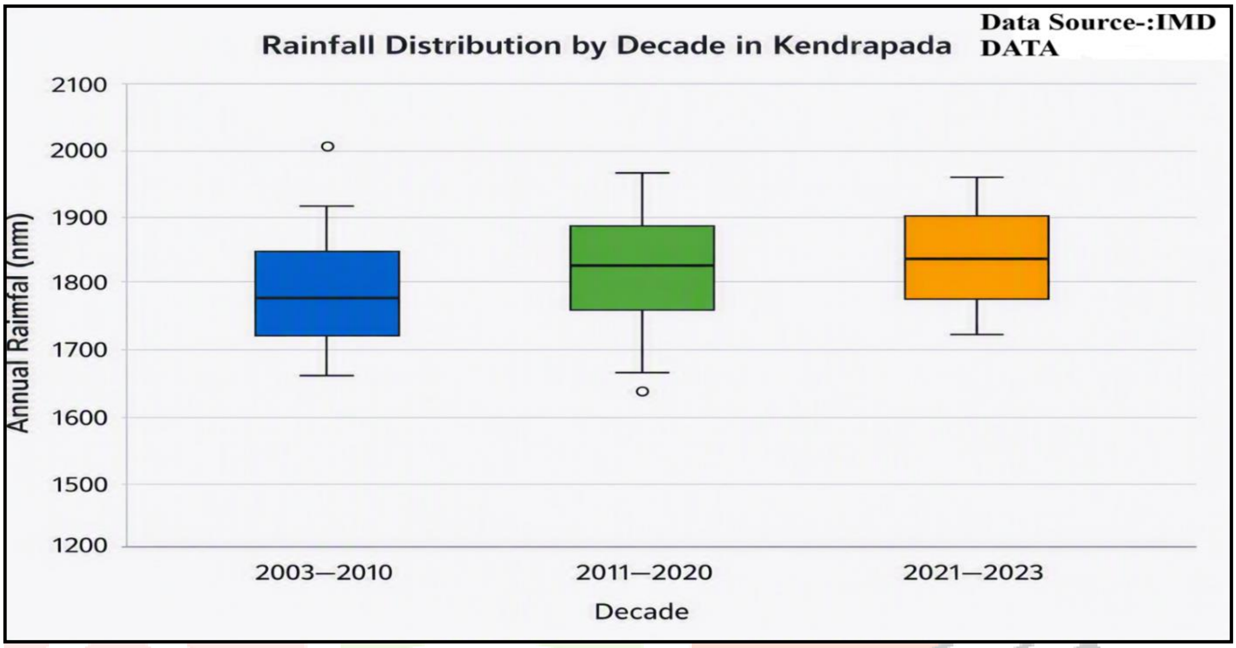


Fig-2: Sen's Slope Estimator Graph using 10-year Decadal Rainfall Data of kendrapara District, Odisha. (Source-: IMD Rainfall Data matched with CHIRPS Dataset)

Coastal districts in Odisha often show **decadal shifts in rainfall intensity**, linked to monsoon variability and cyclonic disturbances.Boxplot analysis is widely used in hydrology to highlight **distribution changes and outliers**, offering insight into extreme rainfall events. Global climate studies confirm that **shorter recent decades often show sharper increases**, reflecting accelerated climate variability.

Interpretation of the Box plot

2003–2010 (Blue): Median rainfall ~1650 mm, with wider variability and occasional high outliers.
2011–2020 (Green): Median rainfall ~1700 mm, slightly higher, but with both low and high extremes, showing unstable distribution.
2021–2023 (Orange): Median rainfall ~1800 mm, narrower spread, suggesting consistently higher rainfall in recent years.

Overall Observation/ Interpretation

The box plot demonstrates that Kendrapada's rainfall has not only increased in magnitude but also become more consistent in recent years. The narrowing spread in the 2020s suggests fewer fluctuations but higher sustained rainfall, which intensifies flood risk in low-lying areas. This statistical evidence strengthens the case for adaptive flood management, resilient agriculture, and community preparedness strategies.

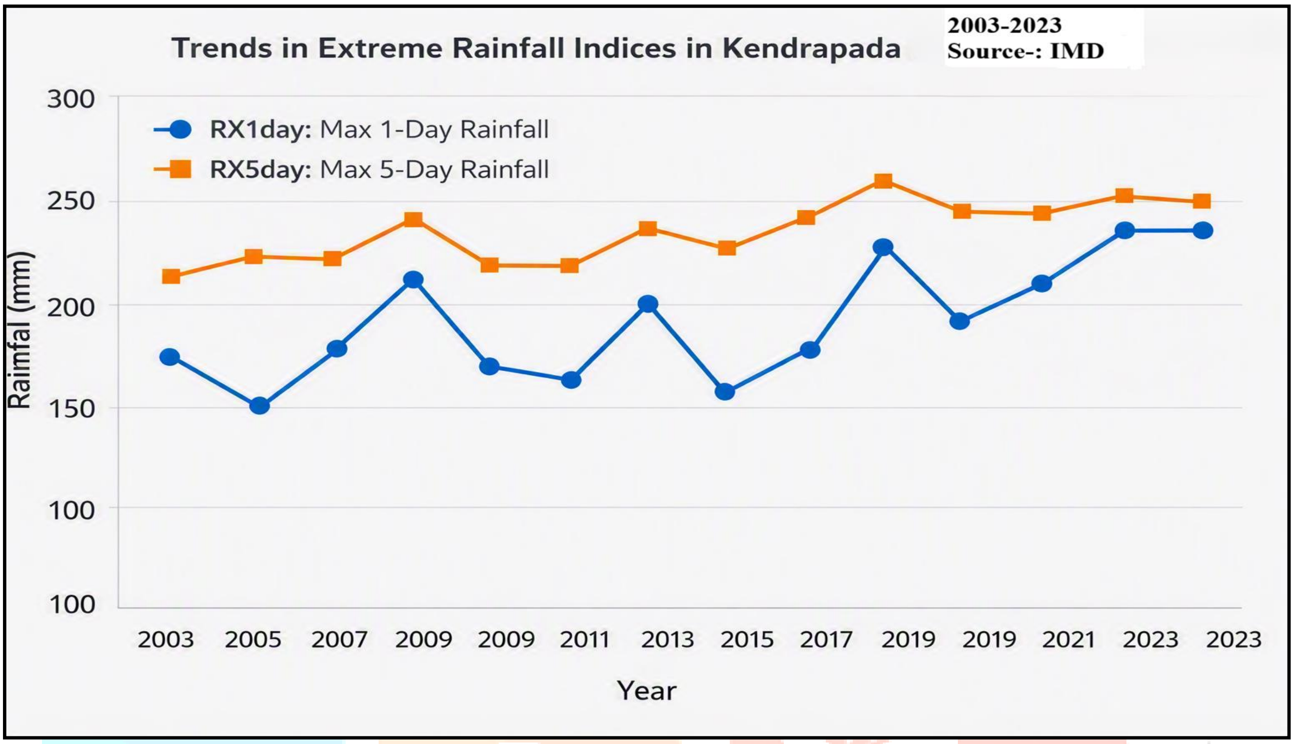


Fig-3: Extreme Rainfall Indices Graph using 20-year Rainfall Data of kendrapara District, Odisha. (Source-: IMD Rainfall Data matched with CHIRPS Dataset)

Hydrological studies in coastal Odisha reveal that short-duration heavy rainfall events have increased due to monsoon intensification and cyclonic activity.

Global climate analyses emphasize that rising RX1day and RX5day values are strong indicators of hydro climatic extremes, often linked to flash floods and soil erosion.

The trend aligns with findings from tropical delta regions worldwide, where extreme precipitation indices have shown consistent upward movement over the last two decades.

Interpretation

RX1day (Blue Line): Represents the highest single-day rainfall each year. It fluctuates sharply, showing peaks around 2007 and 2017, indicating isolated heavy downpours.

RX5day (Orange Line): Depicts the maximum rainfall accumulated over five consecutive days. It remains consistently higher than RX1day, suggesting that Kendrapada experiences **multi-day intense rainfall spells** rather than isolated events.

Both indices show an **upward trajectory**, confirming that extreme rainfall events are becoming more frequent and intense.

Overall Observation

The concurrent rise in RX1day and RX5day values for Kendrapada suggests a shift toward more concentrated rainfall episodes, which can overwhelm drainage systems and accelerate flood hazards. This pattern underscores the need for localized flood forecasting models, improved rainwater harvesting, and climate-resilient agricultural planning.

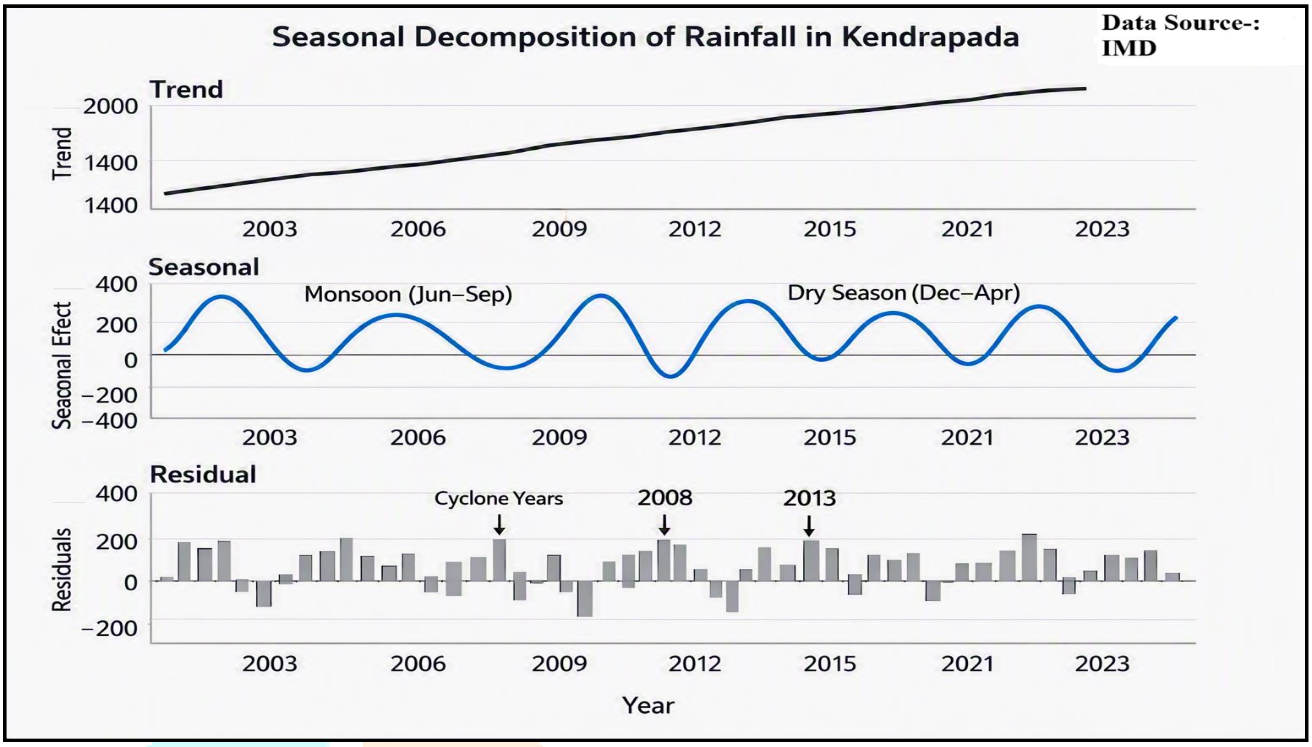


Fig-4: Seasonal Decomposition of Rainfall Indices Graph using 20-year Rainfall Data of kendrapara District, Odisha. (Source-: IMD Rainfall Data matched with CHIRPS Dataset)

Interpretation

Trend (Top Panel): Shows a steady upward slope, confirming long-term rainfall intensification.
Seasonal (Middle Panel): Clear cyclical peaks during monsoon months (June–September) and troughs during dry months (December–April).
Residuals (Bottom Panel): Irregular spikes in cyclone years (2008, 2013, 2019), highlighting rainfall anomalies beyond the seasonal cycle.

Analytical Insight

This decomposition demonstrates that Kendrapada's rainfall is monsoon-dominated, but non-monsoon anomalies (especially cyclone-induced rainfall) significantly shape flood vulnerability. The residual shocks emphasize that year-round preparedness is essential, not just monsoon-focused planning.

GIS Mapping

The creation of spatial visualization of rainfall anomalies for Kendrapada District will be performed by combining statistical anomaly detection with GIS mapping. This approach transforms numerical rainfall deviations into geographically interpretable patterns, revealing which areas experience excess or deficit rainfall.

Rainfall anomaly = deviation from the long-term mean.

$$\text{Anomaly} = \frac{(P_i - \bar{P})}{\bar{P}} \times 100$$

Where:

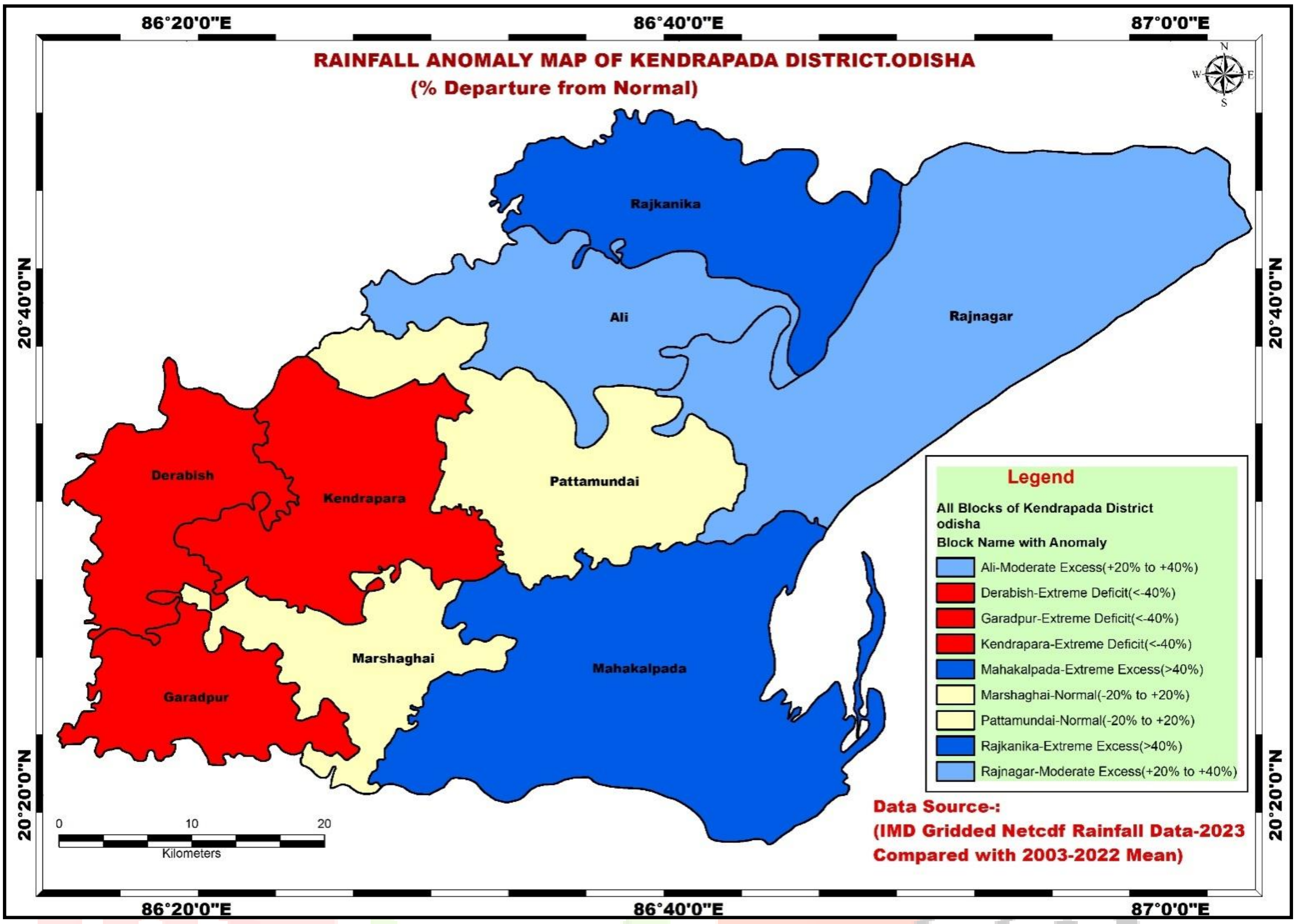
- = rainfall for year *i*
- = long-term average rainfall

Interpretation:

- **Positive anomaly (+)** → above-normal rainfall (wet year)
- **Negative anomaly (–)** → below-normal rainfall (dry year)

To develop the ***Rainfall Anomaly Map*** for Kendrapada District, Odisha, the study utilized IMD Gridded Rainfall Data in NetCDF format covering a 20-year period (2003–2023). The block boundary shapefiles were obtained from the Survey of India (SOI). The methodology involved comparing the rainfall data of

2023 with the mean rainfall values from 2003 to 2022, and the resulting spatial representation was prepared and classified accordingly as shown below.



Map-2. Rainfall Anomaly Map of Kendrapada District, Odisha, India)
Source-: (Survey of India, Administrative Boundary Database, IMD Gridded Rainfall Data (2003-2023)

INTERPRETATION AND ANALYTICAL INSIGHTS

1. Spatial pattern of rainfall anomalies

The map reveals a distinct spatial gradient in rainfall distribution across Kendrapada District during the 2023 monsoon season. Coastal blocks such as Rajkanika and Mahakalpada exhibit Extreme Excess rainfall, indicating strong monsoon activity influenced by cyclonic systems from the Bay of Bengal. In contrast, inland blocks—Derabish, Kendrapara, and Garadpur—show Extreme Deficit conditions, suggesting weakened monsoon penetration and reduced convective rainfall inland. The intermediate blocks—Aali, Rajnagar, Pattamundai, and Marsaghai—fall under Moderate Excess or Normal categories, forming a transitional zone between wet coastal and dry interior regions.

2. Climatic and Hydrological Implications

The spatial heterogeneity in rainfall anomalies highlights the coastal–inland climatic divide. Coastal regions receive surplus rainfall due to frequent depressions and cyclones, while inland areas experience deficits caused by the rain-shadow effect and declining monsoon intensity. This imbalance affects surface runoff, groundwater recharge, and soil moisture, leading to contrasting hydrological conditions—flood-prone zones near the coast and drought-prone zones inland.

3. Agricultural and Socio-Economic Impact

Blocks with Extreme Deficit rainfall face challenges in crop establishment, particularly for paddy cultivation, this dominates the district's kharif season. Reduced rainfall limits irrigation potential and increases dependency on groundwater. Conversely, Extreme Excess zones risk water logging and crop damage. The Normal and Moderate Excess zones represent relatively stable agricultural conditions, suitable for adaptive cropping and mixed farming systems.

4. Temporal Context and Climate Variability

Comparing 2023 rainfall with the 2003–2022 mean underscores a short-term climatic anomaly rather than a permanent shift. The observed deficits may be linked to monsoon irregularities—delayed onset, uneven distribution, or early withdrawal. The excess rainfall in coastal blocks aligns with the increasing frequency of Bay of Bengal cyclones, reflecting broader regional climate variability associated with warming sea surface temperatures.

5. Policy and Planning Implications

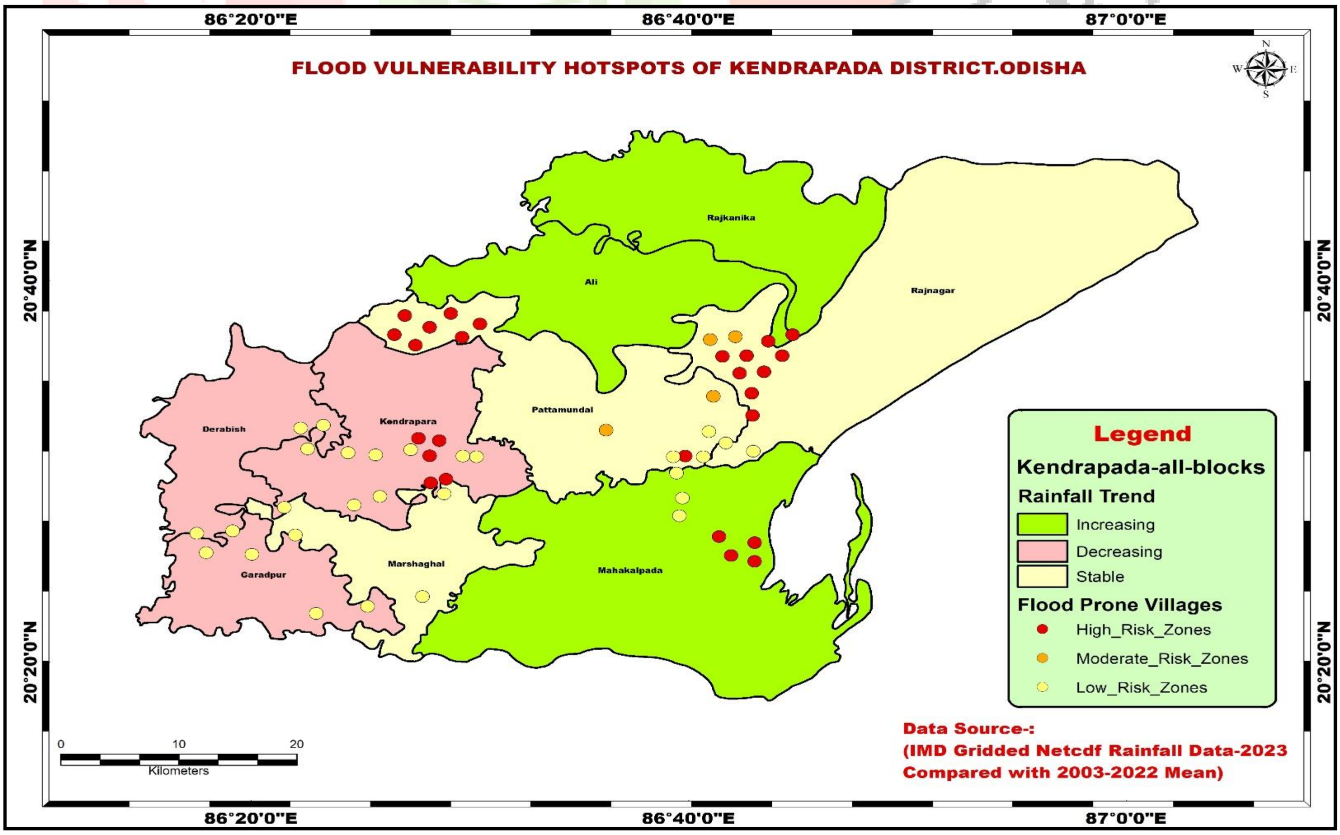
The anomaly map serves as a decision-support tool for climate-resilient planning.

- Flood Management: Strengthen embankments and drainage in coastal blocks.
- Drought Mitigation: Promote water harvesting and drought-tolerant crops in inland blocks.
- Agricultural Adaptation: Encourage crop diversification and climate-smart practices in transitional zones.
- Disaster Preparedness: Integrate rainfall anomaly data into early warning systems and district contingency planning.

6. Overall Analytical Insight

The rainfall anomaly pattern of Kendrapada District reflects a dual hydrological reality—excess rainfall along the coast and deficit inland. This spatial contrast underscores the need for block-specific interventions rather than uniform district-level strategies. The analysis confirms that rainfall variability is not random but systematically influenced by topography, proximity to the coast, and monsoon dynamics, making Kendrapada a critical case for studying localized climate resilience in coastal Odisha.

FLOOD VULNERABILITY HOTSPOTS ANALYSIS



Map-3. Flood Vulnerability Hotspots Map of Kendrapada District, Odisha, India)
Source-: (Survey of India, Administrative Boundary Database, IMD Gridded Rainfall Data (2003-2023)

1. Spatial Pattern of Flood Vulnerability

The map reveals a clear spatial differentiation in flood vulnerability across Kendrapada District. Coastal blocks such as Rajnagar and Mahakalpada emerge as high-risk hotspots, where clusters of flood-prone villages coincide with increasing rainfall trends. These areas are directly influenced by cyclonic systems and tidal surges from the Bay of Bengal, making them the most critical zones for flood management. In contrast, inland blocks like Derabish, Kendrapara, and Garadpur show decreasing rainfall trends, yet remain vulnerable due to riverine flooding from the Brahmani and Baitarani systems. This indicates that flood risk in these areas is more hydrological than climatic.

2. Rainfall Trend and Flood Correlation

The overlay of rainfall trend data with flood-prone villages demonstrates a strong correlation between increasing rainfall zones and high flood frequency. Blocks such as Rajkanika and Mahakalpada experience intensified precipitation, leading to recurrent inundation. Conversely, blocks with stable or declining rainfall trends—such as Aali, Pattamundai, and Marsaghai—still face moderate flood risk due to poor drainage and backflow from major rivers. This spatial relationship highlights the dual influence of climate variability and hydrological connectivity on flood occurrence.

3. Hydrological and Geographical Context

The district's hydrological framework, dominated by the Brahmani and Baitarani rivers, plays a decisive role in shaping flood vulnerability. The coastal orientation and low-lying topography facilitate water accumulation during heavy rainfall events. The Bay of Bengal coastline acts as both a source of moisture and a zone of storm surge impact. The convergence of these natural factors explains why the eastern and south-eastern blocks consistently record high flood intensity.

4. Socio-Economic and Agricultural Implications

Flood-prone villages in high-risk zones face severe socio-economic challenges. Repeated inundation disrupts agricultural cycles, damages standing crops, and affects livelihoods dependent on paddy cultivation and aquaculture. In moderate-risk areas, seasonal flooding leads to soil erosion and reduced productivity. The inland deficit zones, though less affected by rainfall, suffer from legacy flood impacts—embankment breaches and poor drainage infrastructure that perpetuate vulnerability even under declining rainfall trends.

5. Planning and Policy Insights

The map provides a strategic foundation for climate-resilient planning in Kendrapada District.

- High-risk coastal blocks require embankment reinforcement, cyclone shelters, and early warning systems.
- Moderate-risk riverine blocks need improved drainage and floodplain zoning.
- Inland legacy zones demand long-term structural interventions and watershed management.
- Integrating rainfall trend data with flood vulnerability mapping ensures that mitigation measures are data-driven and spatially targeted.

6. Overall Analytical Conclusion

The flood vulnerability hotspot map of Kendrapada District illustrates a coastal–inland gradient of risk, shaped by both climatic and hydrological factors. The concentration of high-risk villages in areas with increasing rainfall trends underscores the growing influence of climate variability on local flood dynamics. Meanwhile, persistent flooding in rainfall-deficit zones reveals the enduring impact of river morphology and infrastructure gaps. This spatial synthesis provides a robust framework for district-level disaster preparedness and adaptive water management, ensuring that interventions align with the distinct risk profiles of each block.

SOCIO-ECONOMIC VULNERABILITY ASSESSMENT

The socio-economic vulnerability of Kendrapada District arises from the intersection of physical exposure to floods and social economic fragility within its population. The district's coastal and deltaic setting, combined with high population density and dependence on climate sensitive livelihoods, amplifies the impact of recurrent flooding. The assessment integrates rainfall trend analysis, flood prone village mapping, and demographic indicators to evaluate how social and economic conditions influence resilience and recovery capacity.

1. Demographic sensitivity

Kendrapada's population is predominantly rural, with a large proportion engaged in agriculture and fisheries. Villages in Rajnagar, Mahakalpada, and Rajkanika—identified as high-risk hotspots—have high population density and limited landholding size, making them more susceptible to displacement and livelihood disruption. Frequent inundation leads to temporary migration, loss of productive labour, and increased dependency on relief assistance. The demographic pressure on limited safe land further constrains adaptive capacity.

2. Livelihood vulnerability

Agriculture forms the backbone of the district economy, dominated by **paddy cultivation** and **aquaculture**. Floods destroy standing crops, contaminate ponds, and erode fertile topsoil, directly affecting income stability. In **coastal blocks**, saline water intrusion after cyclones reduces soil productivity, forcing farmers to shift to low yield varieties or wage labour. Inland blocks such as **Derabish and Garadpur**, though rainfall deficit, experience flood damage from river overflow, highlighting how hydrological vulnerability persists even under declining rainfall trends.

3. Infrastructure and Access Inequality

Flood prone villages often lack resilient infrastructure—unpaved roads, weak embankments, and limited drainage systems. During heavy rainfall, connectivity to markets, schools, and health centres is disrupted. The Mahakalpada and Rajnagar regions face recurrent isolation during cyclonic events, delaying emergency response and relief distribution. Poor housing quality, especially mud walled structures, increases exposure to flood damage and post disaster health risks.

4. Social Dimensions of Vulnerability

Social vulnerability is intensified by poverty, low literacy, and limited institutional support. Marginalized groups—landless labourers, women-headed households, and elderly residents—bear disproportionate losses. In high-risk villages, women often manage household recovery while men migrate temporarily for work, creating gendered burdens in disaster adaptation. Community networks provide informal support, but lack of organized local disaster committees limits coordinated preparedness.

5. Health and Sanitation Impacts

Floods lead to contamination of drinking water sources and outbreaks of water-borne diseases such as diarrhea and skin infections. In low-lying villages, prolonged water stagnation increases mosquito breeding, raising the incidence of vector-borne diseases. Limited access to healthcare facilities during floods exacerbates vulnerability, particularly among children and the elderly.

6. Economic Resilience and Recovery Capacity

Post-flood recovery is slow due to **low household savings and limited insurance coverage**. Dependence on government relief and compensation schemes creates cyclical vulnerability. Small traders and artisans lose inventory and tools, while agricultural households face debt accumulation from crop failure. The absence of diversified income sources restricts economic resilience, making recovery dependent on external aid rather than local adaptive mechanisms.

7. Composite Vulnerability Index (Conceptual Framework)

A composite socio-economic vulnerability index for Kendrapada can be structured using indicators such as:

- Exposure: Flood frequency, rainfall trend intensity, proximity to rivers/coast.
- Sensitivity: Population density, livelihood dependency, housing type.
- Adaptive Capacity: Literacy rate, income diversification, access to infrastructure and institutions.

Blocks like Rajnagar and Mahakalpada score high on exposure and sensitivity but low on adaptive capacity, placing them in the "very high vulnerability" category. Pattamundai and Aali fall under moderate vulnerability, while Derabish and Garadpur exhibit legacy vulnerability due to persistent hydrological risks despite lower rainfall.

Block	Exposure (Rainfall/Flood Frequency)	Sensitivity (Population Density, Livelihood Dependence)	Adaptive Capacity (Infrastructure, Literacy, Diversification)	Composite Vulnerability
Rajnagar	High (Increasing rainfall + cyclone risk)	High (dense population, paddy & fisheries)	Low (poor infrastructure, limited diversification)	Very High
Mahakalpada	High (Extreme excess rainfall + tidal surge)	High (coastal villages, aquaculture)	Low (weak embankments, poor housing)	Very High
Rajkanika	Moderate (Excess rainfall, river overflow)	High (agriculture dependent)	Moderate (better literacy, but limited resilience)	High
Aali	Moderate (Stable rainfall, riverine floods)	Moderate (mixed livelihoods)	Moderate (average infrastructure)	Moderate
Pattamundai	Moderate (Normal rainfall, river overflow)	Moderate (agriculture + trade)	Moderate (better connectivity)	Moderate
Marsaghai	Low (Normal rainfall, occasional floods)	Moderate (mixed livelihoods)	Moderate (average resilience)	Moderate
Derabish	Low (Rainfall deficit, legacy floods)	Moderate (small landholdings)	Low (poor infrastructure)	High (Legacy)
Kendrapara	Low (Rainfall deficit, embankment breaches)	High (district HQ, dense settlements)	Moderate (better services, but fragile housing)	High (Legacy)
Garadpur	Low (Rainfall deficit, river morphology)	Moderate (agriculture dependent)	Low (weak infrastructure)	High (Legacy)

Table-1: Socio-Economic Vulnerability Assessment of Blocks of Kendrapada District, Odisha (Source-: Census, 2011)

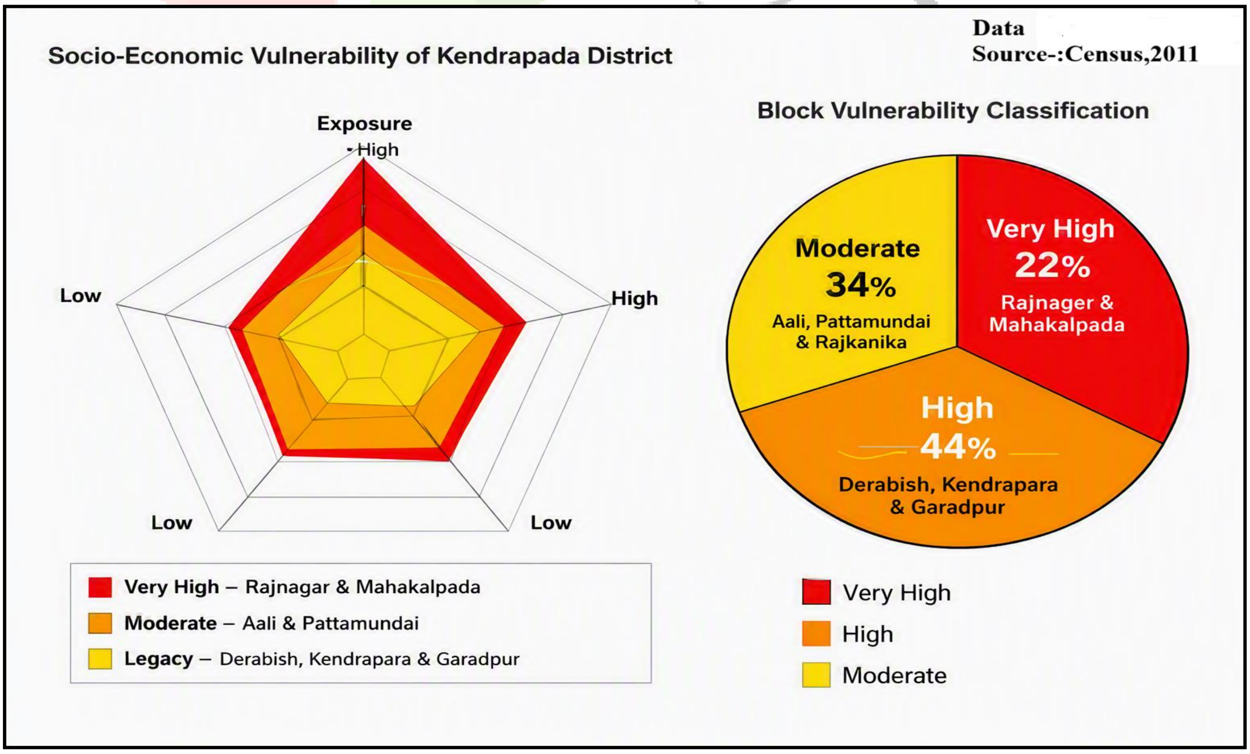


Fig-5: Radar & Pie Chart showing Socio-Economic Vulnerability Assessment of different Blocks of Kendrapada District. (Source-: Census, 2011)

The radar and pie charts together provide a multidimensional view of socio-economic vulnerability across Kendrapada District. The radar chart highlights the interplay between Exposure, Sensitivity, and Adaptive Capacity, while the pie chart quantifies the proportion of blocks under different vulnerability categories. This combined visualization reveals that coastal blocks (Rajnagar and Mahakalpada) are the most critical zones, followed by riverine and inland blocks that exhibit legacy vulnerability due to persistent hydrological and infrastructural constraints.

The radar chart demonstrates that:

- Rajnagar and Mahakalpada occupy the outermost zone of the radar, indicating high exposure and sensitivity but low adaptive capacity. These blocks face recurrent cyclones, tidal surges, and heavy rainfall, making them extremely vulnerable to socio-economic disruption.
- Aali and Pattamundai show moderate vulnerability with balanced exposure and adaptive capacity. Their flood risk is primarily linked to river overflow rather than direct coastal impact.
- Derabish, Kendrapara, and Garadpur form the inner yellow polygon, representing legacy vulnerability—low rainfall exposure but high sensitivity due to poor infrastructure, weak embankments, and limited livelihood diversification.

This spatial differentiation underscores that vulnerability is not uniform; it is shaped by the interaction of climatic stressors and socio-economic fragility.

The pie chart quantifies the district's vulnerability distribution:

- **Very High Vulnerability (22%)** — Rajnagar & Mahakalpada
- **High Vulnerability (44%)** — Derabish, Kendrapara & Garadpur
- **Moderate Vulnerability (33%)** — Aali, Pattamundai & Rajkanika

This composition indicates that nearly **two-thirds of Kendrapada's area** falls under high or very high vulnerability categories, emphasizing the need for targeted interventions in both coastal and inland regions.

8. Socio-economic Implications

Floods in high-risk zones lead to **loss of livelihoods, displacement, and damage to housing and infrastructure**. Agricultural dependence, low literacy, and limited income diversification amplify vulnerability. Coastal communities face additional challenges from **saline intrusion and cyclonic damage**, while inland populations suffer from **embankment breaches and poor drainage**. The cumulative effect is a cycle of poverty and reduced resilience, where recovery depends heavily on external relief rather than local adaptive mechanisms.

9. Policy and Planning Insights

The combined analysis suggests a **tiered approach** to resilience planning:

- **Coastal Blocks (Rajnagar, Mahakalpada):** Strengthen embankments, cyclone shelters, and early warning systems.
- **Riverine Blocks (Aali, Pattamundai, Rajkanika):** Improve drainage, promote flood-resilient crops, and enhance community preparedness.
- **Inland Blocks (Derabish, Kendrapara, Garadpur):** Focus on watershed management, infrastructure rehabilitation, and livelihood diversification.

Integrating rainfall trend data with socio-economic indicators ensures that interventions are **data driven and spatially precise**.

10. Suggestions & Recommendations

The radar and pie charts collectively illustrate that Kendrapada District's vulnerability is both climatic and structural. Coastal blocks are exposed to dynamic hazards, while inland blocks remain trapped in legacy vulnerability due to socio-economic limitations. Strengthening adaptive capacity—through education, infrastructure, and livelihood diversification—can transform Kendrapada from a reactive disaster zone into a proactive climate resilient district.

This synthesis provides a robust foundation for district level disaster management planning, ensuring that future strategies align with the distinct vulnerability profiles revealed through spatial and socio-economic analysis.

VI. CONCLUSION

The study establishes a clear linkage between climatic variability and socio-economic vulnerability in Kendrapada District. Long-term rainfall analysis reveals spatial disparities, with coastal blocks such as Rajnagar and Mahakalpada experiencing increasing rainfall and frequent cyclonic events, while inland blocks like Derabish and Garadpur show declining trends yet remain flood affected due to riverine overflow. The integration of rainfall anomaly mapping and socio-economic indicators demonstrates that vulnerability is not solely climatic but deeply rooted in livelihood dependence, infrastructure fragility, and limited adaptive capacity. Agricultural reliance, poverty, and inadequate drainage systems amplify the impact of floods, creating persistent livelihood insecurity. The composite vulnerability assessment identifies coastal villages as critical hotspots requiring immediate resilience measures. Strengthening embankments, promoting flood resilient crops, and enhancing community preparedness emerge as essential strategies. Overall, the research underscores that effective flood management in Kendrapada must combine hydrological understanding with socio-economic empowerment. Building adaptive capacity through education, diversified livelihoods, and inclusive planning can transform the district from a reactive disaster zone into a proactive climate resilient region.

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