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Spatiotemporal Change Detection of Coastline with Satellite Remote Sensing for Environmental Management

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SUMMARY

The Vasai creek, the Manori creek and the Thane creek are estuarine creeks in the Arabian Sea near Mumbai. This area has the highest economic development rates in India. In this estuarine area, extensive land use change including embankments was observed and various constructions have taken place due to rapid urbanization and industrialization. Improper and unplanned sustainable coastal zone management may lead to severe environmental problems such as sea water intrusion, coastal erosion, siltation of river channels and land subsidence, etc. This study evaluates the utility of satellite remote sensing imageries by deploying multi- temporal Landsat series satellite data like Multispectral scanner (MSS), Thematic mapper-5 (TM5) and Operational land imager (OLI) and high-resolution Google earth imagery including a topographic map of Mumbai also. From the change analysis performed through this study, huge variations in the position of the coastline were observed. The Thane creek shows very drastic change near Sewri while Vasai creek near Rai village. The Manori creek shows an overall shrink in its area. At some places on the coastline, large sediment depositions were observed. The Jawaharlal Nehru (JLN) port trust area shows vast change due to the encroachment of sea water. In 1954, the area where current JLN port trust is established has only 0.65 km2 area, but after land reclamation and development in sea water for JLN port trust, the area converted to 3.94 km2 in the year 2015, depicting a vast change of area as 0.5 km2 per year. One of the most noticeable impacts of coastline changes in the study area is the narrowing down of all estuarine creeks at many places and extension of JLN port trust into sea water. Coastline and coastal area change detection are important for environment planners and to protect coasts from climate change.

Keywords: Coastal zone, Coastline change detection, Satellite remote sensing, Spatiotemporal change.

1. INTRODUCTION

Identification and mapping of changes in coastline is very important for sustainable coastal resource management, environmental protection and safe navigation. Mumbai, the commercial capital of India, is situated on the western coast of India. The Mumbai coastline and its adjoining areas are one of the fastest developing regions of India. Rapid urbanization and industrialization in the area have resulted in an extensive change in land use and consequently loss of significant amount of arable land.

At the same time, lack of appropriate land use planning and measures of sustainable development have led to several environmental problems, such as land subsidence, the intrusion of sea water, siltation of river channels and erosion and sedimentation along the coast (Li and Damen, 2010). Land and water resources can be characterized and measured using estimation and assessment of coastline. Coastline mapping and change detection are essential for safe navigation, resource management, environmental protection, and sustainable coastal development and planning (Di *et al*., 2004). Most of the time the enormous development pace of the coastal area may not be detected and gradual changes in coastline may not be observed. However, remote sensing can be an effective tool to map the changes in a fast and cost-effective way (Chen and Rau, 1998; El-Asmar, 2002; Shaghude *et al*., 2003; Chong, 2004; Hennecke, 2004,

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Li and Damen, 2010). Carter (1978) investigated the applicability of satellite images for data collection on wetlands and found quite satisfactory results. Krishna (2012) has also successfully detected urban change and development of Noida, UP, India using satellite data. The spatial resolution of the satellite images, (i.e. Landsat-MSS), was limited to 80 meter, at the time when Frihy *et al*. (1994) identified the pattern of shoreline changes in the Nile Delta. Catastrophic social and economic problems may rise due to rapid shoreline changes. The design of viable land-use and protection strategies to reduce potential loss is necessary and this requires comprehension of regional shoreline dynamics (Blodget *et al*., 1991). The geomorphic processes of erosion and sedimentation, periodic storms, flooding and sea level changes continuously modify shoreline and human activities greatly influence such natural processes. In India, coastal wetland, land use and landform and shoreline-change maps have been produced on 1:250,000, 1:50,000 and 1:25,000 scale using IRS LISS-I, II and III, LANDSAT MSS/TM and SPOT data (Nayak, 2002). But, coastline change detection study at finer resolution is still lacking. Besides this, coastal areas have very high economic importance, therefore, protection strategies to reduce potential loss is necessary and this requires comprehension of the actual current status of coastline dynamics. Keeping these in view the present study was undertaken to delineate the rate of change of the Mumbai coastline in the last 60 years.

2. RESEARCH METHODOLOGY AND DATA USED

The research methodology followed to achieve the objectives is shown in the following flow chart (Fig. 3). The image data were acquired from Landsat series satellites and the necessary processing was done. To delineate the coastline, classification of scenes was performed and the coastline was extracted using various techniques. The classification of raster data was performed using Isodata algorithm. The class water was separated from all other classified layers and separated water layer was converted into vector file. This vector file was in polygon form, therefore, polygon to polyline conversion was performed and hence coastline was extracted. After that the coastline was corrected by visual interpretation. The same process was applied for each year's image. The coastline from toposheet was digitized manually. The spatiotemporal change was quantified by overlaying all coastlines at one place. The overall methodology is depicted in Figure 3.

2.1 Data collection

The study area (Fig. 1) was Mumbai (India) and its suburbs (18^0 55'N, 72^0 54'E). To analyze the changes in coastal line, primary data in the form of satellite data and secondary data as topographic map were used. The satellite data from Landsat series satellites were acquired for analysis which includes one scene each from Landsat MSS for 1973, Landsat TM for 1990 and Landsat OLI 2015. Secondary data includes a topographic map of the year 1954. Details are listed in Table 1.

Table 1. Satellite data and topographic data used in the study

Satellite data/ Topographic map	Acquisition day	Local time	Spatial Resolution/ Scale
Landsat4 MSS	22-03-1973	05:06	60 meter
Landsat5 TM	09-03-1990	04:54	30 meter
Landsat8 OLI	10-02-2015	05:33	30 meter
SOI Topographic map- NE 43-01 & NE 43-05	1954	-	1:250,000

2.2 Imagery pre-processing

To make imagery more interpretable, pre-processing of the imagery was performed *i.e.,* layer stacking, georeferencing, FCC creation and study area subset. In order to keep the same coordinates, the topographic map was registered in UTM projection. All Landsat scenes were already projected in UTM projection with the WGS1984 datum, 43 North zone. These Landsat scenes were just geo-corrected to

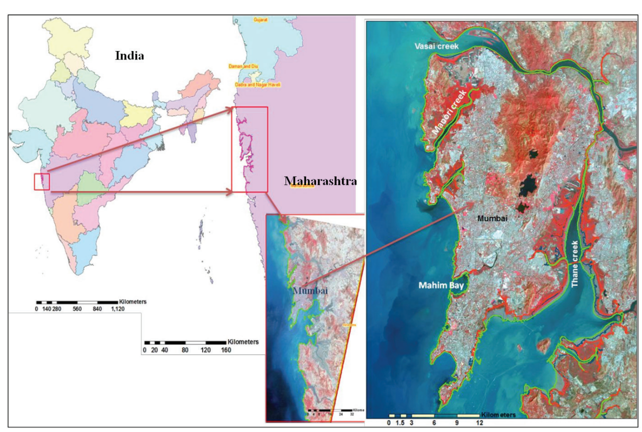

Fig. 1. Location of study area in India and Landsat-8 OLI imagery of the area with coastline of year 2015 overlaid

match with each other. Different bands false color composites were found suitable for visual image interpretation. For MSS, band combination 6, 5 and 4; for TM, band combination 4, 3 and 2, and for OLI, band combination 5, 4 and 3 for RGB was found suitable. Above combinations were found suitable for vegetation identification as well as to discriminate between land and water confluence. Li *et al.* (2010) found that bands 7, 4 and 2 for RGB was found to be most effective for mapping coastline and river band, while the bands 3, 2 and 1 for RGB to be most effective for suspended material and composition of bands 4, 3 and 2 for RGB to be most effective for vegetation.

2.3 Visual and digital analysis

The coastline is considered as the boundary between sea-water and land. To delineate coastline from satellite data, Isodata classification was performed on satellite-borne scenes and the discriminating class was identified. This discriminating class was separated from rest of the classification using decision tree classifier. This single class was converted to vector and then from polygon to polyline (Fig. 2). On the basis of visual interpretation, this coastline polyline was modified. This process was repeated for each scene and coastline was delineated. The Survey of India (SOI) topographic map of the year 1954 was georeferenced and digitized for coastline delineation.

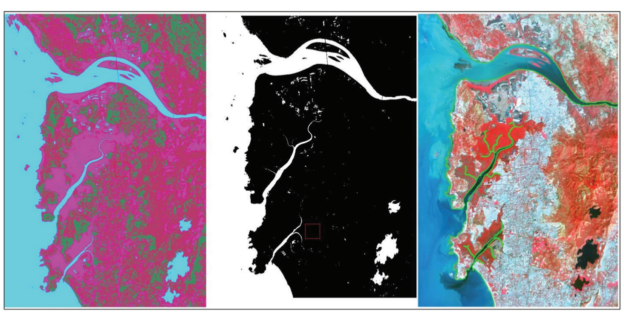

Fig. 2. Process of coastline extraction from satellite data: Classified Imagery (left), extraction of water layer from the classified image (middle), extraction of coastline – Green colored (right)

2.4 Identification of coastline changes

After that coastline from Landsat MSS for the year 1973, Landsat TM for the year 1990, Landsat OLI for the year 2015 and topographic map of 1954 were extracted; they were overlaid together for detection of changes over the period. To highlight the local changes, sub-maps of creeks and other areas were created (Fig. 4, Fig. 5 and Fig. 6).

2.4.1 Jawaharlal Nehru Port Trust area

Jawaharlal Nehru port trust area is located in the southern direction of the study area and has increased 5 times in the last 63 years. With a very high economic growth rate in recent years and ambitious projects of the port development authority, this area has seen significant change over time. The coastline changes in this region are one of the largest changes in the study area. The main reason behind the changes is the land reclamation in the sea, especially opposite to Elephanta island. The port area is located in Sheva area of Mumbai (Fig. 4). This port area, for instance, expanded rapidly after 1954, from a surface area of only 0.69 km. sq. up to 1.20 km. sq. in 1973. The average rate of expansion in this period is computed as almost 0.03 km. sq. per year in 19 years time span. This trend increased until an area of 2.16 km. sq. in 1990 up to even 3.94 km. sq. in 2015, with growth rates of 0.06 km. sq./year and 0.08 km. sq./year respectively (Table 1).

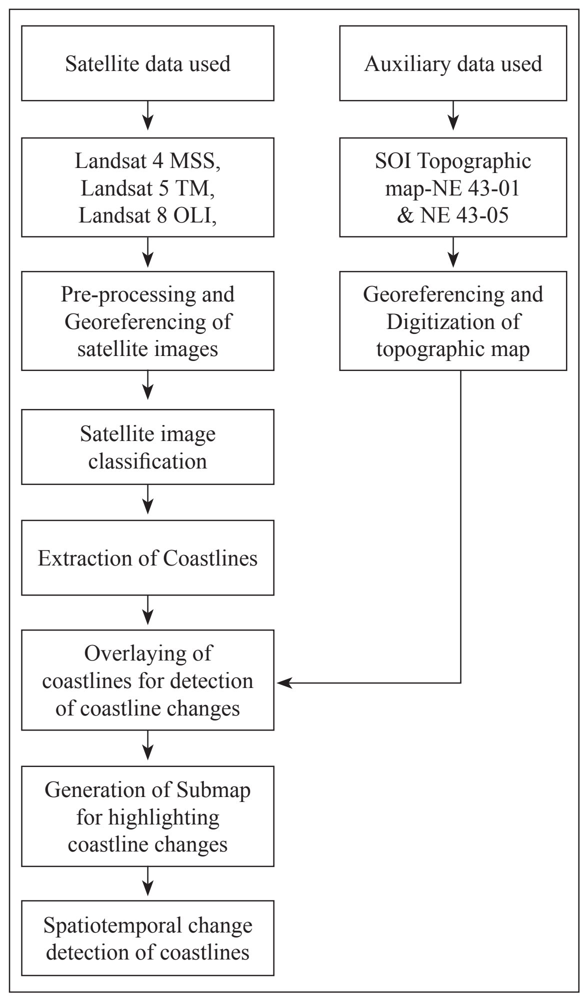

Fig. 3. Schematic diagram of methodology

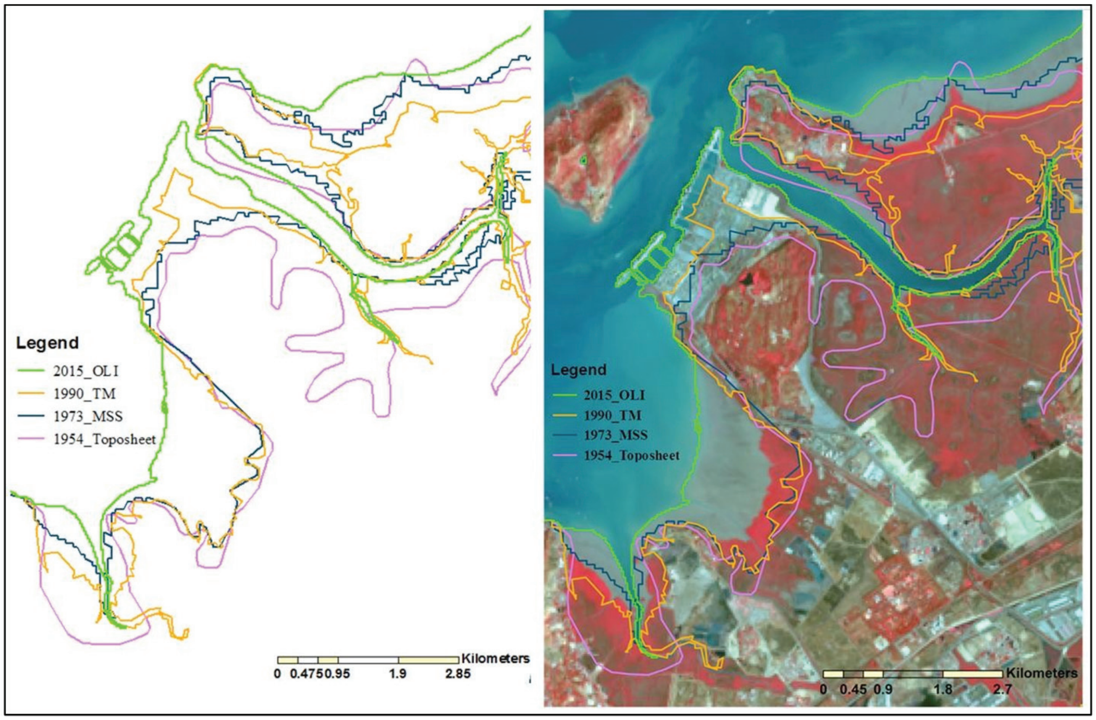

Fig. 4. Jawahar Lal Nehru Port Trust area- coastlines of different years (left), coastlines of different years overlaid on Landsat 8 OLI image (Right)

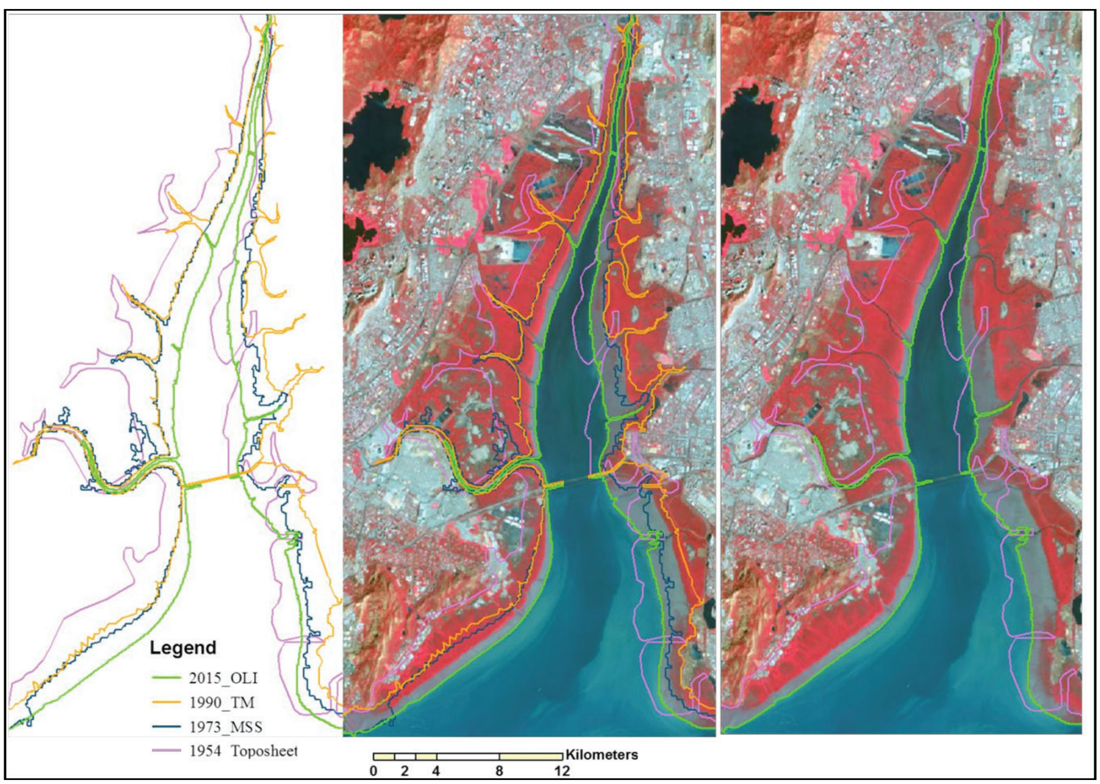

Fig. 5 Thane creek- coastlines of different years (left), coastlines of 1954, 1973, 1990 and 2015 years overlaid on Landsat 8 OLI image (Middle), coastlines of 1954, and 2015 years overlaid on Landsat 8 OLI image (Right)

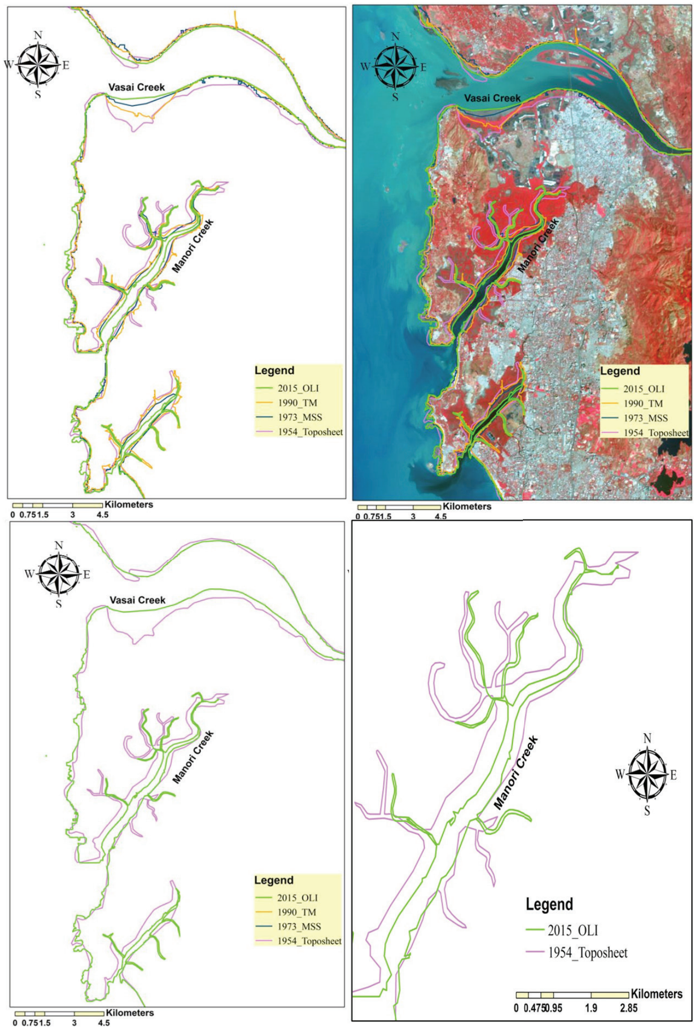

Fig. 6. Vasai and Manori creeks- coastlines of different years (upper left), Vasai and Manori creeks- coastlines of different years overlaid on Landsat- 8 OLI (upper right), Vasai and Manori creeks- coastlines of year 1954 and 2015 (lower left), Manori creek- coastlines of year 1954 and 2015 (lower right)

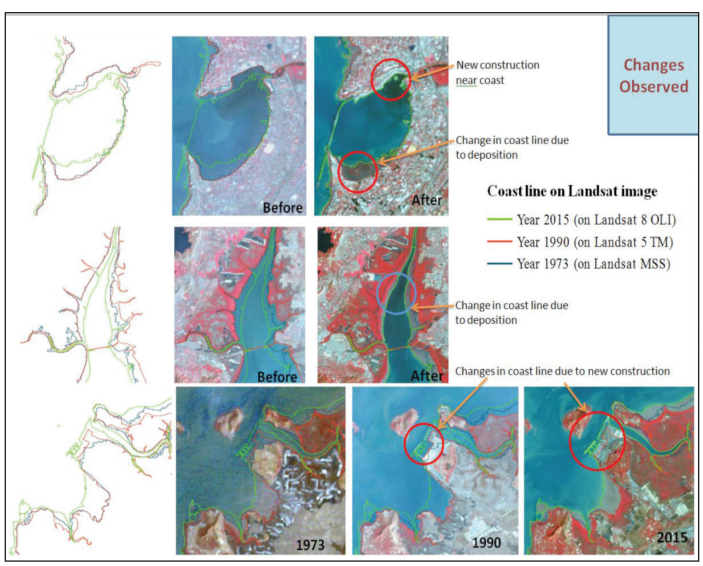

Fig. 7. Change at various places due to deposition and construction

2.4.2 The Thane creek

The Thane creek is an outlet to Ulhas River into the Arabian Sea. Precisely it is a section from where the Ulhas River flows from the north of Mumbai Island to meet the Arabian Sea on the west. The formation of Thane creek is a result of seismic fault situated below it which runs from Uran to Thane. This area exhibits narrowing down of the creek over the time. The adjacent areas of this creek are Thane, Mulund, and Ghatkopar. This creek found to be narrowed down (Fig. 5) after from a surface area of 46.88 km. sq. in 1954 to 39.23 km. sq. in 1973, 35 km. sq. in 1990 and 25.07 km. sq. in the year 2015. A gradual shrinkage was recorded after 1954. In the year 1973, 0.4 km. sq./year change in coastline was recorded while 0.25 km. sq. rate of change for the time between 1973 to 1990 and 0.67 km. sq. rate of change between 1990 and 2015 period was observed.

2.4.3 Vasai creek and Manori creek

Vasai creek and Manori creeks are located in the North-West part of the study area. Vasai creek is the creek where Vaitarana river flows from the east of Mumbai to meet the Arabian sea on the south. The Manori creek is located in the North-West part of Mumbai below Vasai creek (Fig. 6). Compared to the coastline of Thane creek, Vasai Creek almost remained same during the period of study from 1954 to 2015. The Vasai creek decreased from 29.55 km^2 in 1954 to 26.24 km^2 in 1973, to 26.01 km^2 in 1990 and 23.52 km^2 in 2015. However, the Vasai Creek near Dongri showed significant changes as seen from latest satellite image of year 2015. The highest change was observed for the period 1954 to 1973 (11.2 %) due to construction activities as observed from the satellite data. The changes in coastline were 0.9 and 9.6 % during 1973 to 1990 and 1990 to 2015, respectively. An overall change in Vasai creek area was 0.097 km^2 in 63 years duration. The highest change was observed for the period 1954 to 1973 due to construction activities as observed from the satellite data. The overall change statistics is shown in Table 2, for all of the creeks.

The area statistics of Manori creek also depicts an overall shrinkage for every subsequent year. The overall area of this creek was 7.35 km^2 which got decreased to 6.00 km^2 in 1973 (0.07 km^2 change/year), 5.19 km^2 in 1990 (0.05 km^2 change/year) and 2.97 km^2 in 2015 (0.09 km^2 change/year). An overall 40% decrease with 0.07 km^2 change per year due to shrinking of coastline was observed during 1954 and 2015 time period (Fig. 7).

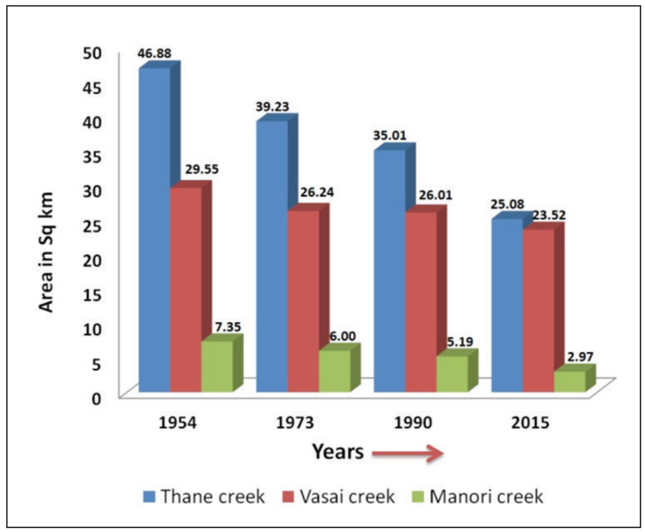

Fig. 8. Change in the area (km^2) vs. Years, for Thane, Vasai and Manori creeks

3. CONCLUSION

The coastline change study of Mumbai and its suburb from 1973 to 2015 depicts that JLN port trust area in 2015 has increased 6 times compared to the

Table 2. Area figures of harbour and creeks with change rate

Time	Image/ Topographic map	JLN Port Trust /km^2		Thane creek/ km^2		Vasai creek/ km^2		Manori creek/km^2	
		Area	Change Rate	Area	Change Rate	Area	Change Rate	Area	Change Rate
1954	SOI Topographic map	0.69	-	46.88	-	29.55	-	7.35	-
1973	Landsat MSS	1.20	0.03	39.23	0.40	26.24	0.17	6.00	0.07
1990	Landsat TM	2.16	0.06	35.01	0.25	26.01	0.01	5.19	0.05
2015	Landsat OLI	3.94	0.08	25.08	0.40	23.52	0.10	2.97	0.09
	Overall Change	-	0.05	-	0.35	-	0.097	-	0.07

year 1954 primarily due to the construction of new port by invasion in sea territory. The land reclamation was the main reason for coastline change in this area. The Thane creek, the Vasai creek and the Manori creek also shrinked due to sedimentation and land reclamation during the same period; Thane creek by 46.50%, Vasai creek by 20.40% and Manori creek by 59.59%. The study positively contributes in the arena of coastal area change detection and management. Use of geo-information techniques in such type of studies is very useful for environmental and natural resources managers for planning and policy making.

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