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## Land resource management of coastal areas in Indian cities: comparative assessment with prevailing methods

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# Land resource management of coastal areas in Indian cities: comparative assessment with prevailing methods

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**Abstract.** Indian coastal cities, enriched with a variety of marine resources, are a major driver of economic growth where the Indian coast provides shelter to a large part (~49%) of the total population in India. Proper planning of coastal resources is crucial for sustainable development, which can be achieved through advanced planning methods. Current methods for the planning of coastal landscapes in Indian coastal cities are ineffective in sustainable utilization of coastal resources and need improvements. This paper evaluates the application of the new planning method for classification of coastal landscapes in Mumbai city. The new method incorporates geospatial technology and multicriteria decision-making approach. The existing method of coastal area classification is based on Coastal Regulation Zone (CRZ) notifications by the central government, which has ambiguities in implementation. In the new method, coastal areas of Mumbai city are classified based on the physical eligibility of the coast for management of coastal resources and spatially compared with prevailing unscientific classification of coastal areas. The most dense urban area is considered for quantitative comparison of prevailing and new classification approach. Results of coastal area classifications by both methods disclosed the significant differences among different classes of coastal land. The results are validated with field visits and ground truthing along the coast of Mumbai. The findings of this study will enable the stakeholders to utilize available coastal land resources in an efficient manner for developmental and conservational activities at regional and neighborhood scale.

## 1. Introduction

Coastal areas are recognized as vital support to the regional and global economy around the world. Researchers are emphasizing the challenges of coastal resource planning at present due to the continuous increase in anthropogenic pressure along the global coastline [1]. Dynamics of geomorphological, climatic, and socioeconomic changes are altering the coastal system at spatial and temporal scale resulting in degradation of ecosystem services, biodiversity, and infrastructure [2]. Similarly, the Indian coast is also exposed to natural hazards like tsunamis, cyclones, extreme rainfall, coastal flooding and pressure of allied developmental activities along 7200 km of shoreline [3]. Indian coastal zone is managed to control the physical and socioeconomic vulnerability with the help of coastal regulations at



the central and state level. According to Coastal Regulation Zone (CRZ) notification, eco-sensitive areas are classified into four different categories, but the distinction of these categories is based on the coastal boundary of different distances (500 m or 100 m) from the High Tide Line (HTL) towards the landward side. The CRZ notification is a strategic planning method of integrated coastal governance but unable to deliver the expected because of subjectivity and ambiguity at both fundamental and implementation level [4]. Current CRZ method is inconsistent and empirical, which does not consider the physical eligibility of different coastal features at spatial and temporal scale. Coastal planning and management is a challenge for other developing countries as well due to similar unclear policies like CRZ in India [5]. CRZ method of coastal land classification tries to deliver sustainable coastal governance for land management with limited capability. However, this CRZ method has been ineffective and failed in the past to achieve the aim of integrated coastal management at the Indian coast [6,7]. Therefore, an objective based robust classification approach for coastal areas is required to improve the coastal planning in India. It is essential to have a robust solution to address the conflicting interests of associated stakeholders during coastal land classification.

In this study, we demonstrated the application of Coastal Area Index (CAI) method, which is quantitative and capable of addressing the current challenges in existing CRZ method [8]. CAI method is applied to the coastal area of Mumbai city in India. Furthermore, a comparative assessment of the spatial extent of different categories classified by the existing CRZ method with the CAI method is carried out. Feasibility and advancement of the CAI method over CRZ method are validated by field visits and ground truthing at the selected location.

## 2. Methods

This study presents the application of a newly established quantitative method (CAI) for the classification of coastal land, which is based on geospatial science and multicriteria decision-making approach. We selected the coastal stretch of Mumbai city for classification into different categories based on the CAI method. Mumbai city in India is a coastal megacity of regional and global importance, located at the west coast of India and the unique dynamic coastal environment of the city represent all important geomorphological features [9]. Mumbai, an Island city, is surrounded by the Arabian Sea along the west coast and a large Thane creek in the east representing a large natural mangrove cover and associated biodiversity. Additionally, key reason for selecting this study area is the availability of signatures of ecosystem degradation related to coastal pollution, coastal flooding, the significant increase in urban development along the coast and violation of current existing CRZ method [10,11].

This study uses primary remote sensing data for quantification of physical coastal features. Important geomorphological variables representing physical coastal features are pre-processed and converted into raster format at 30m pixel level, as shown in Table 1. Land Use Land Cover (LULC), Digital Elevation Model (DEM), Normalized Difference Vegetation Index (NDVI) and coastal slope (%) are processed and classified using remote sensing data whereas soil and geology types are processed based on secondary data from central agencies namely Survey of India (SOI) and Geological Survey of India (GSI) respectively. CRZ areas are digitized using digital vector maps sourced from the State Coastal Zone Management Authority (SCZMA).

### 2.1. Comparative assessment of CRZ and CAI method

CAI method is developed by coupling GIS and multicriteria decision-making techniques; these techniques are well recognized and accepted in literature for land classification and policy-oriented conflict resolution among decision makers [12]. According to the CAI method, subclasses of physical coastal features are converted into utility functions based on the relative importance of particular feature towards environmental sensitivity followed by overall weight assignment to an individual layer of a coastal feature. Linear weighted sum method is used to generate the CAI by multiplying the layer weights with the respective utility value of the particular feature. Final CAI is obtained on a scale of 0-10 and classified in three distinct categories representing low, moderate, and high sensitive areas for developmental activities. CRZ classes are also demarcated according to the digital maps and converted into vector graphics in GIS tool for quantitative comparison with the areal extent of classes derived by

CAI as shown in Figure 1. This selected area is a predominantly urban area having inhabitants and commercial activities in 90% of the total area.

**Table 1.** Description of data types and processing.

Data layer	Source	Sub-classes
Land Use Land Cover	LANDSAT 8 (30 m)	built-up and fellow land, salt pans, vegetation, cropland, mudflats, marshes, mangroves, water bodies
Coastal slope (%)	SRTM (30 m)	< 25, 25-50, 50-75, >75
Elevation (m)	SRTM (30 m)	<1, 1-5, 5-10, >10
NDVI	LANDSAT 8 (30 m)	water, barren land, sparse and dense vegetation
Geology	GSI	rhyolite, trachyte, AA and compound flows, intertrappean, alluvium, agglomerates tuff, mud
Soil	SOI	backfilled, fine, clay, mud
CRZ classes	SCZMA	CRZ I, CRZ II, CRZ III

### 2.2. Validation method

Field visits are conducted at the selected site for validation of different classes by CAI and CRZ method. For this, a small area of 0.2 km<sup>2</sup> at the mouth of Mahim Bay, Mumbai is selected by considering the physical access to the site. This area is visited personally during clear weather. Visual observations are documented, and geotagged pictures are captured for meaningful interpretations.

## 3. Results

The coastal area along the coast of Mumbai city is classified and compared using CAI and CRZ approach to identify the better and more appropriate land classification method as presented in Figure 1.

### 3.1. Validation

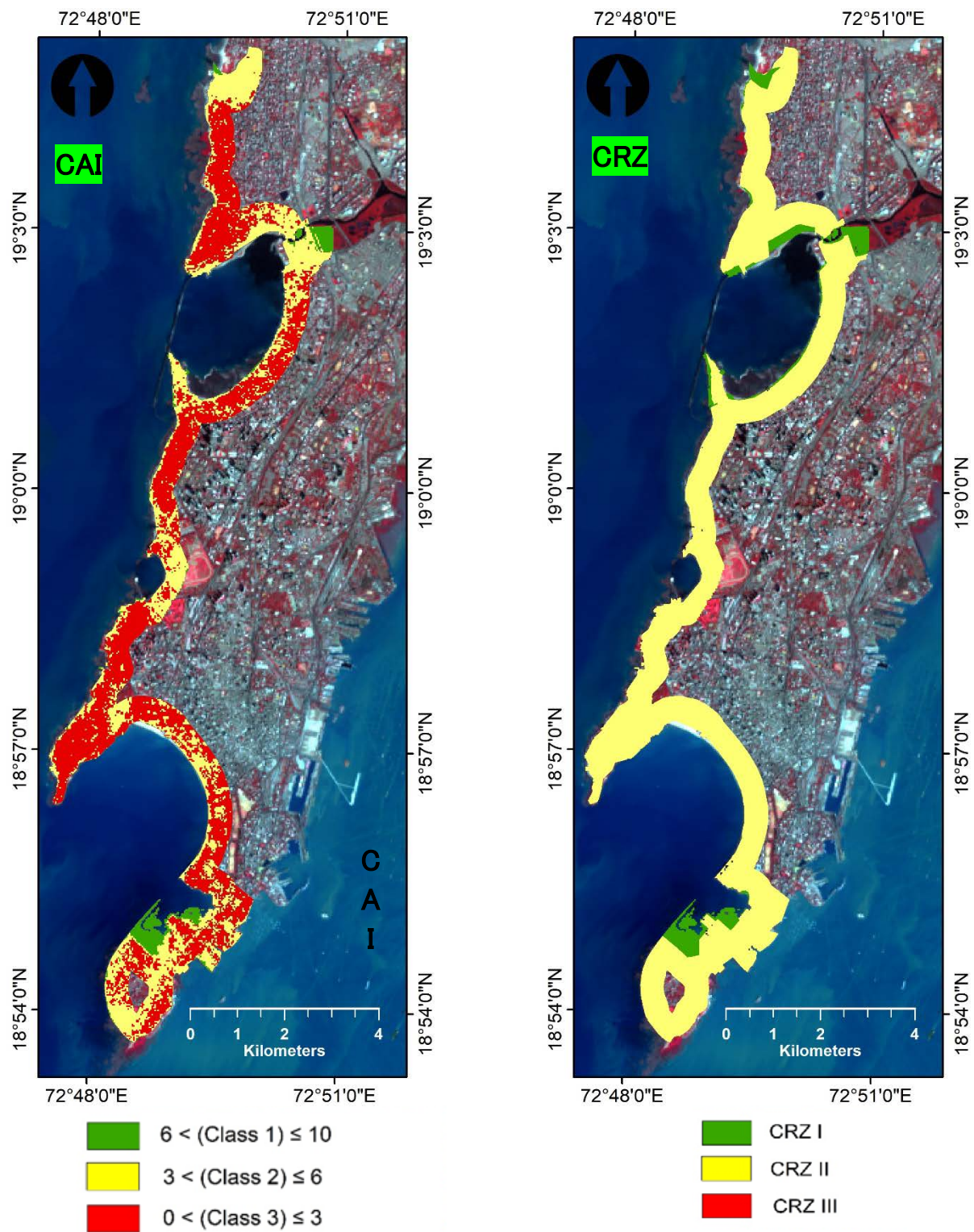
Selected location near Mahim Bay in Mumbai is considered and visited for field validation, as shown in Figure 2. The visited area is demarcated with a white box in Figure 2, and satellite imagery of a particular area is shown. In Figure 2, the CAI classifies this area as low to moderately sensitive, whereas presently, this area is in CRZ II. This area is fully urbanized, and validation exercise shows the agreement between both methods. We observed the open defecation and solid waste pollution activities along the HTL which need immediate interventions from governing authorities.

### 3.2. Spatial extent comparison of classified areas by CRZ and CAI approach

Field visits combined with CAI and CRZ classification presented the effectiveness of CAI method for coastal land classification. Comparative results of the spatial extent of different classes are presented in Table 2.

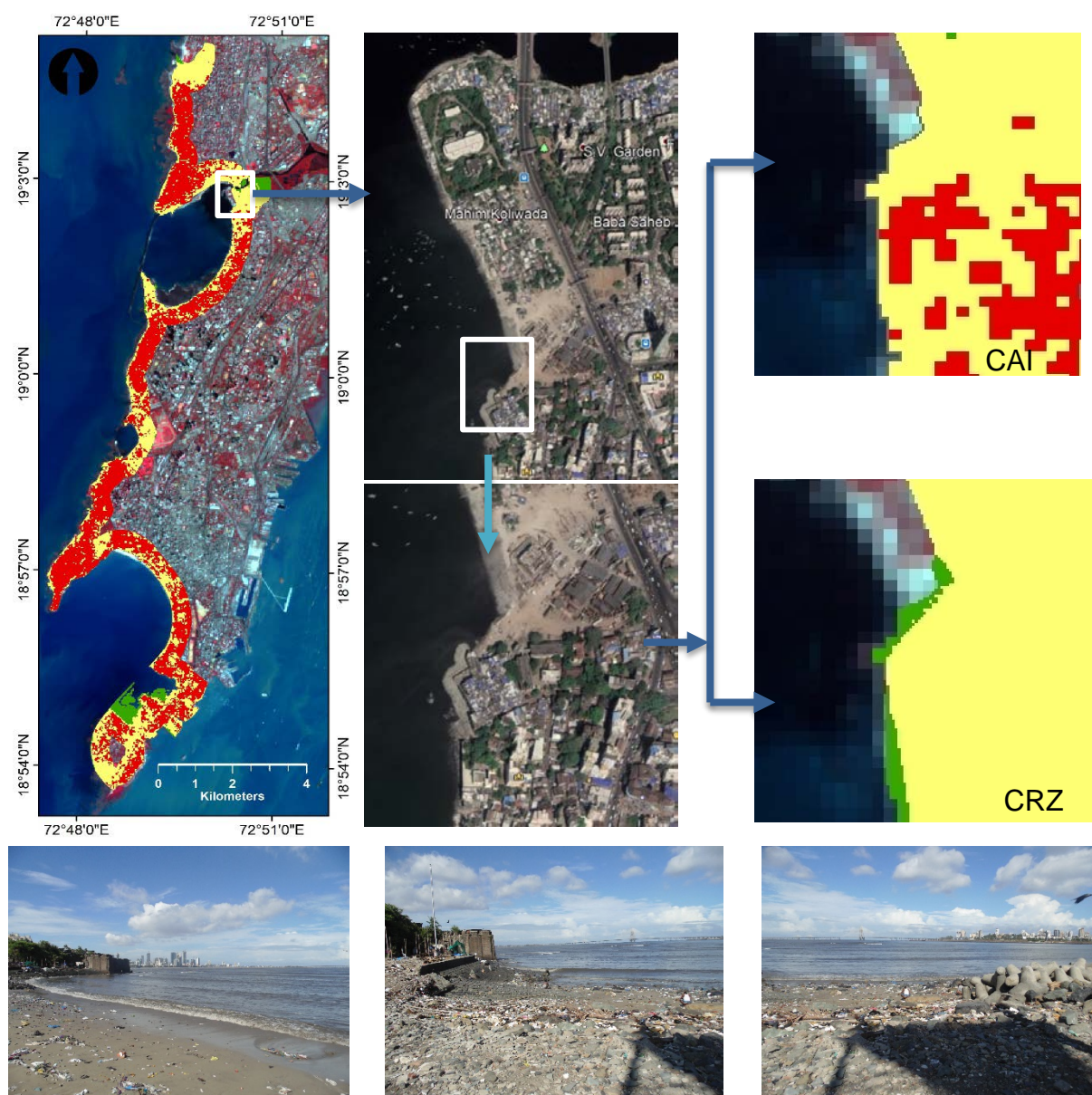
**Table 2.** Spatial extent comparison of classes in CRZ and CAI for the selected site.

Classes	CRZ Area		CAI Area	
	km <sup>2</sup>	(%)	km <sup>2</sup>	(%)
I	1.6	7.8	0.9	4.6
II	18.5	92.0	8.1	40.1
III	0	0	11.1	55.3
Total	20.1	100	20.1	100



**Figure 1.** CAI and CRZ classification at the coast of Mumbai city for quantitative comparison.





**Figure 2.** Validation of CAI based on ground-truthing at three selected sites along the Mumbai coast.

CAI method classifies 3.4% less coastal land in highly sensitive class compared to CRZ method as given in Table 2. The spatial extent in class two, which is moderately sensitive according to CRZ method is 52% more compared with the CAI method. Class 3, which is less sensitive in CAI, is measured 55% higher compared with CRZ. Comparison of CRZ and CAI extent shows that around 90% area is classified in a similar category of less to moderately sensitive, and the results of both methods are aligned with each other.

Results of the comparative assessment show the ability of the CAI method to classify coastal areas quantitatively at the pixel level by incorporating the physical characteristics, whereas CRZ method demarcates the fixed boundary at any given geographical location. CAI is a more robust decision-making method for coastal land classification, and the potential of this method for integrated coastal management in coastal urban areas is demonstrated in this study. Suitable applicability of CAI method will synergize the coastal protection and development by addressing the limits of current prevailing CRZ method.

#### 4. Conclusion

The current method of coastal land classification needs to be replaced by a coherent solution to achieve effective planning of built environment from available coastal land resources. Demonstrated method of CAI is quantitative and suitable for land classification in coastal cities. Proposed CAI approach is efficient, robust, and easy to implement at a city scale. The classification differences of the spatial extent by CAI and CRZ method might be useful for coastal managers and researchers as the potential areas for development, built environment and environmental management are evaluated. CAI method allows the land classification at a precise scale in a transparent manner and addresses the subjectivity of existing CRZ method.

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