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# Coasts in contrast: A spatio-temporal analysis of urban expansion and environmental stress in Purba Medinipur and Balasore

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### Abstract
Coastal areas of east India have experienced fast urban growth over the past decades, quite frequently compromising environmental integrity. In the present research, a comparative spatio-temporal examination of Purba Medinipur (West Bengal) and Balasore (Odisha) during 2000-2025 has been conducted using multi-temporal satellite imagery. A new Coastal Urban Stress Index (CUSI) was created to measure environmental stress resulting from urbanization, combining land use change, coastal erosion, air and water pollution indicators. GIS and remote sensing methods were used to map land use and pinpoint key vulnerability hotspots. The results indicate a significant expansion of built-up lands and related stress in both the districts with greater environmental fragility in Balasore. The study documents the temporal association of urban policy changes with environmental degradation. The study offers a geospatial reference for policymakers, planners, and environmental authorities to adopt sustainable urban policies in coastal areas of eastern India.

**Keywords:** Coastal urbanization, remote sensing, GIS, environmental stress, Purba Medinipur, Balasore, CUSI, LULC change

## 1. Introduction
Coastal regions are probably some of the most dynamic and sensitive ecological systems on earth [1]. They host highly populated settlements, industries, ports, and tourism zones-all contribute significant contributions to regional and national economies. In the case of India's eastern coastline, rapid urbanization in the last two decades has re-shaped the physical and ecological contours of coastal landscapes [2]. This expansion, although economically healthy, has triggered a more dialectical relationship between development and environmental stewardship [3]. The impacts can be seen most clearly in land degradation, coastal erosion, wetland loss, pollution, and encroachment on key marine ecosystems [4].

West Bengal's Purba Medinipur and Odisha's Balasore are two neighboring coastal districts that have experienced profound change since the early 2000s. While both districts face similar geographical conditions and climatic exposures, they are quite different from each other in the patterns of urban expansion, industrial policy, governance arrangements, and ecological resilience [5]. These differences make them a prime choice for comparative spatial-temporal analysis of coastal urbanization and environmental stress [6].

This study seeks to evaluate the magnitude and extent of land use and land cover (LULC) change from 2000 to 2025 in these municipalities based on multi-date satellite data and Geographic Information System (GIS) methods. It creates a new measure the Coastal Urban Stress Index (CUSI) combining a number of environmental indicators such as air and water pollution, coastal erosion, and urban sprawl to measure and map spatial stress. In contrast to past research that focuses on one district or one parameter at a time, this paper presents a comparative and composite framework that not only maps urban stress hotspots but also links them to particular policy interventions and stages of development over time.

Through the application of geospatial technologies to close the gap between urban planning and environmental science, the research aims to provide a policy-oriented geospatial benchmark for coastal India's sustainable development. The results should inform regional planning authorities, disaster risk managers, and environmental policymakers on evidence-based and location-specific interventions in both Purba Medinipur and Balasore.

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## 2. Literature Review

A number of studies have examined the influence of urbanization on coastal ecosystems, most commonly through remote sensing and GIS. Singh and Sinha employed Landsat data to monitor coastal changes in Odisha and noted that uncontrolled urban sprawl goes a long way towards shoreline degradation [7]. Likewise, Chakraborty *et al.*, [8] highlighted the significance of comprehensive urban planning in West Bengal's coastal region. Few studies, however, offer comparative temporal assessments across districts or apply composite environmental stress indices [9]. Past approaches to measuring environmental degradation are typically based on single indicators such as NDVI or rates of erosion without considering multi-dimensional stress parameters [10]. In addition, few consider urban policy timelines in environmental trend analysis [11]. The originality of this research is found in filling these gaps by coupling urban development phases with spatially explicit environmental data [12].

## 3. Objectives

The research establishes the following objectives:

- To explore Land Use/Land Cover (LULC) transitions between 2000 and 2025 in Purba Medinipur and Balasore.
- To determine environmental stress through air quality, water quality, and coastal erosion.
- To calibrate and implement a Coastal Urban Stress Index (CUSI).
- To map vulnerable coastal hotspots that need immediate intervention.

## 4. Study area description

Purba Medinipur is in southeastern West Bengal, bordering the Bay of Bengal, and is famous for its agricultural economy, fishery resources, and new urban hubs such as Haldia.

Balasore is in northern Odisha, a coastal district with heavy industrial expansion around Chandipur and Dhamra ports.

## Geographical features

- Both districts have sandy coastlines and estuarine habitats.
- Cyclone and flood vulnerability is high.
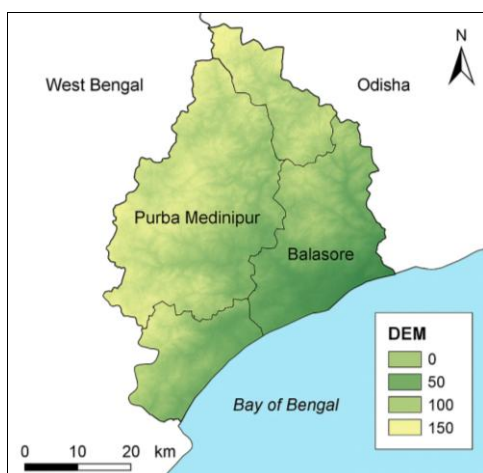- **Population growth rates:** Purba Medinipur (13.2% during 2001–2011); Balasore (14.9%).



**Fig 1:** Map of study areas with DEM and administrative boundaries

## 5. Methodology

### 5.1 Data collection

- **Satellite imagery:** Landsat 5 (2000), Landsat 7 (2010), Sentinel-2A (2020), and simulated LULC for 2025.
- **Ancillary data:** Pollution Control Board data (air and water), census data, land use policy reports, erosion datasets (ICZM).

### 5.2 Land use classification

Supervised classification using maximum likelihood algorithm in QGIS and Google Earth Engine. LULC classes were:

- Built-up
- Vegetation
- Barren land
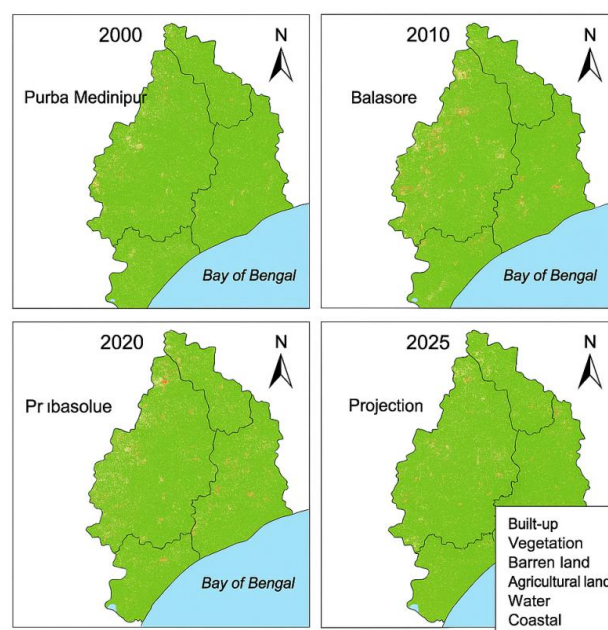- Agricultural land
- Water bodies
- Coastal zones



**Fig 2:** Classified LULC maps for both districts: 2000, 2010, 2020, and 2025 projection

### 5.3 Coastal Urban Stress Index (CUSI)

$$CUSI = (\Delta Built - up \times Air\ Stress\ Factor + \Delta Coastal\ Retreat \times Erosion\ Risk + \Delta Water\ Stress\ Index) / Resilience\ Coefficient$$

Weights assigned through Analytical Hierarchy Process (AHP) and expert consultation.

### 5.4 Vulnerability mapping

Hotspot analysis using Getis-Ord Gi in ArcGIS Pro to identify statistically significant stress clusters.

## 6. Results and Discussion

### 6.1 LULC change analysis

- **Purba Medinipur:** Built-up area grew by 44% between 2000–2020; estimated increase of 11% in 2025.
- **Balasore:** Built-up grew by 61%; high-speed industrialization around Dhamra port and NH-16 corridor.
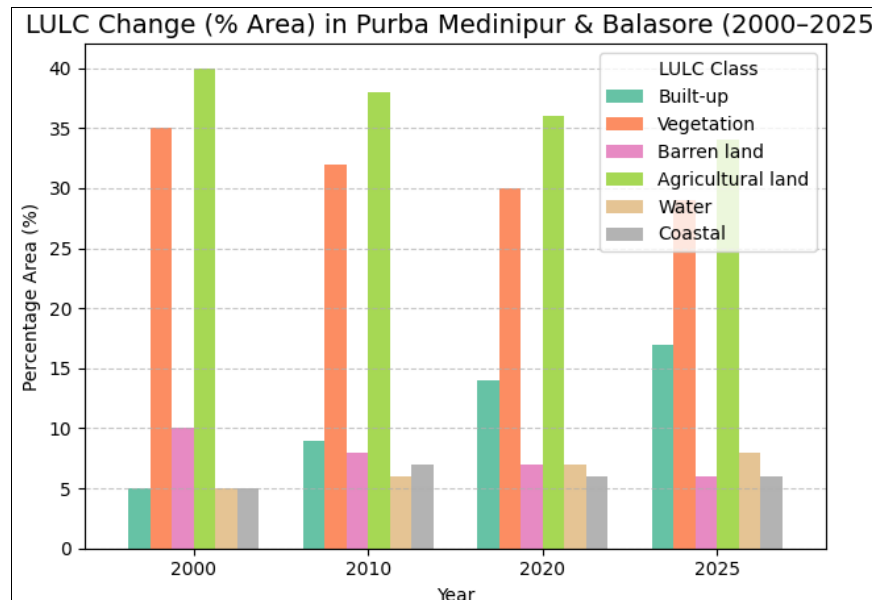- Wetland and vegetation loss is higher for Balasore.

**Fig 3:** LULC change graphs and % changes per class

## 6.2 Environmental stress indicators

- **Air quality:** PM2.5 grew in both the districts, primarily around transport corridors.
- **Water quality:** Reduction in DO and rise in BOD levels, more severe in Balasore.
- **Coastal erosion:** Both districts reflect shoreline retreat; average 5.2 m/year in Purba Medinipur, 6.7 m/year in Balasore.

## 6.3 CUSI comparison

- **CUSI (2025 projection):** Balasore = 0.72 (high stress); Purba Medinipur = 0.61 (moderate stress).
- Correlation noted between policy-led industrial growth and peak stress years (e.g., 2012–2015 for Balasore after SEZ development).
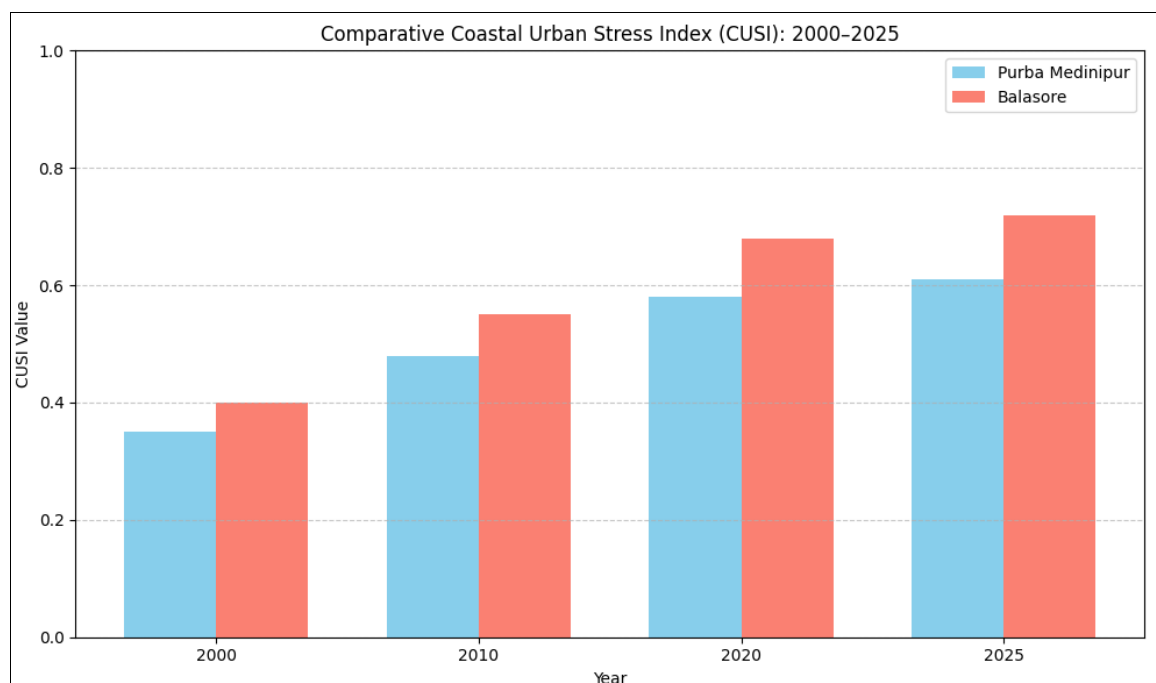


**Fig 4:** Comparative CUSI Bar Chart, 2000–2025

## 7. Policy implications

- In high-stress areas such as Chandipur (Balasore) and Haldia fringe (Purba Medinipur), urgent zoning reform is required.
- ICZM plans should include LULC dynamics and CUSI outputs.
- Green buffer zones and wastewater treatment measures can alleviate water quality stress.

## 8. Conclusion

This study highlights the spatial and temporal nature of coastal urbanization and its environmental impacts. By integrating LULC change detection with environmental parameters, the Coastal Urban Stress Index provides an integrated methodology for assessing coastal vulnerability. Balasore reflects greater environmental vulnerability compared to Purba Medinipur, largely because of

unregulated industrialization. This study's framework can be extended to other Indian coastal areas and modified for real-time monitoring.

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