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# Vulnerability of Mangroves to Changing Coastal Regulation Zone: A Case Study of Mandovi and Zuari Rivers of Goa

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## ABSTRACT

Goa is a coastal State located on the west coast of India, known for its pristine sandy beaches and environment. Ministry of Environment and Forest implemented Coastal Regulation Zone Notification in 1991 for monitoring the coastal zones for unplanned developmental activities but has been just for name-sake purposes (Mascarenhas 1999, Agarwal 2019). The regulation has been changed in recent years thereby making the coastal and the riverine ecosystem more vulnerable to human interference. In the name of development, various hap-hazardous, unplanned activities have taken place which is degrading the coastal and riverine environment, especially mangroves. This paper studies the vulnerability of mangroves to the changing regulations with respect to 1991 and the 2018 CRZ notifications considering the land use land cover changes in the regulated zones of Mandovi and Zuari rivers. Spatial analysis techniques and software such as Arc GIS 10.3, and ERDAS IMAGINE 2014 have been used for analysis and results. The findings from the study can be effectively implemented in monitoring the regulated zones and protecting mangroves efficiently.

## INTRODUCTION

### Coastal Regulation Zone

The Ministry of Environment and Forest issued the Coastal Zone Regulation notification under the Environment Protection Act of 1986. The main purpose of issuing the notification was to regulate, minimize and protect the sensitive coastal environment from unplanned human interference (Mascarenhas 1999). The Government of India declared the coastal stretches of seas, bays, estuaries, creeks, rivers, and backwaters as CRZ. These areas are influenced by tidal action (on the landward side) up to 500 meters from the High Tide Line (Ministry of Environment and Forests 1991).

India adopted formal Coastal Regulation Zone legislation in the year 1991 which was the first specialized step to control the unsustainable activities around the coastal zones (Agarwal 2019). It identified the necessity to protect the interests of millions of people along the coastal areas of India while ensuring their overall development and protecting fragile coastal ecology (Agarwal 2019).

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However, the Coastal Regulation Zone notifications were further modified and revised in the years 2011 and 2018. As per the 2011 CRZ Notification, the coastal areas from High Tide Line to 500 meters on the landward side and the land area between High Tide Line to 100 meters along the tidal-influenced water bodies that are connected to the sea are declared as protected under Coastal Regulation Zone (CRZ Notification 2011).

As per the recent implementation of the CRZ Notification of 2018, the CRZ shall apply to the land area between High Tide Line to 50 meters of the coast or the width of the creek, influenced by tidal action (CRZ Notification 2018). With the new CRZ Notification of 2018, the coastal areas will be heavily impacted by numerous unsustainable developmental activities that will lead to tragedy and imbalance in the ecological system if due care is not taken (Dhargalkar & Kavlekar 2019).

### Mangroves

Mangroves are salt-tolerant plants commonly found in tropical and sub-tropical regions located in intertidal zones

either as narrow strips or as extensive patches (Ajai et al. 2013). Kathiresan & Rajendran (2005), stated mangroves are the only forest situated at the convergence zone of land and sea. The mangrove ecosystem plays a very important role in terms of ecology and economy (Kamboj & Das 2019).

India is among the 17 mega biodiversity countries in the world, well known for its terrestrial, coastal, and marine biodiversity (Saravanan et al. 2013). India is home to a diversity of coastal and marine ecosystems including mangrove forests (DasGupta & Shaw 2013a). Mangroves are found along the 7516.6 kilometers of coastline of India including the islands (Sahu et al. 2015). India has the fourth largest mangrove area in the world occupying 0.14% of the country's land area (Sahu et al. 2015, Saddhe et al. 2016, Basha 2018).

The mangrove cover in Goa is approximately 0.5% of the total mangrove cover of India (Mesta et al. 2014). As per the recent data published by the India State of Forest Report (2021), Goa has a mangrove cover of 27 $km^2$. Mangroves are found along the estuaries of Terekhol, Chapora, Mandovi, Zuari, Sal, Talpona, Galgibag, and Cumbarjua canal (Singh et al. 2004).

### Land Use Land Cover (LULC)

Land use land cover conversion refers to the process of transformation of land cover to land use and change in land uses from one type to another in periodical time due to natural or anthropogenic activities (Kaliraj et al. 2017). Butt et al. (2015), stated that it is essential to study change analysis for a better understanding of the relationship between human activities and natural phenomena. Land use land cover change detection has become a significant necessity for developing efficient strategies for managing natural resources monitoring environmental changes and planning policy in various coastal areas (Muttitanon & Tripathi 2005, Kaul & Ingle 2012, Islam et al. 2016). Monitoring the land use land cover change along the Coastal Regulation Zone (CRZ) areas is essential for understanding the existing status of ecologically sensitive areas to protect the ecosystems from damaging activities (Shaji et al. 2017).

Remote sensing and Geographic Information System (GIS) provide efficient tools for ecosystem and socio-economic management (Haque & Basak 2017). Misra & Balaji (2015), stated that these tools provide unique opportunities for building information sources and support in decision-making activities for various coastal zone applications. Remote sensing data is a very useful source of information as it provides up-to-date and complete coverage of any area and is proven useful in assessing and monitoring land use land cover changes (Muttitanon & Tripathi 2005). To manage and protect the coastal environment from further exploitation, land use land cover changes must be studied.

The present study is carried out to understand the vulnerability of mangroves to changing CRZ limits. The objective of the paper is to study the changes in land use land cover along the Zuari and Mandovi rivers (including Cumbarjua Canal) using remote sensing data and geospatial techniques.

## STUDY AREA

Goa, a coastal State on the Western Coast of India lies between 1455°' N to 1545°' N and 7440°' E to 7410°' E (Nagi et al. 2014). Numerous estuaries in Goa, namely Terekhol, Chapora, Mandovi, Zuari, Sal, Talpona, and Galgibag support mangroves. Mandovi estuary has luxuriant mangrove growth in its 68 kilometers length estuarine channel. Cumbarjua Canal is 15 kilometers long and joins Mandovi and Zuari estuaries and is commonly called as "Mandovi-Zuari-Cumbarjua estuarine complex" (Nagi et al. 2014). Most of the mangroves in Goa are fringing mangroves bordering the estuaries and creeks (Jagtap et al. 2001, Mesta et al. 2014).

The major mangrove formations are along the Mandovi, Zuari, and Cumbarjua estuaries comprising almost 80% of the total mangrove cover in Goa (Mesta et al. 2014). There are 16 true mangrove species in Goa belonging to 11 genera and 7 families. Amongst all these estuaries, Mandovi River has the most number of mangrove species in Goa (Ragavan et al. 2016). *Avicennia*, *Sonneratia* and *Rhizophora* species dominate the Mandovi-Zuari-Cumbarjua estuarine complex (Ajai et al. 2013). Fig. 1 represents a map of the study area.

## MATERIALS AND METHODS

In the current study, both primary and secondary data were utilized. The primary data includes ground-truthing through field visits. However, a major part of the study is based on secondary data sources which include satellite imageries of different periods. For analysis, geospatial software such as ArcGIS 10.3 and ERDAS IMAGINE 2014 software were used.

LANDSAT satellite images are used to classify and map the land use land cover changes within the CRZ using geospatial techniques. LANDSAT 4-5 TM and LANDSAT 8 OLI images of the years 1991 and 2018 of 30 m resolution each and Survey of India (SOI) topographic maps of 1:50,000 scale are used to derive necessary data for analysis. Both the rivers including Cumbarjua Canal are demarcated up to the tidal influence using the toposheets as shown in Fig.

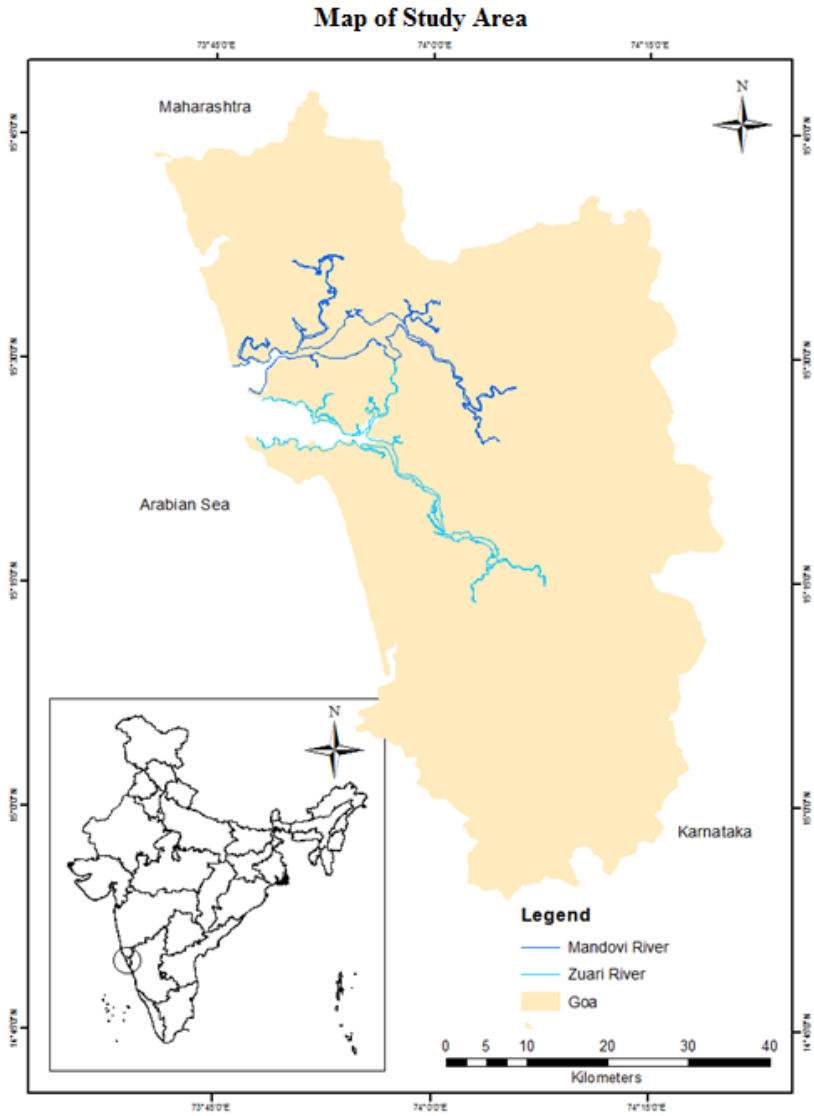


Fig. 1: Map of the study area.

Table 1: Data source and data derived.

| Sr. no. | Data | Source | Data derived |
|---|---|---|---|
| 1. | Survey of India (SOI) toposheets of 1:50,000 scale (48 E/14, 48 E/15, 48 I/2, 48 I/3) | Survey of India | High Tide Line (HTL) |
| 2. | LANDSAT 8OLI images (19/01/2018) LANDSAT 4-5 TM images (10/02/1991) 30 meters spatial resolution each | United States Geological Survey (USGS) website | Land use land cover (LULC) |
| 3. | GPS Survey Google Earth | Field Visit | Ground Truthing |

1. Cloud-free LANDSAT images are downloaded from the United States Geological Survey (USGS) website. The satellite images corresponding to low tide conditions were preferred to get maximum exposure to the land features and to yield accurate results. Table 1 displays the data used and derived for the analysis.

The pre-processing of the images (atmospheric and radiometric corrections), layer stacking, and mosaic were carried out using the image processing software ERDAS IMAGINE 2014. Stacking of Green, Red, and Near Infra-Red (NIR) generated False Colour Composite (FCC) images for both satellite data. ArcGIS 10.3 software was used for geo-referencing and projecting the Survey of India toposheets (WGS84 UTM Zone 43 N). Survey of India (SOI) toposheets were used for reference and for the generation of foundation data i.e. to demarcate the high tide line. The high tide line was demarcated up to the tidal influx in the rivers.

Upon demarcation of the high tide line, the Buffer Analysis tool was used to extract 100 meters and 50 meters zone along the HTL of Zuari and Mandovi rivers including the Cumbarjua Canal which connects rivers Mandovi and Zuari. The extracted zones of 100 meters and 50 meters for the years 1991 and 2018 were used for studying land use land cover changes and the vulnerability of mangroves to the changing CRZ Regulation. The satellite images of 1991 and 2018 were specifically chosen, as the CRZ notifications were implemented and amended during the same time frame.

The land use land cover classes were categorized into 5 classes namely, vegetation, mangroves, built-up, water, and barren lands. The classes were demarcated using the onscreen digitization method. Mangrove patches were verified and identified from other land use using high-resolution images on the Google Earth platform. Field visits and ground truthing have added more details in discriminating mangroves from other vegetation. Later, change detection of LULC classes for 100 meters zone between the period 1991 and 2018 was performed in ArcGIS 10.3 software. Graphs and charts were prepared using MS Excel.

## RESULTS AND DISCUSSION

According to Berlanga-Robles and Ruiz-Luna (2011), land use land cover changes are responsible for 35-50% loss of coastal wetlands. Anthropogenic activities harm the natural environment through the dynamic change of land use land cover (Daba & You 2022). Increasing human interference in the form of infrastructure development, pollution, and over-exploitation of resources along the regulated zones has increased the vulnerability of ecosystems. Moreover, the natural problems of cyclones, tidal surges, and rise in sea level are also threatening the sensitive ecosystems. To combat the problems related to the development and regulate human activities, regulated zones were implemented. But the integrity of the government's intentions for coastal protection is doubtful as meager executive action to address such a big issue shows gross negligence. Legislation has failed to implement and monitor the regulation (Agarwal 2019).

In Goa, most of the mangroves are located in the estuarine regions. Mandovi-Zuari-Cumbarjua estuarine complex has a dense area under mangroves. Zuari and Mandovi, the twin rivers are the lifelines of the Goans and their economy. Hence, the mangroves are vulnerable due to various anthropogenic activities taking place in these rivers and along their bank which includes settlement, bridge construction, widening of roads, agriculture, aquaculture, salt extraction, tourism, etc. Over the last two decades, vast mangrove areas along the Goan rivers are being reclaimed for developmental purposes such as settlements, industrial establishment, road extension, construction of bridges, harbors, and jetties, dredging and discharge of sediments, dumping of garbage, pollution, etc. which has resulted in severe damage to the fragile ecosystem (Dhargalkar & Kavlekar 2019).

Through the study of land use land cover change within the 100 meters and 50 meters CRZ, it was found that tremendous changes have occurred within the regulated zones along the Mandovi and Zuari rivers including Cumbarjua Canal. Moreover, in 2018 the changes in the CRZ notification which reduced the CRZ from 100 meters to 50 meters along the creeks and estuaries are likely to enhance changes in the land use pattern.

Table 2: LULC changes within the 50 meters and 100 meters CRZ Zone of the Zuari and Mandovi Rivers (including Cumbarjua Canal) (1991 and 2018).

| Land use / Year | Zuari River (Area in km$^2$) | | | Overall Loss (Area in km$^2$) | Mandovi River (Area in km$^2$) | | | Overall Loss (Area in km$^2$) |
|---|---|---|---|---|---|---|---|---|
| | 1991 (100 meters) | 2018 (100 meters) | 2018 (50 meters) | 2018-1991 (100 meters) | 1991 (100 meters) | 2018 (100 meters) | 2018 (50 meters) | 2018-1991 (100 meters) |
| Barren land | 3.17 | 4.30 | 1.16 | 1.13 | 6.79 | 3.84 | 1.23 | -2.95 |
| Built-up | 1.17 | 1.65 | 0.89 | 0.48 | 1.44 | 2.35 | 1.08 | 0.91 |
| Mangroves | 6.66 | 5.50 | 3.90 | -1.16 | 6.70 | 6.40 | 4.65 | -0.3 |
| Vegetation | 6.12 | 6.21 | 2.56 | 0.09 | 8.55 | 11.06 | 4.62 | 2.51 |
| Water | 4.07 | 3.53 | 2.29 | -0.54 | 3.59 | 3.42 | 2.17 | -0.17 |
| Total | 21.19 | 21.19 | 10.80 | - | 27.07 | 27.07 | 13.75 | - |

Source: Image Classification

As inferred in Table 2, changes are observed in the land use land cover pattern along the high tide zones of Mandovi and Zuari rivers over 27 years (1991-2018), most of the changes are the result of human interference. In the year 1991, the area under barren land, built-up, mangroves, vegetation, and water in Zuari river was 3.17 $km^2$, 1.17 $km^2$, 6.66 $km^2$, 6.12 $km^2$, and 4.07 $km^2$ respectively. Whereas, in the year 2018, the area under barren land, built-up, mangroves,

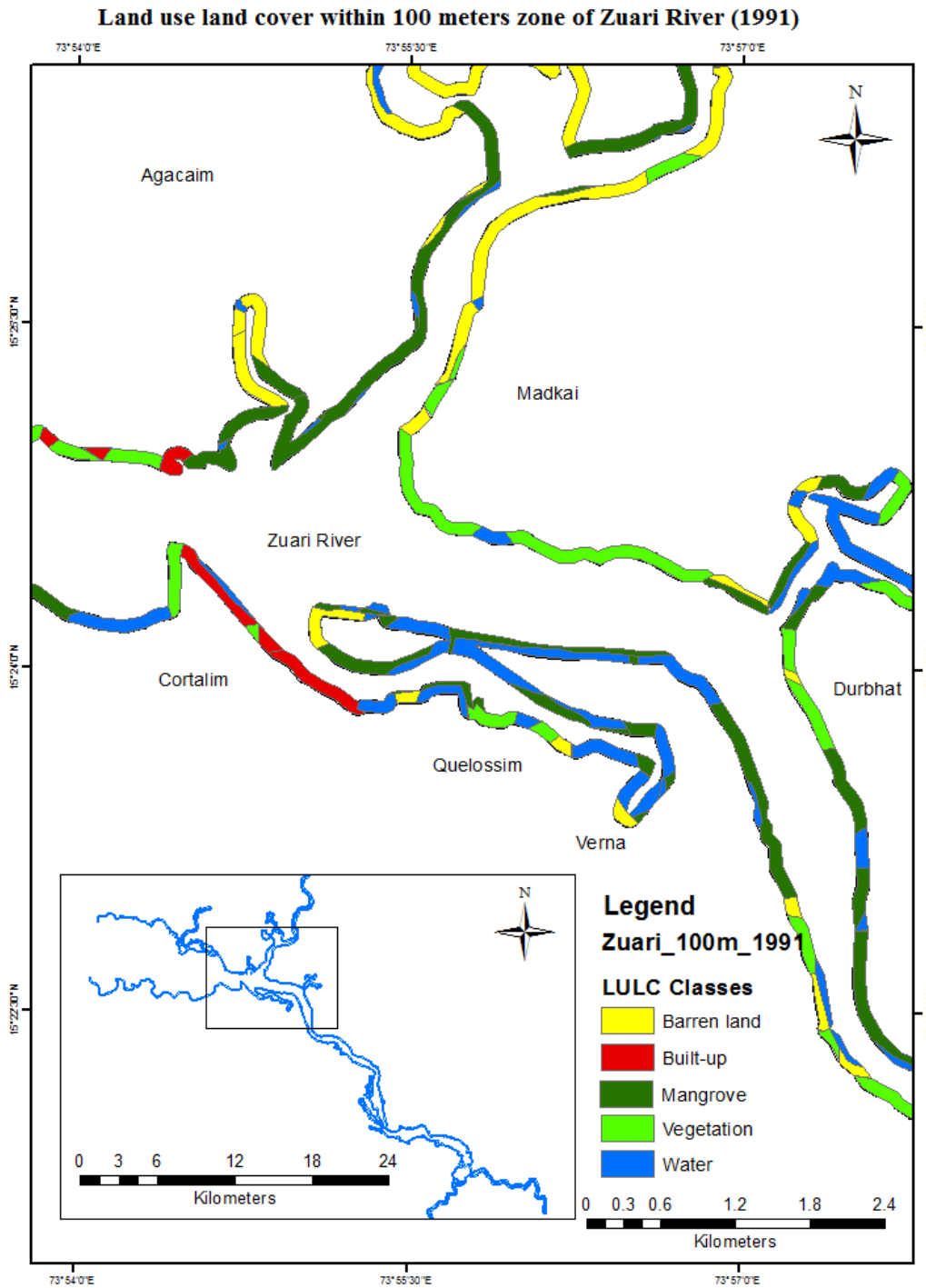


Fig. 2: LULC changes within 100 meters zone of Zuari River (1991).

vegetation, and water in Zuari river was 4.30 km$^2$, 1.65 km$^2$, 5.50 km$^2$, 6.21 km$^2$, and 3.53 km$^2$ respectively. In the case of the Zuari river, over 27 years, the area under barren land, built-up, and vegetation has increased by 1.13 km$^2$, 0.48 km$^2$, and 0.09 km$^2$ respectively. On the other hand, areas under mangroves and water have decreased by 1.16 km$^2$ and 0.54 km$^2$ respectively. Figs. 2, 3, 4, and 8 represent LULC changes within 100 meters and 50 meters zones of the Zuari river. Fig. 10 depicts the conversion of the LULC classes in the Zuari river from 1991 to 2018.

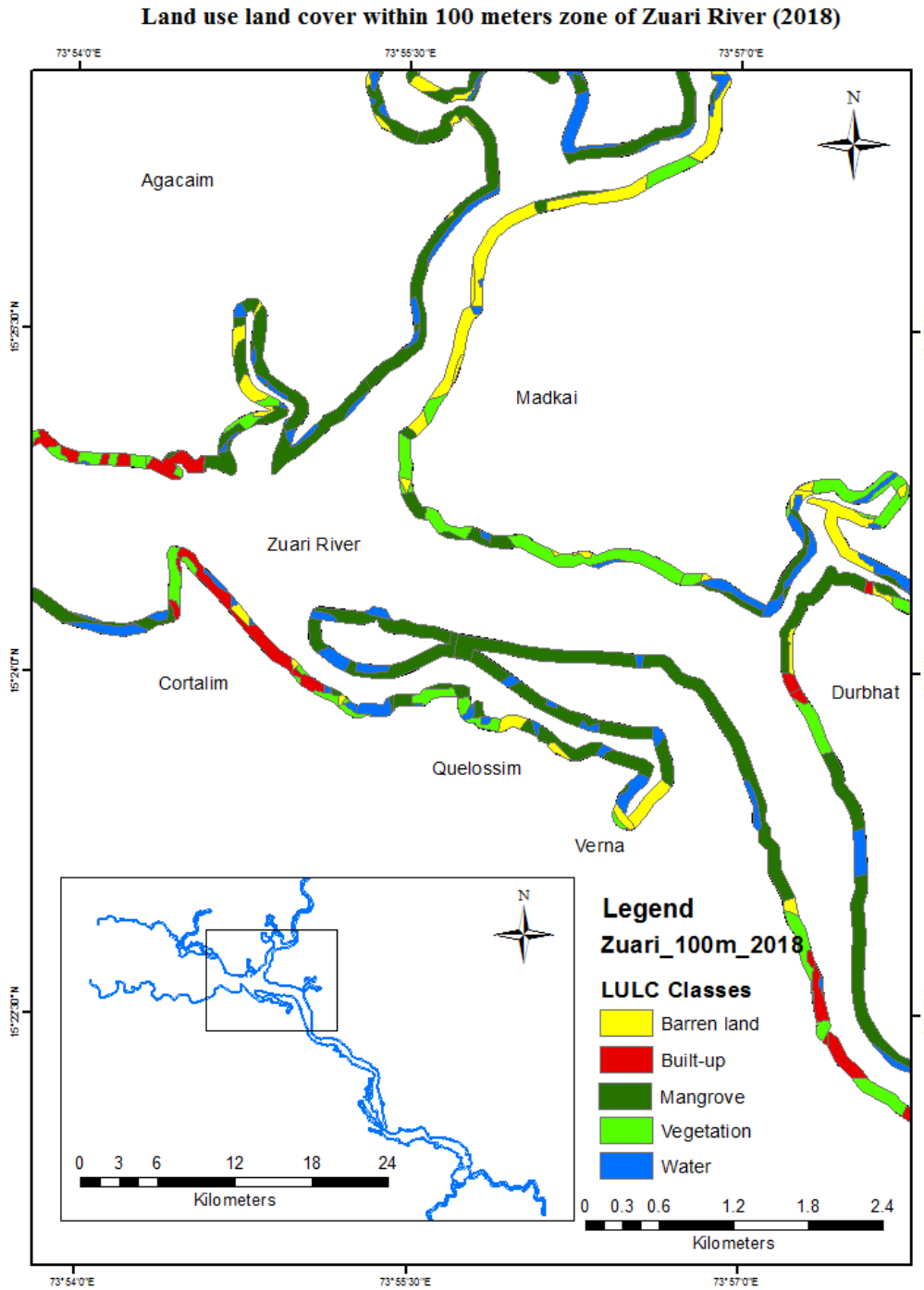


Fig. 3: LULC changes within 100 meters zone of Zuari River (2018).

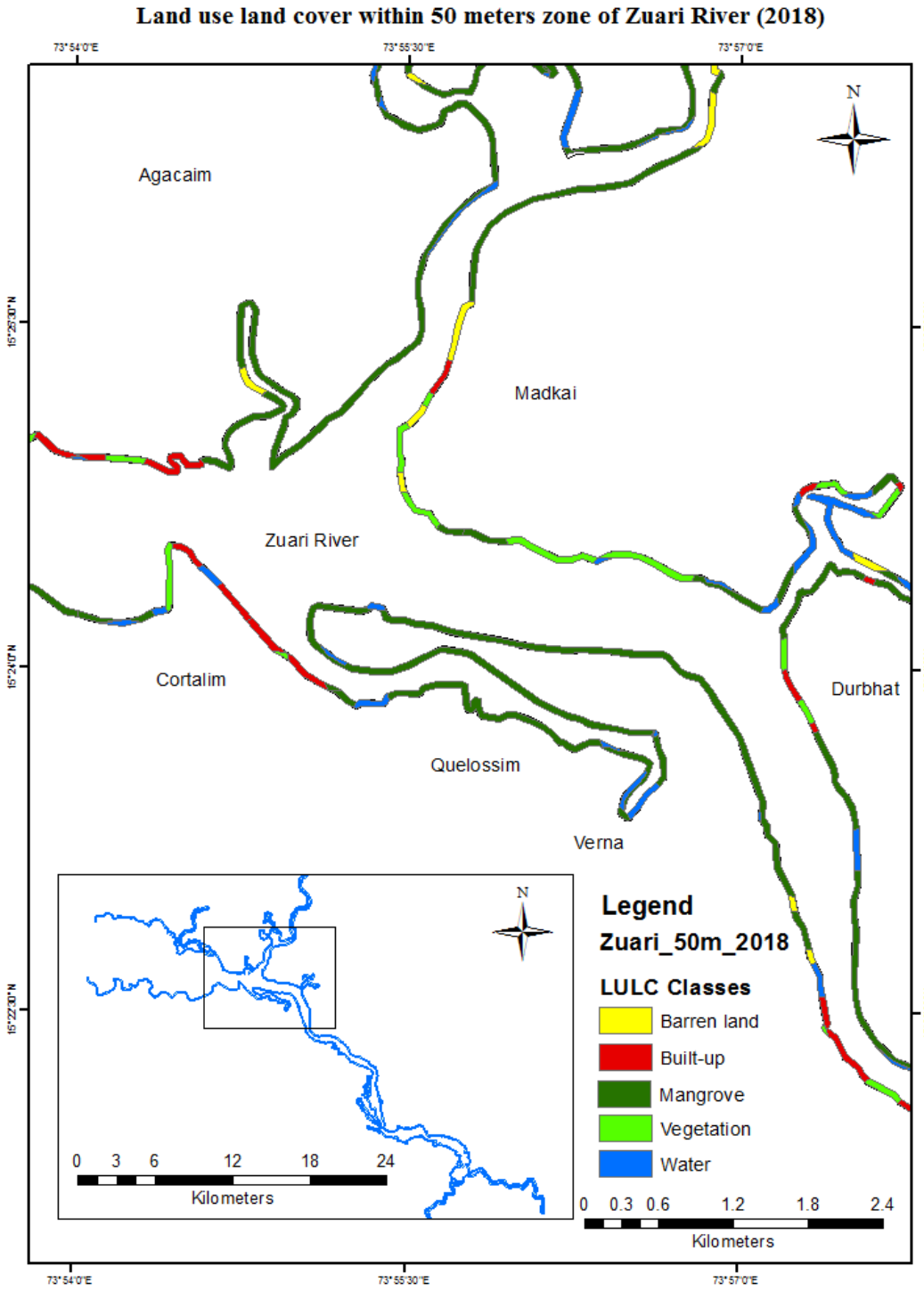


Fig. 4: LULC changes within 50 meters zone of Zuari River (2018).

Similarly, in the year 1991, the area under barren land, built-up, mangroves, vegetation, and water in Mandovi river was 6.79 $km^2$, 1.44 $km^2$, 6.70 $km^2$, 8.55 $km^2$, and 3.59 $km^2$ respectively. Whereas, in the year 2018, the area under barren land, built-up, mangroves, vegetation, and water in Zuari river was 3.84 $km^2$, 2.35 $km^2$, 6.40 $km^2$, 11.06 $km^2$, and 3.42

km$^2$ respectively. In the case of the Mandovi river, over 27 years, the area under built-up and vegetation have increased by 0.91 km$^2$ and 2.51 km$^2$ respectively. But, the area under barren land, mangroves, and water is found to have decreased by 2.95 km$^2$, 0.3 km$^2$, and 0.17 km$^2$ respectively. Figs. 5, 6, 7 and 9 represent LULC changes within 100 m and 50 m zones of Mandovi river. Fig. 11 depicts the conversion of the LULC classes in the Mandovi river from 1991 to 2018. Figs. 12 and 13 are glimpses of mangroves in the Zuari and Mandovi rivers.

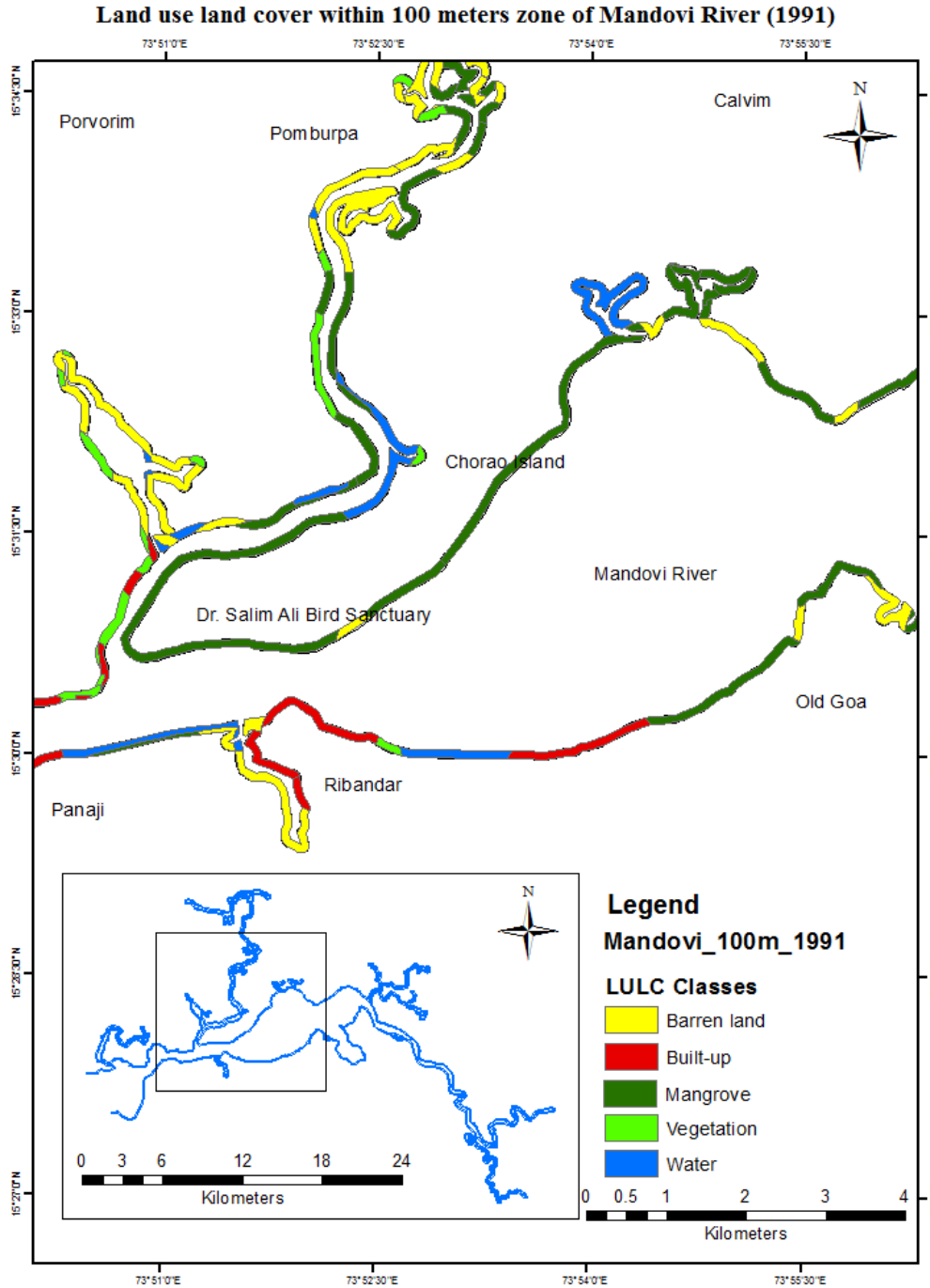


Fig. 5: LULC Changes within 100 meters zone of Mandovi River (1991).

As per the CRZ Notification of 2018, the regulated zone was reduced to 50 m from HTL. With the reduction in the CRZ demarcation, human interference is likely to increase leading to more hap-hazardous and unplanned development within the zone, thereby making mangroves vulnerable to degradation. From the findings, it was observed that a major portion of the mangrove is present within 50 m of the high tide line. Upon reducing the CRZ limit to 50 m, depletion

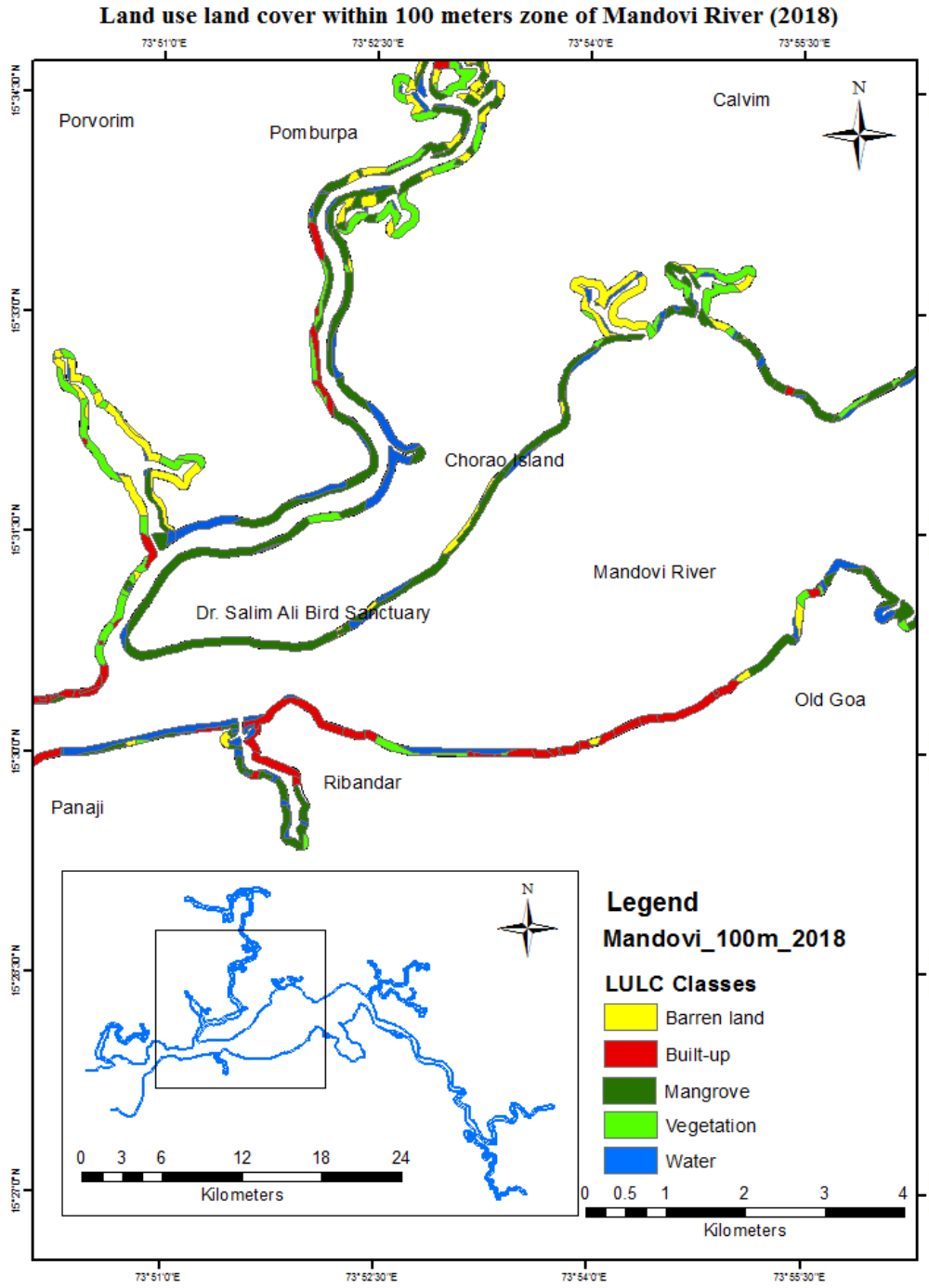


Fig. 6: LULC changes within 100 meters zone of Mandovi River (2018).

of mangroves will occur definitely, and the mangrove ecosystem will almost cease which we cannot afford to lose. The proportion of mangrove cover is 3.90 $km^2$ and 4.65 $km^2$ respectively within the 50 m zone of the Zuari and Mandovi rivers. The mangroves are vulnerable to changing land use patterns likely to arise with the implementation of a 50 m regulation zone. Agarwal (2019) stated that inefficient and inadequate monitoring of the demarcated CRZ coupled with increasing human interference is placing the mangroves at immense threat and overall the absence of monitoring the regulation by the government poses additional threats.

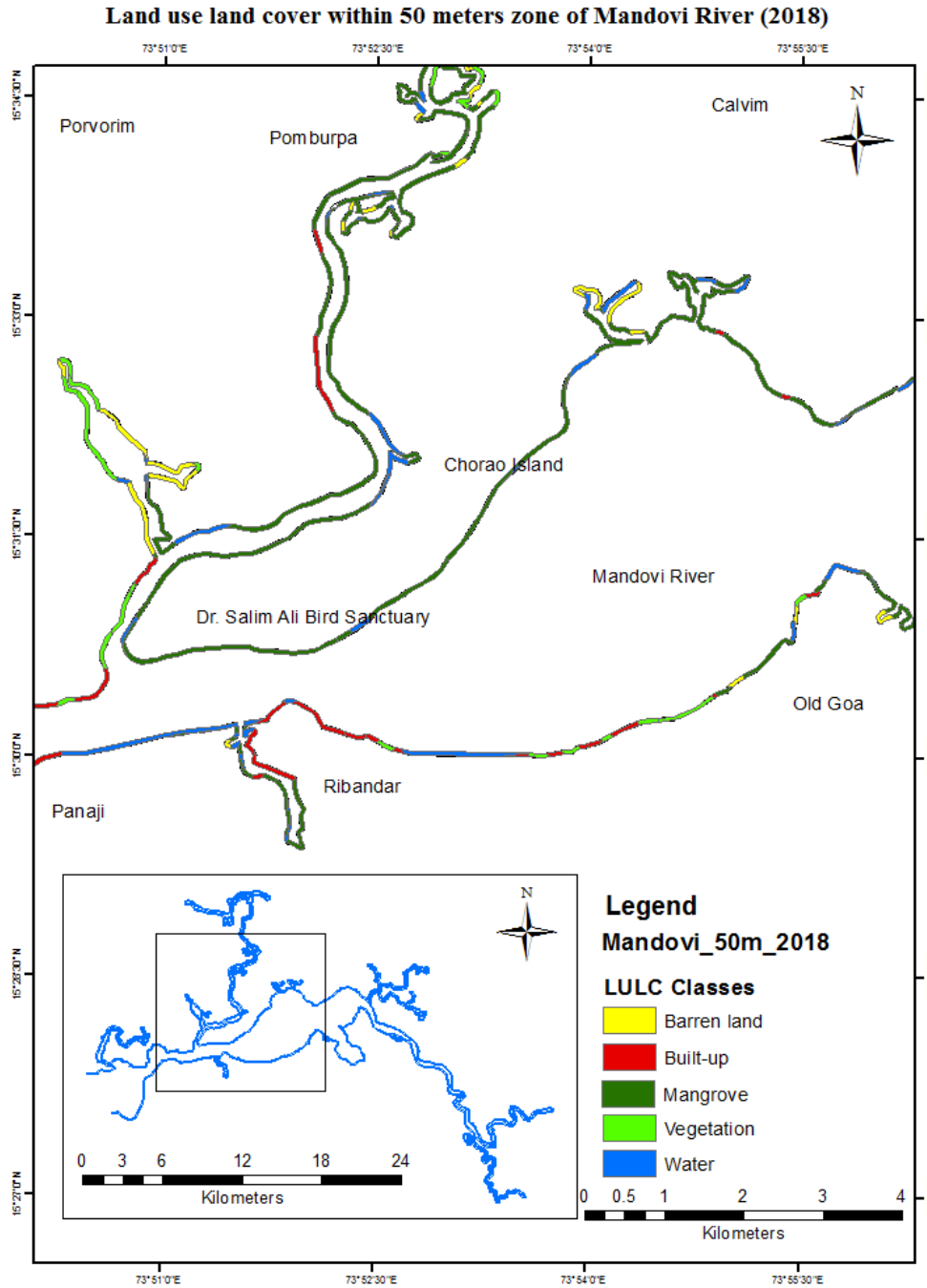


Fig. 7: LULC changes within 50 meters zone of Mandovi River (2018).

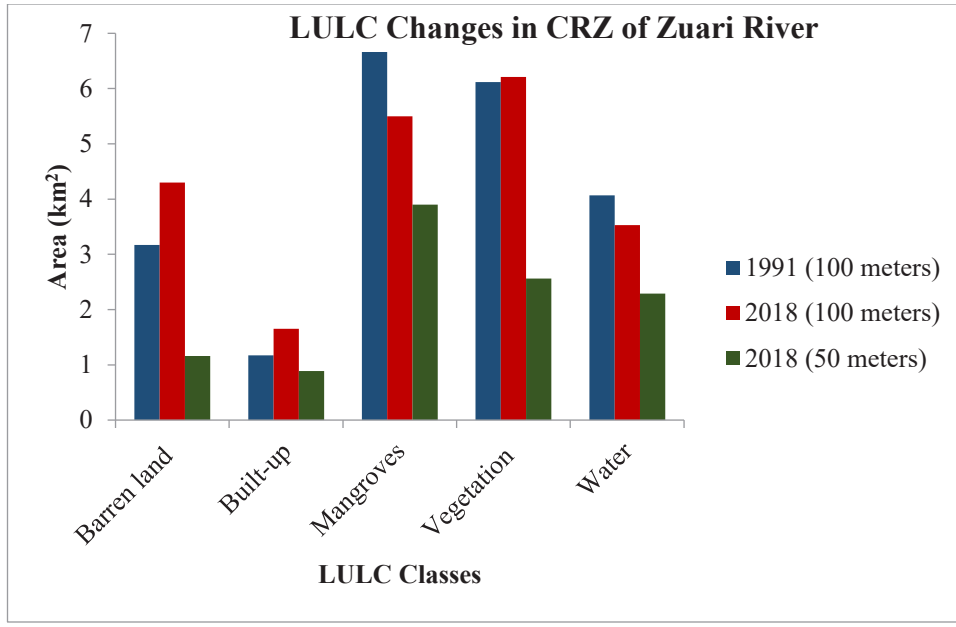


Fig. 8: LULC changes in 100 meters and 50 meters zones of Zuari River.

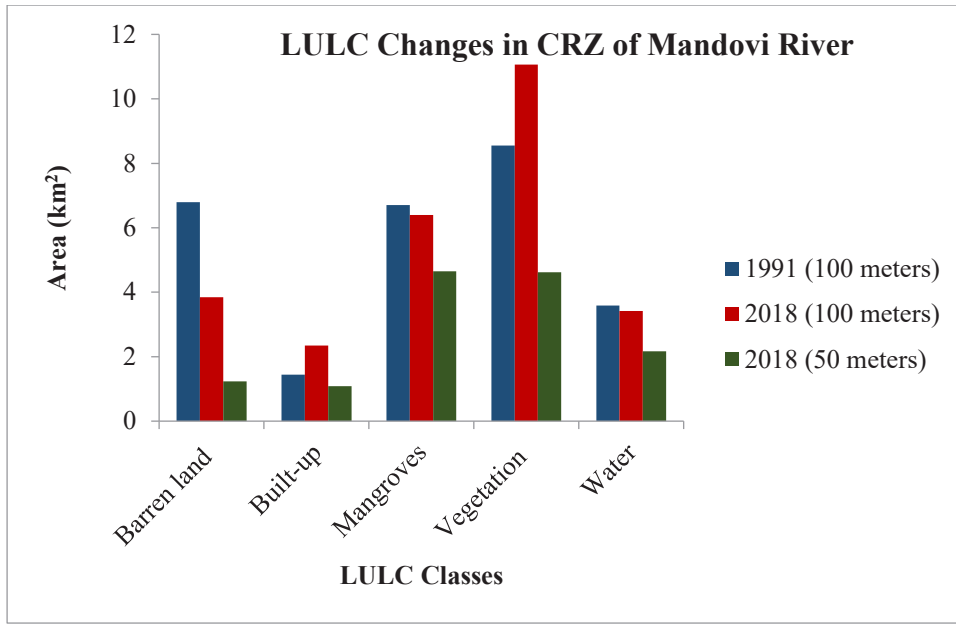


Fig. 9: LULC changes in 100 meters and 50 meters zones of Mandovi River.

Recent developmental activities including settlements, construction of bridges, road widening, and land reclamation constitute major negative changes in the HTL zone of both the rivers. Moreover, agriculture and aquaculture, plantations, and salt extraction activities are dominating the areas formerly covered by mangrove vegetation. Several of the activities mentioned here cause direct or indirect damage to the environment such as habitat fragmentation, the natural loss of available resources, and the addition of pollutants thereby affecting the water quality, etc. This indicates the vulnerability of mangroves to the changing land use pattern. Despite the formulation of regulation, coastal and estuarine areas are under threat from unplanned and hap-hazardous human activities.

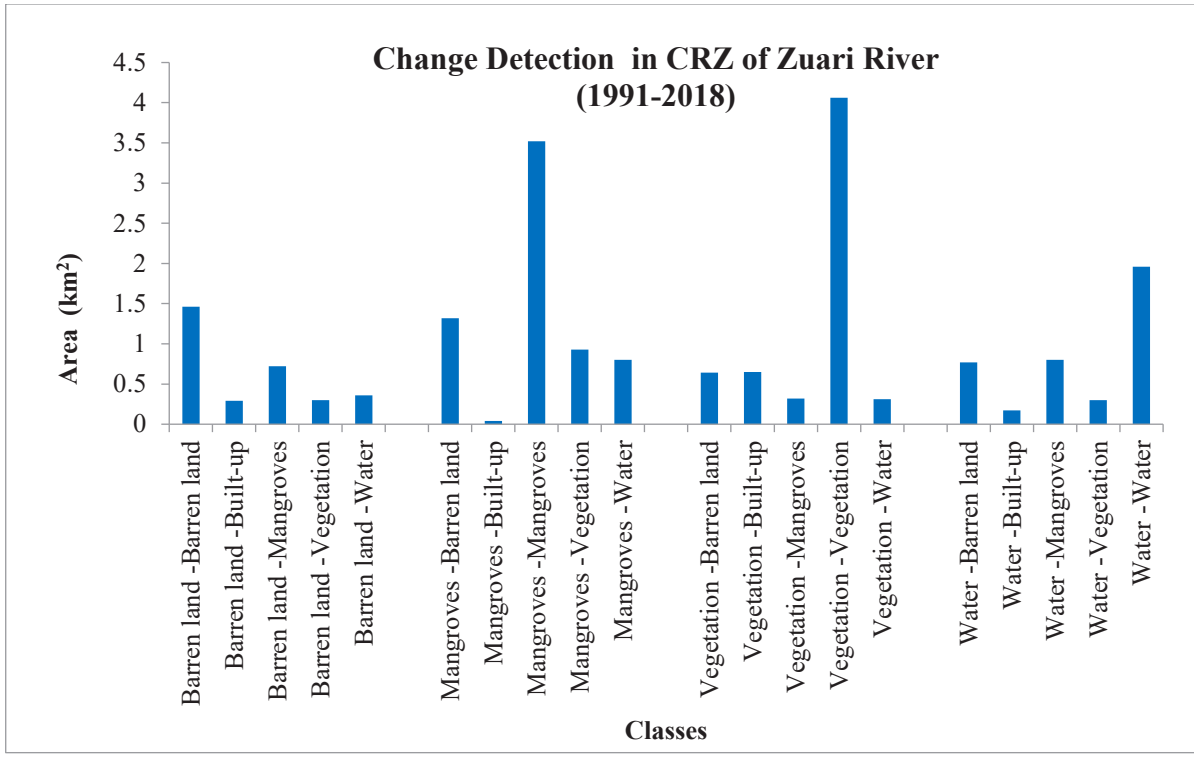


Fig. 10: Change detection in 100 meters zone of Zuari River (1991-2018).

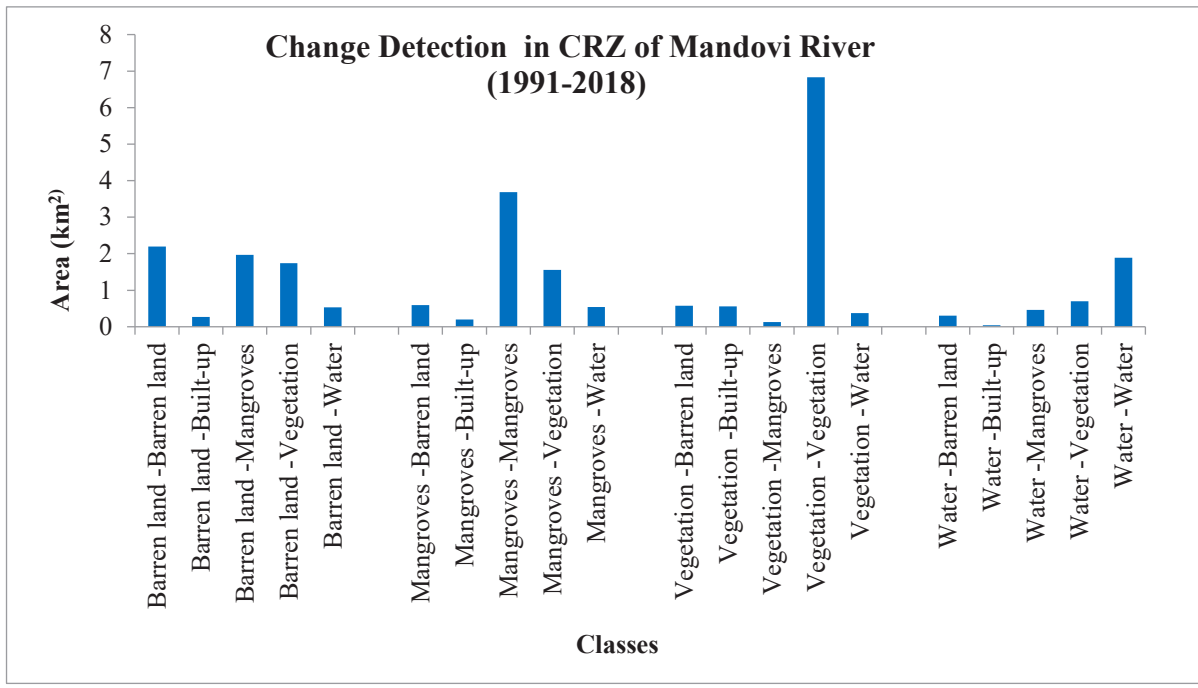


Fig. 11: Change detection in 100 meters zone of Mandovi River (1991-2018).

Fig. 12: Mangroves in Zuari river. (Source: Field visit)

Fig. 13: Mangroves in Mandovi river. (Source: Field visit)

## CONCLUSION

From the above study it was found that, over 27 years, the land use land cover pattern in CRZ of Mandovi and Zuari rivers has undergone changes which can be attributed to the interference of human activities followed by a lack of implementation and monitoring of rules and regulations and as well as natural factors. Over 27 years, there has been an increase in the area of some land use classes in the Zuari river such as barren land, built-up, and vegetation by 1.13 $km^2$, 0.48 $km^{2,}$ and 0.09 $km^{2,}$ and a decrease in mangroves and water class by 1.16 $km^2$ and 0.54 $km^2$. In Mandovi river, an increase in the area has been observed for built-up and vegetation by 0.91 $km^2$ and 2.51 $km^2$, whereas the area under barren land, mangroves, and water has decreased by 2.95 $km^2$, 0.3 $km^2$ and 0.17 $km^2$.

Increasing anthropogenic interference in the regulated zone is making mangroves more vulnerable to degradation. Mangroves are the most important ecosystem and yet the most fragile. Regardless of their importance, the mangrove ecosystem remains threatened. Threatened by rising sea levels, storm surges, and human interventions (Pramanik 2014, DasGupta & Shaw 2013b). Its role in maintaining biodiversity, reducing the impact of natural disasters, and providing a source of livelihood is often ignored due to a lack of awareness (Avatar et al. 2021).

Uncontrolled and hap-hazardous development needs to be replaced by sustainable development. Government individually or in association with NGOs or Private partners should undertake the rejuvenation of areas under mangroves. This herculean task requires proper surveys, documentation, and mapping. Organizing plantation drives and encouraging people's participation could go a long way in saving the fragile ecosystem for posterity. There is a need for special implementation for the regulation of the riverine ecosystem i.e. River Regulation Zone (RRZ) to monitor human interference along the river banks. This regulation needs to be propounded and should be implemented at the earliest for preventing further damage to the mangrove ecosystems. Moreover, sustainable tourism can be promoted in mangrove areas to create awareness about the mangrove ecosystem amongst the people and generate a source of livelihood amongst the locals.

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