

Study of Land Reclamation and its Influence on Mumbai's Coastline and Implications for Proposed Projects

Sponsored by

Mumbai Transformation Support Unit (MTSU),
All India Institute of Local Self Government (AIILSG)

Final report

Part 1 of 4

January 2016



	<p>सीएसआईआर – राष्ट्रीय समुद्र विज्ञान संस्थान CSIR-NATIONAL INSTITUTE OF OCEANOGRAPHY (वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद) (COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH) दोना पावला, गोवा भारत / DONA PAULA, GOA - 403004 India फ़ोन/Tel : 91(0)832-2450450/ 2450327 फैक्स /Fax: 91(0)832-2450602 इ-मेल/e-mail : ocean@nio.org http:// www.nio.org</p>	
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Executive Summary

Present Mumbai city has been shaped by the socio-economic and political forces since the 17th century. Its shoreline has since then been altered in shape, size and profile. Land reclamation in Mumbai during the eighteenth and nineteenth centuries was mainly for two reasons:

- a) To expand the land mass for agriculture and horticulture as well as for urban use and infrastructure development (for example, Mumbai port, various causeways, Marine Drive, Nariman Point, among others). The seven islands as well as the Salsette Island in the north of Mumbai were home for just 10,000 people in the mid seventeenth century while it is inhabited presently by more than twelve million people. The Metropolitan region, which is almost ten times larger than Mumbai city, has over twenty one million people. Mumbai is one of the densest cities in the world with an average density of nearly 25000 persons per sq. km.
- b) To mitigate the adverse impact of natural coastal environment and to protect the life and property as well as health of the population, their economic activities, and mitigate risks of natural disasters, such as erosion and flooding.

Growing population and infrastructural demands continue to pose challenges in the Mumbai Metropolitan Region in terms of availability of land and sometimes land reclamation from the sea becomes necessary. Government of Maharashtra is committed to preserve and protect the natural environment of the ever-growing and ever-changing Mumbai region. It is sensitive to the cause of environmental sustainability and plans to improve the infrastructure facilities with minimal impact to the environment.

In this background, Government of Maharashtra wanted to carry out a comprehensive scientific study on the impact of past land reclamations as well as potential impact of proposed / conceptualised developmental projects on the coastal environment of Mumbai region. The Mumbai Metropolitan Region Development Authority (MMRDA) assigned this task to Mumbai Transformation Support Unit (MTSU). MTSU prepared detailed Terms of Reference (TOR) for the study and following due procedure, assigned this task to CSIR–National Institute of Oceanography (CSIR-NIO), Goa. The main objectives of the study are

to assess the impacts on the Mumbai shoreline due to past reclamations as well as proposed/ conceptualised projects as outlined below:

- a) Expansion of Financial Center near Colaba Causeway and present Nariman Point, as suggested in the Concept Plan for Mumbai Metropolitan Region (2012-2052) prepared by MTSU through the international consultants M/S Surbana of Singapore for MMRDA. The proposed/ suggested project envisages restoration and expansion of the financial district of south Mumbai and to protect the fishermen's habitats and livelihoods as well as creation of waterfront promenade with public amenities and a green, attractive waterfront.
- b) Creation of sweet (fresh/potable) water lake at the Mahim Bay, drawing and storing water from the Mithi River.
- c) Coastal Road on the western edge of Mumbai as proposed by the Municipal Corporation of Greater Mumbai.

The assignment entrusted by MTSU was accepted by CSIR-NIO, Goa and a project was undertaken with the following scope of work:

- i. To assess the shoreline and morphological changes along the select regions of Mumbai coast using the available past data and past efforts in land reclamation done by any agency.
- ii. Measurement and modelling of physical processes for assessment of impact of selected reclamation projects on Mumbai Coast.
- iii. To assess the morphological impacts due to earlier and proposed reclamation, i.e. erosion and deposition, silting and sedimentation along the coastline.
 - a) Hydrodynamic impact, i.e., tidal levels, waves, sea level changes, changes in currents and in mud flats and mangroves.
 - b) Impact on aquatic life due to water turbidity and changes in the level of sedimentation near and around reclaimed area as well as due to industrial/urban effluent, primarily based on available secondary data and studies.
 - c) Biological impact on mangroves, intertidal vegetation, mud flats, grasses on sand dunes etc. and subsequent regeneration, if any; and also impact of mangrove destruction on the composition of soil and its acidic contents, which

could have adverse impact on the RCC foundations of buildings constructed on such soil, primarily based on available secondary data and studies.

The study was undertaken to address the above scope of work and the summary of the results is presented below in various categories viz., (a) Land use / land cover / shoreline changes through remote sensing, (b) present physical coastal processes, (c) assessment of impact on physical processes through numerical modeling, and (d) environmental impacts due to proposed projects and recommendations.

Land use / land cover / shoreline changes through remote sensing:

The present study has been taken up to assess the spatial and multi temporal land use/ land cover changes of Mumbai during 1972-2015 using Landsat satellite data. Most of the available datasets, such as a) Topographic sheets, b) Satellite images, c) Published available data, and d) Historical maps were used in this study. Multi temporal datasets observed by Landsat Multi Spectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager and Thermal Infrared Sensor (OLI&TIRS) were used for the years 1972, 1977, 1991, 1998, 1999, 2000, 2001, 2002, 2003, 2005, 2009, 2011, 2013, 2014 and 2015. These satellite images were classified and accuracy was assessed and tabulated as overall accuracy and kappa coefficient. It was found that the overall accuracy was above 83% with a kappa coefficient of above 0.80 for all the years.

Land use/ Land cover changes:

It is evident from the results that built up land has expanded from an area of 172.5 sq. km in 1972 to 319.7 sq. km in 2015, almost a 100% increase over a period of 42 years. Rapid urbanization phase is markedly seen from 1972 to 1998. Thereafter there is a steady increase of built up land from 1999 to 2015. The transition matrix reveals that 30 sq. km of barren land and 31 sq. km of vegetation have been converted to urban land since 1991. Although the main changes occurred in these two classes of land, 13 sq. km of fallow land also contributed to the urbanization in Mumbai. Conversion of fallow land into urbanization is noticed in Mira Bhayandar and a few parts of Thane. Fallow land of 25.41 sq. km was demarcated in 1972 which was found reduced to 8.56 sq. km in 2015. There is a gradual decrease in the vegetation cover from 73.80 sq. km to 54.02 sq. km during the period from 1991 to 2015. This decline in vegetation cover over the 25-year period accounts for 27%.

Forest region in the study area was about 65.54 sq. km. The encroachment of built up space over the national park is a notable feature. Forest land of 5 sq. km is converted to built up area during the period 1991- 2015. Barren land of 30 sq. km has been converted into built up land. Barren land shows an average area of 76.83 sq. km. The main transformations in barren land have occurred in the Mumbai suburban and Thane regions of the study area. From the above analysis, it is seen that the urban growth over the study area has totally transformed the face of Mumbai region.

Mangroves are the most important land cover along the Mumbai coastline. Mumbai is rich in mangroves all along the creeks. The major creeks of Mumbai area are the Manori creek, Malad creek, Mahim creek, Mahul creek, Thane creek, and the Vasai creek. Manori creek was marshy in the 1990s with small patches of mangroves. Later on, marshy areas have changed to mangrove region. The present condition of the Manori creek is that there are thick mangroves along the creek. Almost the same situation is with the Malad creek. Mahim creek along the sides of the Mithi River also shows presence of Mangroves. It can be clearly demarcated from the study that the sides of Mithi River with mangroves were converted to built-up space in the later stage. Mangroves are present all along the sides of Thane creek. Study showed that the width of the mangroves over the Thane creek has increased. Vasai creek in the northern part of the Mumbai region showed an increase in the mangrove cover. Some area on the sides of the Malad creek has been transformed into barren land during 1991 to 2015. Cuffe Parade and Versova regions of Mumbai also have mangrove patches. However, overall area of mangroves in Mumbai has increased from 56.50 sq. km to 65.90 sq. km during the period 1991 to 2015, i.e., a net increase of 9.40 sq. km. It is noticed from the land use / land cover classification of the area that 0.06 sq.km of mangroves were present in the Cuffe Parade in 1991. It has decreased to 0.03 sq. km in 2015. Thus, almost 50% reduction in the mangrove cover has happened in Cuffe Parade. In case of Mahim, there is a reduction of 39.91 % of mangroves, which occurred along the sides of Mithi River. Juhu Moragaon showed an increase of 47.88% of mangroves along the Juhu beach sides.

Analysis shows that marshy area increased from around 44 sq. km in 1972 to around 55 sq. km in 1977. Thereafter it shows a sharp decline over the years to fall to 16.43 sq.km of area in 1991. It has further reduced to 8.47 sq. km in 2015. The decline in marshy area of 8 sq. km almost matches with the corresponding increase in mangroves in Mumbai during the period from 1991 to 2015.

Shoreline changes:

Accretion / erosion of land along the shoreline is primarily a natural phenomenon occurring due to the impact of currents, tidal waves and sea changes. Human intervention through land reclamation also changes the shoreline. It was generally observed that the western coast of Mumbai which is exposed to the direct ocean / sea currents and waves showed greater propensity for erosion except in same creek areas where small accretions also happened. Accretions happened relatively more on the eastern Thane creek due to low tidal and current action in the relatively sheltered area.

During the 75 years from 1879 to 1954, highest erosion of 1137 m and the highest accretion of 1291 m are observed on the mouth of Mahul creek. The highest accretion has occurred because of the construction of the Mumbai port. Higher level of accretion is also found from Juhu till Mahim bay, and the port region and Colaba. During 1926-1954, accretion is observed mainly along the open sea side and erosion found mainly through the Vasai creek. The highest accretion of 336 m as well as highest erosion of 293 m are observed in the regions near Mira Bhayandar. During 1954 – 1970, highest accretion of 1137 m and highest erosion of 302 m are observed in the Colaba region. Higher levels of accretion are found in the Colaba region as well as near Nariman point. Other places are showing accretion/ erosion at lesser rates. The major eroded regions are North of Malabar hill, Cuffe parade and the northern side of Colaba region.

The net shoreline changes from 1972 to 2015 provide a clear idea about the shoreline changes of the study area. Thane creek has experienced high accretion due to siltation and subsequent growth of mangroves. The north-west regions have eroded at different rates; particularly the shorelines from the mouth of Malad creek to Juhu beach have undergone significant erosion at different rates. South-west parts show combination of accretion and erosion but within 50 m range. This indicates a stable coastline in these parts of the region. Apart from a few patches of mangrove growth, the northern parts can also be defined as stable coast. A few patches of higher erosion can be seen in the north-east region, having the highest erosion of 182 m. Highest accretion is observed near Trombay due to the creation of a new bund.

The overall shoreline change from 1879 to 2015 is shown in the main report (Fig. 4.10). Accretion is dominating over erosion at the few parts in the open sea area. Higher ranges of accretion are mostly along the creeks. In the open sea stretches, the range of accretion is less compared to the creeks. Erosion is also observed near the foot of the Malabar hills. The major accreted spots are Juhu beach, Colaba and along the creeks.

Sea Level Rise impacts:

Impacts of Sea Level Rise (SLR) along the Mumbai coast were also studied. 1 m rise in SLR would inundate an area of 57.21 km², of which more than 50% are under mangroves or mudflats as of today. It must be noted that this is a serious issue for urbanized areas, because 9.5 km² (17%) of the vulnerable region is built-up land. Most of these vulnerable built-up areas are located in the northwestern side, near Mira Bhayandar.

SLR of 2 m may cause inundation of 91.74 km². In which case, 16.15 km² (18%) of built-up area would be submerged in water. 31.04 km² (34%) of the vulnerable area is presently covered by mangroves. Most of the mangrove area within the study area would be vulnerable to the SLR. This can adversely affect the mangrove forests in Mumbai.

SLR of an unlikely 3 m may cause inundation of an area of 134.09 km². The percentage of built up land and mangroves covered in the total vulnerable area will further go up by 2% and 3% respectively.

Prevailing physical processes:

The measurements of waves, tides and currents off Mahim were carried out during 21st November to 10th December 2014 and between 25th November 2014 and 17th December 2014 off Colaba.

The significant wave height off Mahim during the measurement period varied between 0.17 m and 1.04 m and maximum wave height varied from 0.26 to 1.62 m. The mean wave period varied between ~4 seconds and 8 seconds. The predominant wave direction is observed to be from west for location off Mahim whereas it is observed to be predominantly from south at Colaba, which could be due to the waves refracting at this location. The spectral width parameter is observed to vary between 0.3 and 0.9.

The wave measurements off Colaba showed that the significant wave height varies between 0.07 and 0.8 m and the maximum wave height varies between 0.11 and 1.2 m. The mean wave period was observed to vary between 3.8 and 6.7 seconds. The spectral width parameter is observed to vary between 0.35 and 0.75.

Based on the wave measurements during the November-December 2014 (post monsoon season), the wave climate off the study region in general is ascertained. The wave heights at Colaba are comparatively lower than those at Mahim, which is due to the specific features of the location. Measurements off Mahim were carried out in an area which was directly exposed to the open sea conditions whereas at the Colaba measurement site, the waves tend to get dissipated due to shoaling. This was observed to be the cause for reduced wave climate at the Colaba measurement location.

Water currents were measured off Mahim bay at mid depth in water, 8m below Chart Datum (CD). The maximum and average current speed was of the order of 0.63m/s and 0.22m/s respectively. The currents in this region were tide dominated with the current direction varying with tide. The current rose plot clearly shows that the flow is predominantly tide driven with the flow in NNE – SSW direction. Variation of currents measured at Colaba was at water depth of 7 m CD. The maximum current speed was of the order of 0.3 m/s and the average current speed was of the order of 0.11 m/s. The currents were tidal driven with the direction changing with tide.

The tidal current components off Mahim, especially the dominant north components, were of the order of $\pm 0.4\text{m/s}$ whereas the non-tidal components were of the order of $\pm 0.125\text{m/s}$. At Colaba, the north tidal current components were of the order of $\pm 0.2\text{m/s}$ and the non-tidal components were of the order of $\pm 0.05\text{m/s}$. Based on the analysis of measured currents off Mahim and Colaba, it is observed that the flow in the study region is primarily influenced by tides as the tidal components are larger than the non-tidal components.

Numerical modelling of impacts on physical processes:

The hydrodynamics off the Mumbai coast are ascertained through measurements and validated numerical models. The numerical models used in the study provide reliable and reasonable results pertaining to hydrodynamics of the region.

Reclamation of Backbay area at Colaba – Nariman Point for financial district expansion as proposed in the Concept Plan would result in localised increase in flow speeds and associated erosion is envisaged. However, the overall hydrodynamics off the Mumbai coast will remain unaffected by this reclamation.

The Concept Plan proposal for closure of Mahim bay might provide fresh water storage facility but it is observed that, the creation of a sweet water lake would have significant effect on the hydrodynamics of the region. Increased flow speeds on an average by 10% and increased tide levels by 10% are observed in the study region in the simulated model, due to closure of Mahim Bay. This would consequently adversely influence the coastal morphology, including destruction of mangroves and marine flora and fauna.

Proposed reclamation of areas along the west coast for coastal road facility is also observed to influence the hydrodynamics of the region with an increase in flow speeds by about 20% and the water levels by about 10%, similar to that of closure of Mahim Bay, as seen through the simulation. However, the morphology changes are observed to be localised, and only closer to the reclaimed areas.

Environmental Impacts due to proposed projects & Recommendations:

The economic advantage of Mumbai, therefore, needs to be balanced with ecological resources (loss of coast, mangroves, beaches etc.) by adopting a purposeful but cautious approach to achieve sustainable development.

Proposed Backbay Reclamation for Financial District:

The proposed boundary for reclamation at Backbay would add an overall area of 1.10 sq. km. The area is close to existing built up land, and Cuffe Parade fishing village, and part of it is a small area of barren land, vegetation, mudflats as well as water body. Major part is near the built up/urban land which is 0.73 sq.km and water bodies of 0.27 sq. km. Vegetation, barren land and mudflats areas are 0.04, 0.02 and 0.04 sq. km respectively. The proposed project will transform additional 0.37 sq. km of area into built up land at the cost of other classes.

For the case of Back bay reclamation, it is recommended to modify the proposed reclamation plan for the region abutting the coast so as to form a streamlined coast to minimize the flow concentration and consequent erosion of shore and coastal areas. The proposed reclamation may not adversely affect much of the character of the coast if the above recommendations are followed.

Proposed Barrage at Mahim bay:

Concept Plan (2012-2052) had proposed a barrage near Mahim bay, to augment sweet water capacity for urban use by storing water flowing from Mithi River during Monsoon. The proposed plan is to create a fresh water reservoir in the Mahim bay by constructing bund to stop ingress of sea water into the Mahim Bay. This change of salt-water bay into sweet water lake would substantially affect the environment around the bay and the riverbanks of Mithi River, consisting of mangroves and mud flats. The proposed plan would transform 0.31 sq. km of water body and mudflats into bund construction and reclaimed land for recreation at the mouth of the bay.

It is strongly recommended to revisit the proposed / conceptualised sweet water lake at Mahim Bay. The closure of the bay with a bund wall would increase local hydrodynamics and flow velocity from 3% to more than 20%. The cost benefit analysis of the Mahim Bay closure should also consider the impacts of increased force on the prevailing coastline. This would also lead to additional erosion problems, which would need additional and expensive shore protection measures. Most importantly, the existing mangroves and marine aquatic life will be lost forever. Looking to the present ground realities of flow of solid and liquid waste into the Mithi River, the proposed lake will not serve its intended objective. CSIR-NIO would not recommend this proposal as it might seed many other unexpected environmental problems.

Proposed Coastal Road:

The proposed coastal road extends from Kandivali in the north to the Nariman point in the south. The coastal road would be created by various means i.e. through reclaimed land, covering existing land, bridges constructed over mangroves, tunnel under the Juhu Beach and Malabar hill etc. Hence, these areas of water bodies, vegetation, barren land and mudflats are expected to undergo major changes. 1.32 sq. km of area is expected to be added to the

existing land area for construction of coastal road, of which 0.37 sq. km will be reclaimed from mudflats region and 0.93 sq. km from the water bodies. These are the main classes of areas, which will be affected by the reclamation as per the draft proposal. In case the proposal is modified, it has to be re-assessed as per the new alignment.

The model simulations for the case of reclamation for the proposed coastal road facility showed increased water levels, increased flow speeds, and consequent increased bed level changes in the project region. However, the water flow was smooth along the coastline stretches where the proposed reclamation had smooth transition with the existing coastline. It is therefore recommended that reclamations should be done only with smooth transition and not in a zig-zag alignment. It is also recommended that the overall project of coastal road should be planned and executed with minimum interference to the existing environment.

To sum up, any modification to the prevailing coastline and bathymetry will result in altering the hydrodynamics and morphology of the region. It is therefore essential to consider the effects of the altered hydrodynamics when proposing any changes or construction in the coastal region. It is also recommended that the local hydrodynamic changes need to be observed for a longer period than the short span measurements taken in the present study schedule. A periodic and comprehensive information on the hydrodynamics of the coastal region of Mumbai over annual scales would be useful for management of coastal region of Mumbai not only to protect the coastal urban settlements but also to protect the environment and take precautionary measures to mitigate potential negative impacts on them.

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Chapter 1

1 INTRODUCTION

1.1 Background

Mumbai has been shaped by the socio-economic and political forces since seventeenth century. The seven islands, acquired by the British East India Company, eventually were developed into a thriving port and city by the middle of eighteenth century. Purposeful human interactions with the natural endowments, resources and geography of Mumbai Islands completely altered the shape, size and profile of its shoreline. Over the years, the character of the Metropolitan Region has also changed dramatically. Land assembly to cater to the needs of the fast growing economy and population and related infrastructure development in Mumbai was largely by reclaiming land from the sea and assembling seven islands into a single Island city of Mumbai. The process continues even now in the suburban areas as well as in the region.

Land reclamation in Mumbai during the eighteenth and nineteenth century was mainly for two reasons:

- a. Expanding the land mass for agriculture and horticulture as well as for urban use and infrastructure development (for example, Mumbai port, various cause ways, Marine Drive, Nariman Point, among others). The seven islands as well as Salsette islands in the north of Mumbai were home for just 10,000 people in the mid seventeenth century while it is inhabited presently by more than twelve million people. The Metropolitan region has over twenty one million people. Mumbai is one of the densest cities of the world with an average density of nearly 20000 persons per sq. km.
- b. Mitigation of the adverse impact of natural coastal environment and to protect the life and property as well as health of the population, their economic activities, and mitigate risks of natural disasters, such as erosion and flooding.

The ecological endowments in the Mumbai Region were enhanced, modified and shaped for the economy during the colonial period. Search for land for the surging economy and increasing population has not diminished even during the period after independence. In the face of the changing global economy, position of Mumbai as the financial capital of India has not diminished but on the contrary, reaffirmed. The economic advantage of Mumbai, therefore, needs to be balanced with ecological resources (loss of coast, mangroves, beaches etc) by adopting a purposeful but cautious approach to achieve sustainable development.

1.2 Objectives

The main objectives of the study are:

1. To assess the impacts on the Mumbai shoreline due to proposed projects as outlined under:
 - a. Expansion of Financial Center near Colaba Causeway and present Nariman Point, as suggested in the Concept Plan for Mumbai Metropolitan Region (2012-2052) prepared by Surbana for MMRDA. The proposed project envisages restoration and expansion of the financial district of south Mumbai and to protect the fishermen's habitats and livelihoods as well as creation of waterfront promenade with public amenities and a green, attractive waterfront
 - b. Creation of sweet (fresh/potable) water lake near Mahim Bay, drawing water from Mithi River.
 - c. Coastal Road on the western edge of Mumbai as proposed by the Municipal Corporation of Greater Mumbai.
2. Document the outcomes resulting from past reclamations in Mumbai on the physical attributes of its coast - **morphology, territory, hydrology, aquatic life, marine biology and ground water, among others, including** qualitative assessments in terms of the intensity (high, medium, low) as well as its nature (adverse, neutral or beneficial). Such documentation will require identification and study of technical (from various public, semi-public and private agencies) and academic (in different but related fields) studies conducted over the past few decades since land reclamation has been conducted in Mumbai.
3. Using the outcomes of reclamation identified above, establish a list of lessons learned about reclamation. Based on the lessons learned, create likely scenarios of possible outcomes of proposed projects (what is likely to happen if the proposed projects are implemented as planned and what issues, challenges and benefits are likely to present themselves, how they may be addressed and which agencies/entities are best placed to be responsible for addressing them).

1.3 Activities carried out related to this project (Scope of the work)

This section contains an overview of the activities to be carried out under the study, as listed in the ToR. The study is focussed on physical attributes of Mumbai's coast, enlisted below, to facilitate state departments and urban local governments to take informed decisions on various proposed development projects in the Mumbai region and which may have a component of land reclamation. The scope of the work is as follows:

- i. To assess the shoreline and morphological changes along the select regions of Mumbai coast using the available past data and past efforts in land reclamation done by any agency.
- ii. Measurement and modelling of physical processes for assessment of impact of selected reclamation projects on Mumbai Coast.
- iii. To assess the morphological impacts due to earlier and proposed reclamation, i.e. erosion and deposition, silting and sedimentation along the coastline.
 - a. Hydrodynamic impact, i.e., tidal levels, waves, sea level changes, changes in currents and in mud flats and mangroves.
 - b. Impact on aquatic life due to water turbidity and changes in the level of sedimentation near and around reclaimed area as well as due to industrial/urban effluent, primarily based on available secondary data and studies.
 - c. Biological impact on mangroves, intertidal vegetation, mud flats, grasses on sand dunes etc. and subsequent regeneration' if any; and also impact of mangrove destruction on the composition of soil and its acidic contents, which could have adverse impact on the RCC foundations of buildings constructed on such soil, primarily based on available secondary data and studies.

Most of the available datasets such as a) Topographic sheets, b) Satellite images, c) Published available data and d) Historical maps were used in this study.

This report is sub-divided as shown below

Chapter 1 Introduction

Chapter 2 Study area

Chapter 3 Landuse/land cover studies

Chapter 4 Morphological changes

Chapter 5 Measurements

Chapter 6 Numerical modelling

Chapter 7 Impact on aquatic life

Chapter 8 Impact on Mangroves

Chapter 9 Conclusions



Chapter 2

2 STUDY AREA

2.1 Introduction

The study area, Mumbai (previously known as Bombay till 1995) is the densely populated, metropolitan and capital city of the state of Maharashtra and financial capital of India. It lies between the latitude from 18.80 N to 19.32 N and longitude from 72.77 E to 73.01 E. It is bounded by the Arabian Sea in the west and Ulhas River in the east. It is the low lying coastal city which ranks fifth largest among the cities of the world.

Mumbai was originally composed of seven islands namely, Colaba, Old Woman's island or Little Colaba, Bombaim, Mazagaon, Mahim, Worli and Parel. These islands were joined through reclamation of the intervening shallow sea parcels, which formed the present Mumbai Island city. The study area comprises mainly three regions. They are the Mumbai island city, Mumbai suburban areas and Thane. Southern tip of the island Mumbai city covers the financial centres, Nariman point, World Trade Centre. The central part of the Metropolis covers with Sanjay Gandhi National park with three lakes, Vihar, Powai and Tulsi. Vihar and Tulsi lakes are located inside the Sanjay Gandhi national park. Mangroves are the trademark of Mumbai's coastline which is found in the Manori, Malad, Mahim, Mahul, Thane and Vasai creeks of Mumbai. Major part of the Thane district comprises the 3rd region of the Metropolitan region.

Mumbai experiences a tropical wet and dry climate. The climate of the region is characterized by an oppressive summer, dampness in the atmosphere nearly throughout the year and heavy south – west monsoon rainfall from June to September. The mean average temperature is 27.2°C and average precipitation is 242.2 cm. The mean maximum average temperatures are about 32°C in summer and 30°C in winter, while the average minima are 25°C in summer and 20.5°C in winter.

The broad physiographic feature of the Mumbai city is broad and flat terrain flanked by north – south trending hill ranges. The hill ranges from almost parallel ridges in the eastern and western part of the area. The Powai – Kanheri hills ranges are the other hill extending in the eastern and central part running NNE – SSW. The maximum elevation of the area is 450m above mean sea level at some of the peaks of hill ranges. Trombay Island has north – south running hills with maximum elevation of 300 m above mean sea level. Malbar, Colaba, Worli and Pali hills are the isolated small ridges trending north – south in the western part of the district. The Powai – Kanheri hills form the largest hilly terrain in the central part of the Salsette Island

Mumbai is a highly populated city of India. The urban and sub-urban population in Mumbai as per 2011 census is as follows: island city is 30,85,411, Eastern suburb 38,29,973 and western suburb 55,26,989. The population density of the Mumbai city district is 19,652 people per sq.km (Census 2011). The population and slum population in the city and suburbs is increasing very rapidly as the city grows. This is the main threat to the sustainable growth of Mumbai city.

The study area abutting the Mumbai coast is completely encompassed by sea as well as the creek water. The coastal characteristics are very diverse in Mumbai city. These include natural sandy beaches, mangrove forests, mudflats, rocky cliffs, rocky barriers, as well as manmade ports, retaining walls constructed to protect land reclamation and promenades constructed during 19th and 20th century etc.

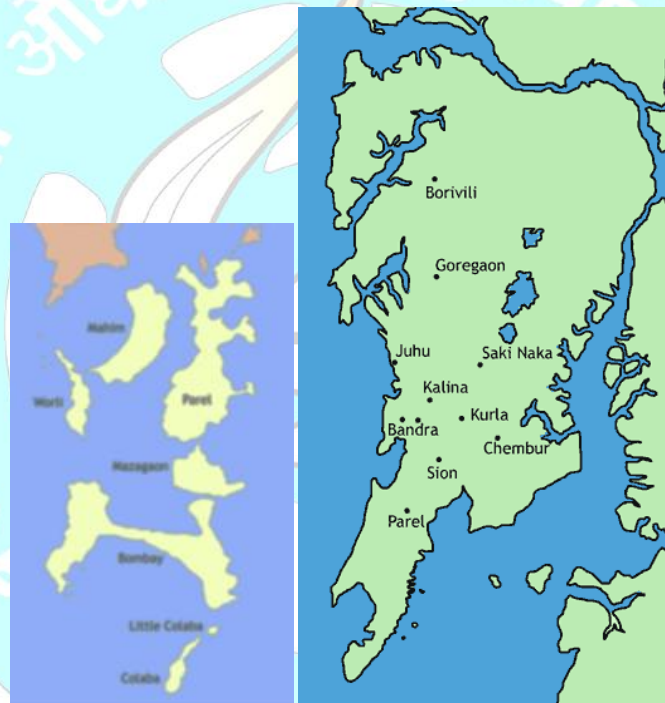


Fig. 2.1. Study area

Chapter 3

3 LAND USE / LAND COVER MAPPING

(Qualitative and quantitative data on impacts of land reclamation on physical attributes of Mumbai coast)

3.1 Introduction

The Earth is rich in natural resources. Land and its resources like forests, wetlands, water etc are the most important phenomena of life. Land use means the use of land by humans or their activities on land whereas land cover means the vegetative part of the land. Land use and land cover became important components due to the socio-economic pressures on the surface.

Rapid growth of population and increase in their demands on environmental resources has led to the expansion of land in an uncontrolled manner and thereby exploitation of natural resources. The Earth which once was covered with greenery has turned into the lands of buildings and pollution. Development in an uncontrolled way will lead to a total deterioration of our earth through many disasters.

The change in the land surface and the anthropogenic activities on the land can be studied using land use and land cover mapping. This study will reveal the changes in the features of land in the Mumbai region during past and present. Thus, it will be more useful to develop measures for attaining sustainability and to mitigate environmental consequences. Remote sensing and GIS data are very cost-effective and freely available. Study of land use/ land cover mapping using remote sensing and GIS is a useful way for extracting different features of land surface.

Megacities like Mumbai, Delhi, Kolkata, Chennai etc are under severe stress due to the growth in the urbanization. Demand for land has increased due to the rapid growth of population and also migration to the megacities. Reclamation of land with encroachment of natural resources leads to the necessity of mapping land use and land cover in these cities. The present study has been taken up to assess the spatial and multi temporal land use/ land cover changes of Mumbai during 1972-2015 using Landsat satellite data.

Reclamation history of Mumbai has been compiled from the available documents and literature sources. "The first reclamation project was started in 1784 where the British governor approved the building of great sea wall which prevented the flooding of low lying areas of Bombay. In the first phase of reclamation (1784-1845), four cause ways, raised well above the sea level, were constructed namely, 1) Hornby Vellard (1784) at Mahalaxmi, which united Cumballa Hill with Worli, 2) Duncan Causeway (1803) which bridged the creek

between Sion and Kurla (Salsette), 3) Colaba Causeway linked Bombay with the two Colaba islands and 4) Mahim Causeway (1845) joined Mahim with Bandra. These reclamation projects joined the islands creating one single land mass known as Bomby Island. Smaller reclamation schemes like Nagpada scheme, Frere Estate, Mody bay Estate, Ballard Estate etc. were implemented in the second phase of reclamation. By 1870s the city had expanded in length to 22 miles (35 km). Back Bay Reclamation Company was incorporated in 1863 to undertake the Back Bay reclamation in the third phase which proved to be the most controversial of the projects of reclamation in Mumbai. Hence one can summarise that the present coastal line configuration and topography of present day Mumbai and its suburbs is not natural but mostly anthropogenic. Similarly the topography and contours of Mumbai Island and its suburban districts are not natural but mostly anthropogenic. The topographic contours of Mumbai have been greatly affected not only by the creation of new land through reclamation for urban settlement but also by the demolition and levelling of hills by quarrying to meet the enormous needs for stone as building material. Reclamations have radically altered the contours of the land topography. However the lack of systematic and efficient and scientific planning for surface water management as well as management of variety of coastal environments found in Mumbai lie at the root of the urban blight situation today. Lack of scientific inquiry, understanding of complex coastal environment and lack of effective management of specific and important natural features of Greater Mumbai have also contributed to the changes in configuration, underwater topography and water circulation in the harbour and its bay (<http://dilernaziya.blogspot.in/2010/04/bombay-to-mumbai-reclamation-of-seven.html>).

3.2 Study Area

Mumbai, one of the megacities of India is located at 18.975° North latitude and 72.8258° E longitude in the state of Maharashtra. Mumbai was bounded by Arabian Sea in the west and Ulhas River in the east. It originally consisted of seven islands namely, Colaba, Old Woman's island or Little Colaba, Bombaim, Mazagaon, Mahim, Worli and Parel. These islands were joined together through reclamation of the intervening shallow sea bed to form the present Mumbai Island city. Study area has mainly three distinct regions. They are Mumbai island city, Mumbai Suburban district and few parts of Thane district. It consists of Sanjay Gandhi National park in the Mumbai suburban region with three lakes; Vihar, Powai

and Tulsi lakes. The climate of Mumbai is tropical wet and dry having a mean average temperature of 27.2 degree Celsius and average precipitation of 242.2cm.

The study area for this study comprises of Mumbai Municipal Corporation area, Mira Bhayander Municipal Corporation area and part of Thane Municipal corporation area as bounded by the Vasai creek and Ulhas river on the north and Thane creek on the east.

A comparison of 1955 toposheet of the U.S army corps and the 2015 Landsat satellite image from usgs.gov.in reveals that the total area of Mumbai (as defined in the study) has increased in the period from 586.81 km² to 635.44 km², an addition of 48.63 km². This is due to narrowing down of creeks and rivers, which can be seen in the result. Mahim bay has widened over the period of 60 years. The reclamation in Colaba region is clearly visible from the comparison of 1955 and 2015 images. Wetlands have increased in the Mahul and Trombay region of Mumbai since 1955 and subsequently urbanized. The study conducted by MTSU through the Geography Department of Mumbai University in 2013 for mapping the land reclamation in Mumbai from 1970 till date, matches with the increase of 48.64 sq. km in the defined study area of the present study. The marginal difference can be attributed to the difference in the study areas of the two studies.

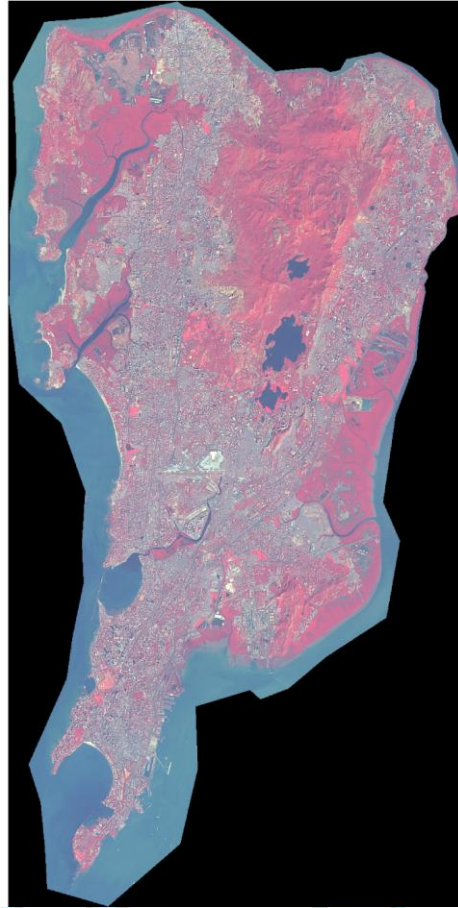


Fig. 3.1. Study Area

3.3 Data Used

Multi temporal dataset observed by Landsat Multi Spectral Scanner (MSS), Thematic Mapper(TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Line Imager and Thermal Infrared Sensor (OLI&TIRS) of 1972, 1977, 1991, 1998, 1999, 2000, 2001, 2002, 2003, 2005, 2009, 2011, 2013, 2014 and 2015. The details of the data used are listed in the table 3.1 below.

Table 3.1 Data Used

Year	Path / Row	Satellite	Sensor	Date & Time of acquisition (GMT)
1972	159 / 047	Landsat 1-3	MSS	10:35:34 AM 10/11/1972
1977	159 / 047	Landsat 1-3	MSS	10:09:04 AM 2/20/1977
1991	148 / 047	Landsat 7	TM	10:23:46 AM 1/7/1991
1998	148/047	Landsat 7	TM	10:40:22 03/15/1998
1999	148/047	Landsat 5	TM	10:42:59 01/13/1999
2000	148 / 047	Landsat 7	ETM+	10:56:24 AM 2/25/2000
2001	148/047	Landsat 7	ETM+	10:53:55 03/31/2001

2002	148/047	Landsat 7	ETM+	10:52:44 03/02/2002
2003	148/047	Landsat 7	ETM+	10:52:30 03/05/2003
2005	148/047	Landsat7(GLS2005)	ETM+	12/07/2005
2009	148/047	Landsat5	TM	10:54:21 12/10/2009
2011	148/047	Landsat 7	TM	10:53:42 01/14/2011
2013	148/047	Landsat 8	OLI & TIRS	11:05:30 04/25/2013
2014	148 / 047	Landsat 8	OLI & TIRS	11:04:32 03/11/2014
2014	148 / 047	Landsat 8	OLI & TIRS	11:04:29 AM 2/23/2014
2015	148/047	Landsat 8	OLI&TIRS	11:04:03 01/09/2015

3.4 Methodology

3.4.1 Data Acquisition

The Landsat data were downloaded from United States Geological Survey (USGS) Earth Explorer. Satellite images of Landsat MSS, TM, ETM+ and OLI&TIRS were downloaded for all the available years with minimum cloud cover and undergone preprocessing stages.

3.4.2 Data Pre processing

Erdas Imagine 2013 software is used for the preprocessing of satellite images. The main stages were;

1. Layer stacking
2. Sub setting of the study area
3. Pan sharpening (ETM+ and OLI&TIRS)

Layer stacking is a process of stacking all the required bands of the data to form a single multi spectral image. It is done using the layer stacking tool in the software. Secondly, the image was sub setted to the region of study. The study area boundary covers Mumbai city, Mumbai suburban and some parts of Thane.

Landsat 7 ETM+ and Landsat 8 OLI&TIRS are having panchromatic band which is the 8th band. Pan sharpening or panchromatic sharpening is the method of enhancing the quality of multispectral images using the panchromatic band. HCS (Hyper spherical Color space Resolution merge) pan sharpening method is used for the present study. This method will improve the contrast and also the resolution will be changed to 15m.

3.4.3 Land use classification scheme

Classification of land use / land cover is followed according to the NRSC level II land use /land cover classification scheme. Thirteen classes were demarcated from the study area. These classes are as follows;

- a) Built up land
- b) Crop land
- c) Fallow land
- d) Plantation
- e) Forest plantation
- f) Mangrove

- g) Aquatic vegetation
- h) Marshy/swampy land
- i) Mudflats
- j) Sandy area
- k) Barren land
- l) Water bodies
- m) Others(Salt pans)

3.4.4 Classification

Land Use - Land Cover (LULC) classification is mainly carried out with supervised classification technique. In supervised classification, spectral signatures are developed from specified locations in the image. These specified locations are given the generic name “training sites” and are defined by the user. Generally a vector layer is digitized over the raster scene. The vector layer consists of various polygons overlaying different land use types. The training sites will help to develop spectral signatures for the outlined areas. Using these signature files, supervised classification is done using Maximum likelihood processing algorithm. The Maximum likelihood is based on the probability that a pixel belongs to a particular class. The classified images were then recoded for every year.

3.4.5 Post-classification

Accuracy assessment is important post classification step for every classified image. The accuracy assessment utility allows you comparison of certain pixels in thematic raster layer to reference pixels for which the class is known (Jenson .J.R 1983). The classification accuracy is most important aspect to assess the reliability of maps, especially when comparing different classification techniques. During this study, the accuracy assessment method were used. Automatic random points are selected by software. Accuracy assessment is done for all the images using ERDAS Imagine2013. Sample areas were selected randomly in each output and Overall accuracy and Kappa statistics were generated. The classified images were then analyzed to compute the areas under LULC class. Percentages were calculated and their changes in each year were analyzed.

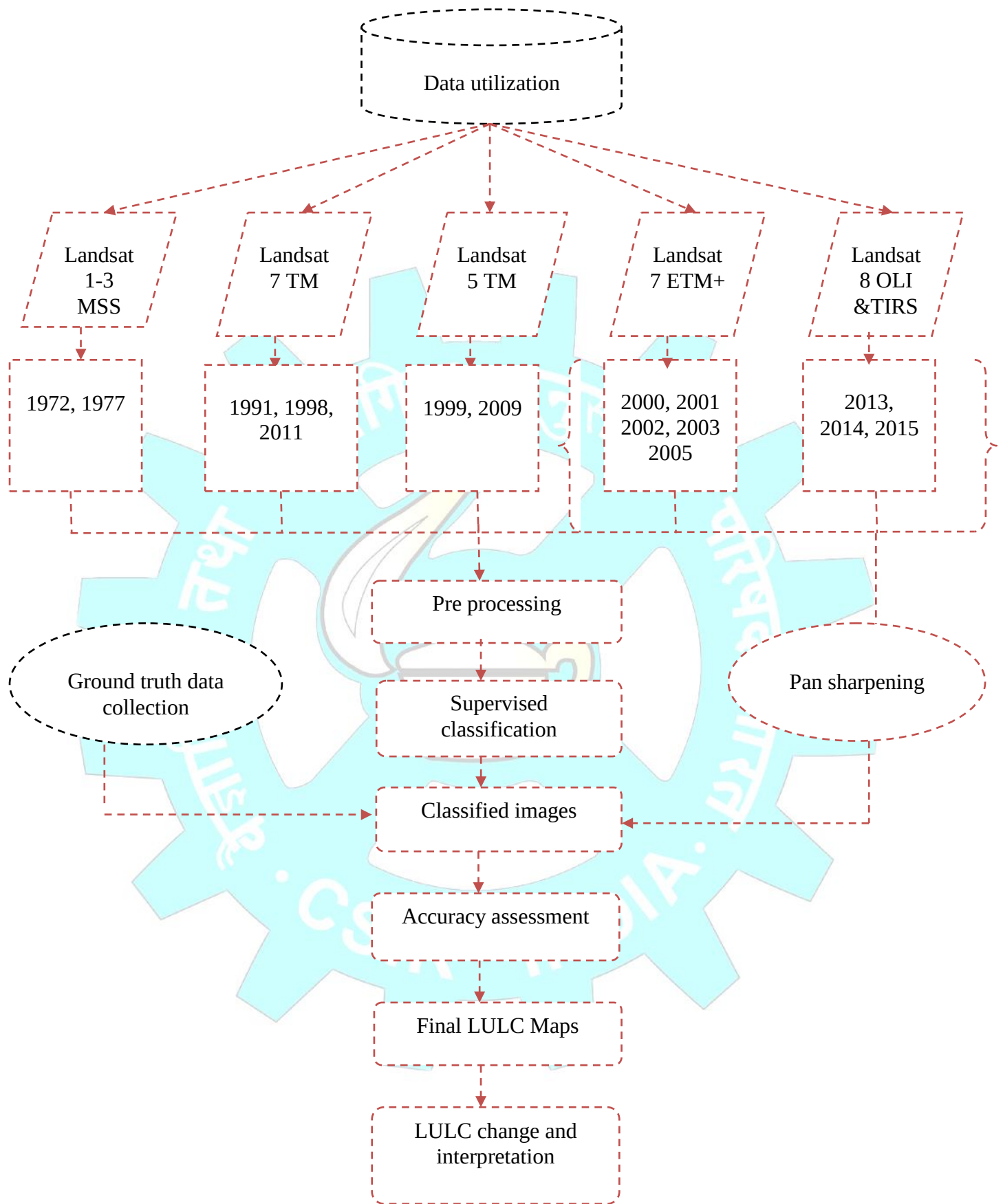


Fig. 3.2. Flow chart of Mapping

3.5 Result and discussions

3.5.1 Accuracy assessment

The satellite images were classified and accuracy is assessed and tabulated as overall accuracy and kappa coefficient. It was found that the overall accuracy was above 83% with a kappa coefficient of above 0.80 for all the years (Table 3.2)

Table 3.2 Overall accuracy and Kappa coefficient

YEAR	OVERALL ACCURACY (%)	KAPPA COEFFICIENT
2015	87	0.8310
Feb 2014	86	0.8166
March 2014	87	0.8299
2013	87	0.8335
2011	91	0.8831
2009	96	0.9484
2005	89	0.8573
2003	91	0.8886
2002	93	0.9046
2001	92	0.8975
2000	90	0.86
1999	86	0.8265
1998	94	0.9274
1991	86	0.8335
1977	83.33	0.8037
1972	83.33	0.8069

3.5.2 Matrix Analysis

Matrix analysis is prepared from years 1991 and 2015 to understand the change in each class. This is made using tabulate area tool in Arc GIS software. The change in the area in sq. km is shown in table 3.3 below.

Table 3.3 Transition matrix 1991-2015

1991 2015	Aqua tic veget ation	Othe rs (Salt pans)	Wat er bod ies	Mud flats	Ve ge tat ion	Buil t up	For est	Mangr oves	Mars hy land	Barr en land	Cro p land	Fallo w land	San dy area
Aquatic vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0
Others(Salt pans)	0	16	0	0	2	5	0	5	1	2	0	0	0
Water bodies	0	0	153	4	1	3	0	1	0	1	0	0	0
Mudflats	0	0	15	6	1	2	0	8	0	0	0	0	0
Vegetation	0	0	0	0	22	31	2	1	0	13	1	0	0
Built up land	0	0	1	1	18	220	1	1	1	12	0	1	0
Forest	0	0	0	0	1	5	59	0	0	18	0	0	0
Mangroves	0	1	2	2	3	5	0	38	3	3	0	0	0
Marshy land	0	0	1	0	0	1	0	10	3	0	0	0	0
Barren land	0	0	0	0	4	30	2	0	0	23	0	1	0
Crop land	0	0	0	0	2	4	0	0	0	1	1	0	0
Fallow land	0	0	0	0	1	13	0	0	0	4	0	5	0
Sandy area	0	0	1	0	0	0	0	0	0	0	0	0	0

3.5.3 Land Use Land Cover Distribution

The classified images using supervised classification were then recoded and land use / land cover map for each year were generated using Arc GIS software. The areas for all the defined classes were tabulated in sq.km. Area for the thirteen classes for all the years, land use /land cover maps and bar diagram of each class are shown below in a chronological order.

Table 3.4 Area of classes in sq. km for different years

CLASS	1972	1977	1991	1998	1999	2000	2001	2002
Aquatic vegetation	1.03	2.88	1.34	1.48	0.55	0.90	1.43	1.93
Barren land	78.91	125.07	65.15	82.09	72.567	85.37	85.005	103.73
Built up land	172.55	201.09	250.87	286.04	288.85	288.71	288.25	287.57
Cropland/Grass land	6.30	8.40	10.21	5.28	4.86	6.55	6.22	6.66
Fallow land	25.41	25.66	24.43	19.68	16.19	14.20	17.37	16.35
Forest	101.20	67.72	81.24	59.46	75.14	63.30	59.07	42.24
Mangroves	45.35	34.52	56.57	54.98	55.56	54.93	56.01	54.07
Marshy area	44.04	55.07	16.43	19.70	17.21	20.17	19.54	14.95
Mudflats	19.52	20.77	34.05	12.28	10.53	29.48	27.11	23.06
Others(salt pans)	22.07	42.65	31.63	19.12	20.60	24.01	22.91	21.61
Sandy area	3.25	6.59	1.43	2.68	1.66	1.65	1.19	0.95
Vegetation	114.16	46.10	73.80	65.02	62.10	63.22	64.30	63.67
Water bodies	176.92	174.18	163.55	184.53	186.45	158.20	165.17	174.95
Total	810.71	810.7	810.7	812.34	812.267	810.69	813.575	811.74

CLASS	2003	2005	2009	2011	2013	Feb-14	Mar-14	2015
Aquatic vegetation	1.67	2.26	1.06	0.83	1.00	0.56	0.63	0.68
Barren land	65.84	60.67	61.45	54.62	80.22	85.20	97.30	76.45
Built up land	290.04	302.50	302.90	312.12	312.00	315.29	316.11	319.75
Crop land/ Grass land	6.26	6.19	4.25	6.86	4.09	3.55	2.94	3.18
Fallow land	17.00	16.73	19.15	13.71	10.47	8.70	9.64	8.56
Forest	78.00	74.27	77.74	76.04	66.66	56.40	42.84	65.29
Mangroves	59.29	55.22	64.28	64.11	61.45	64.53	63.57	65.90
Marshy area	12.20	20.21	11.79	15.31	14.52	15.91	12.96	8.47
Mudflats	12.38	23.84	19.51	17.52	0.00	25.26	13.46	13.74
Others	21.69	21.04	19.30	17.44	16.69	19.19	20.90	18.82
Sandy area	1.07	1.69	1.81	1.67	1.18	1.20	1.50	1.31
Vegetation	64.29	56.85	57.56	59.49	55.12	56.22	56.19	54.02
Water bodies	182.01	170.28	171.54	172.65	188.36	159.73	173.69	175.21
Total	811.74	811.75	812.34	812.37	811.76	811.74	811.73	811.38

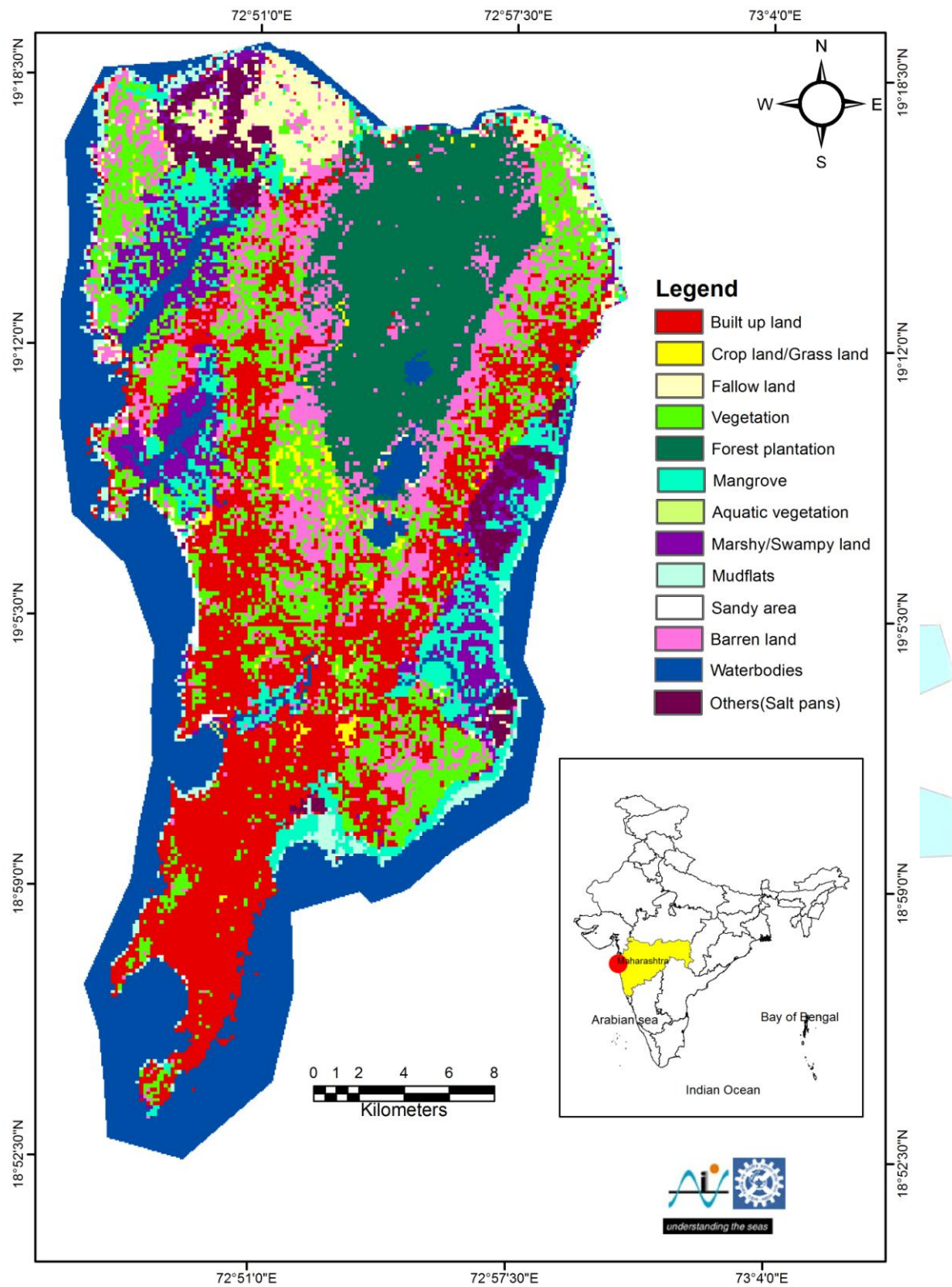


Fig. 3.3. LULC map of 1972

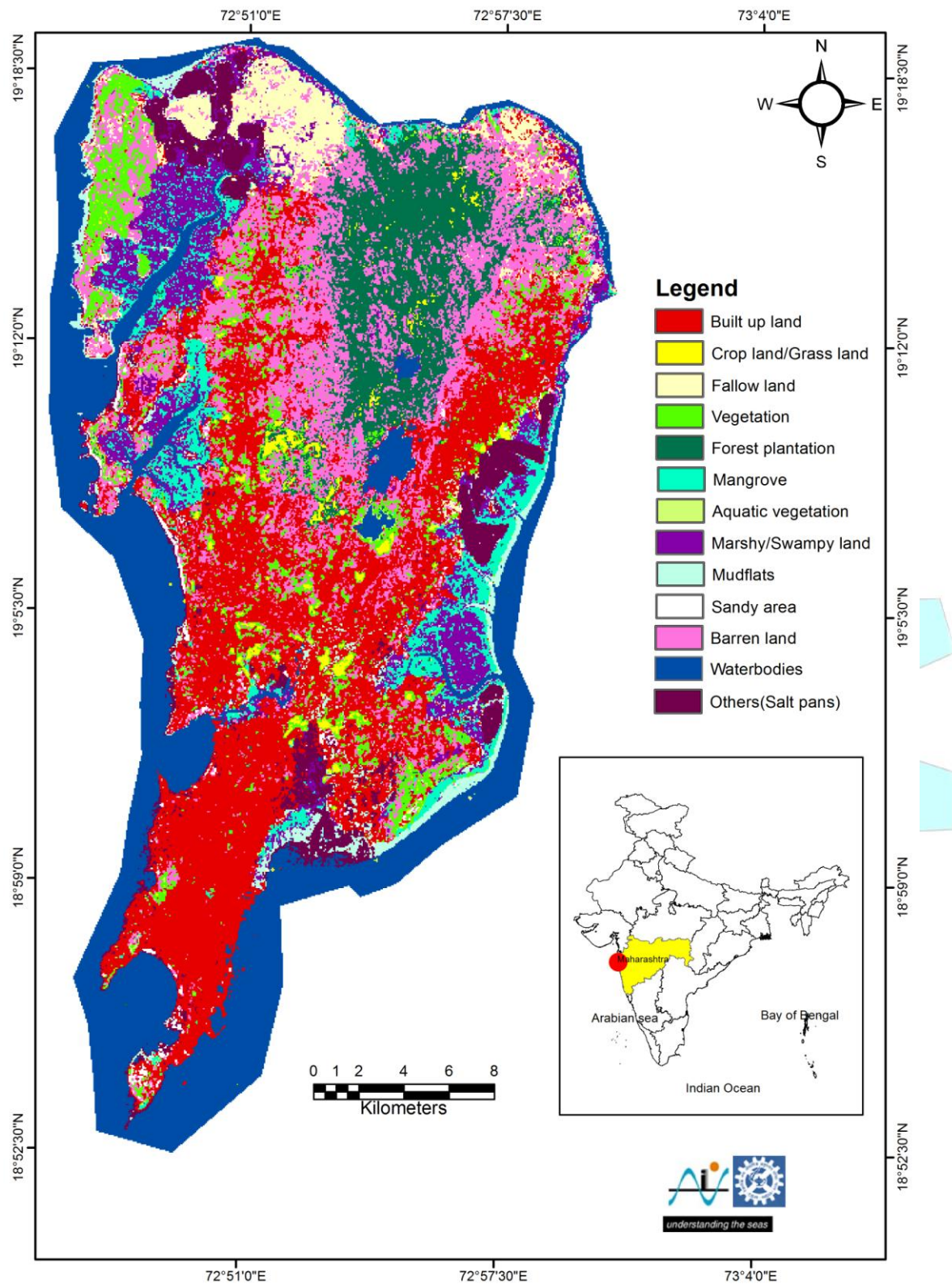


Fig. 3.4. LULC map of 1977

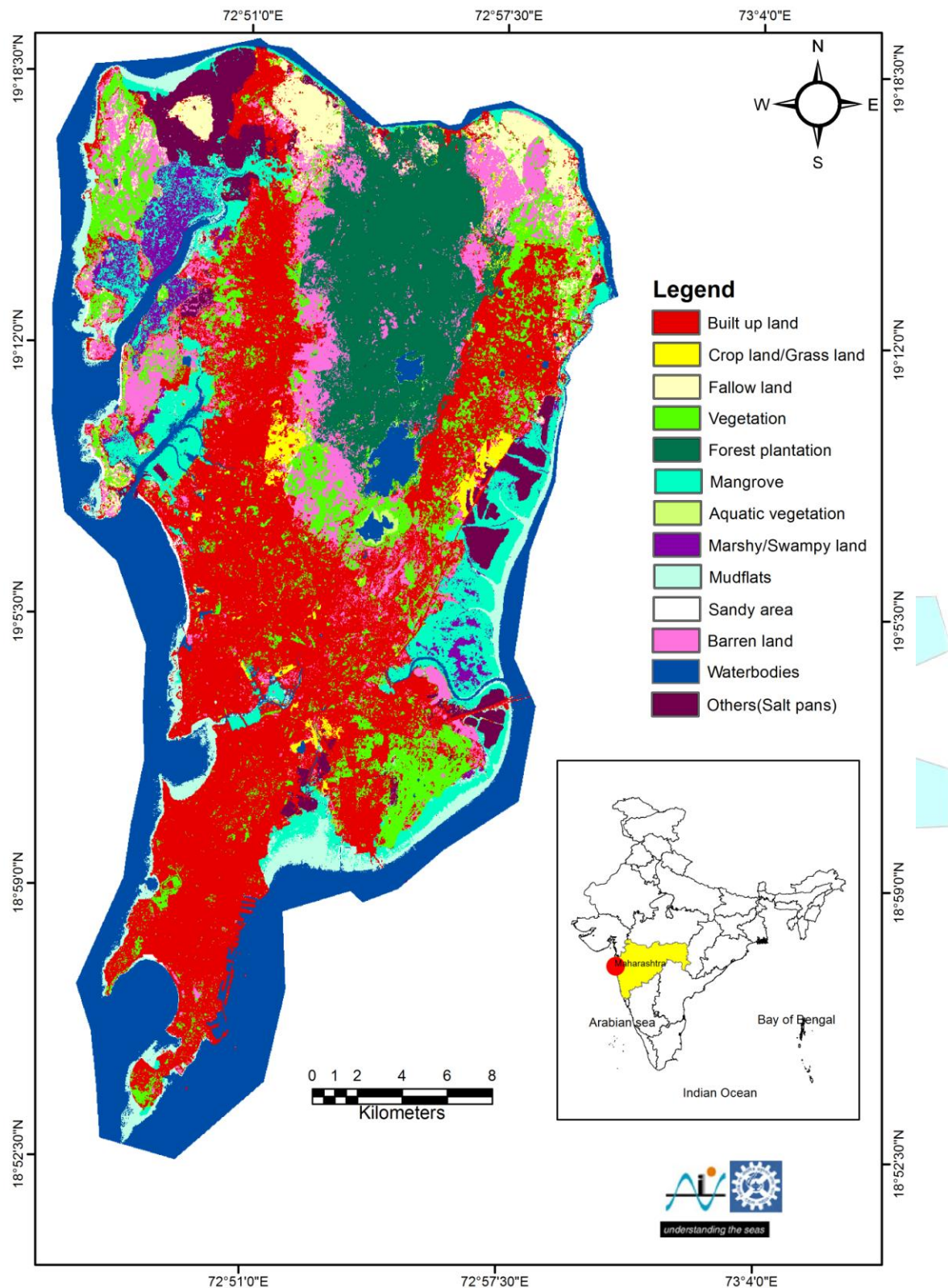


Fig. 3.5. LULC map of 1991

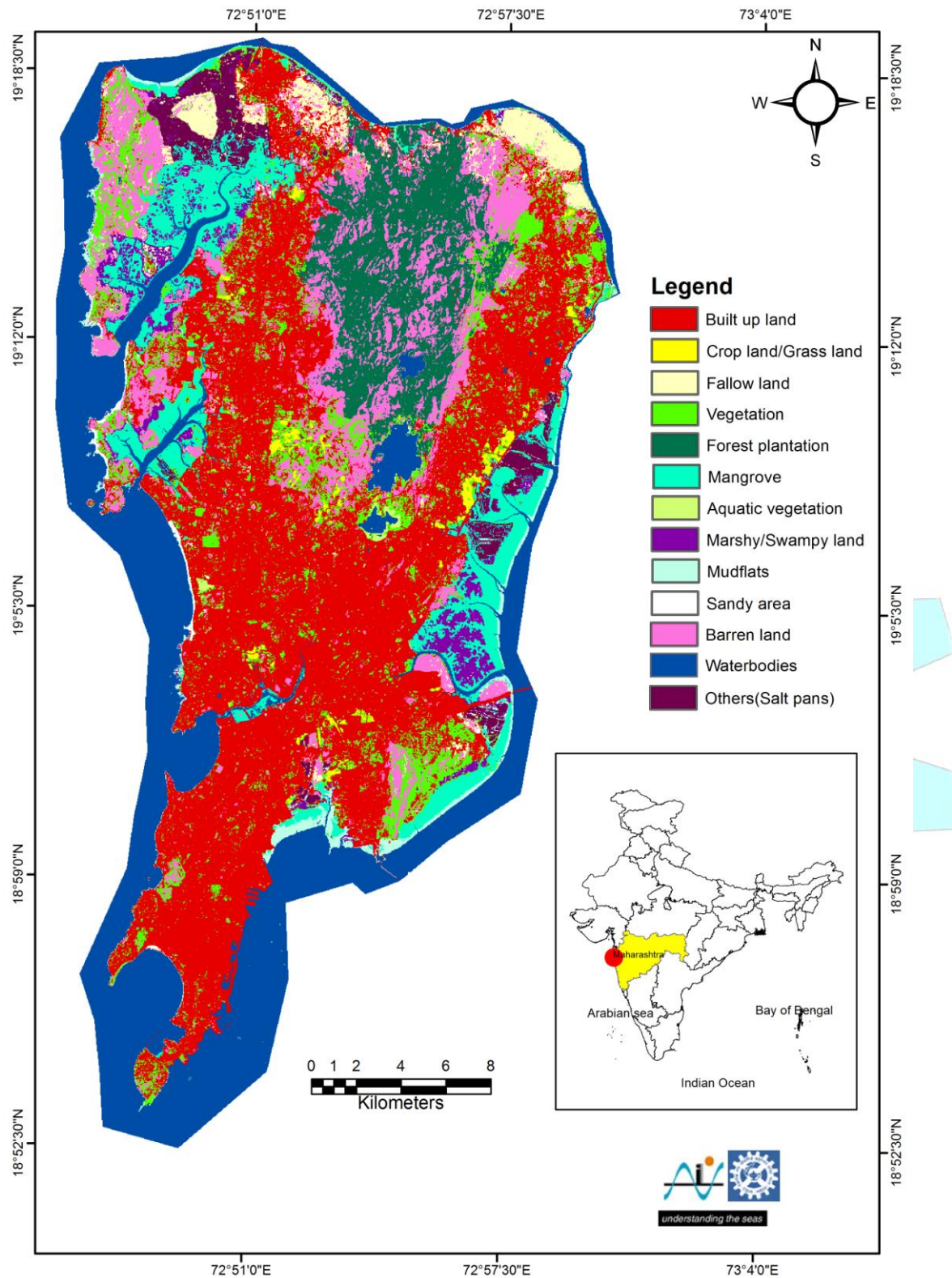


Fig. 3.6. LULC map of 1998

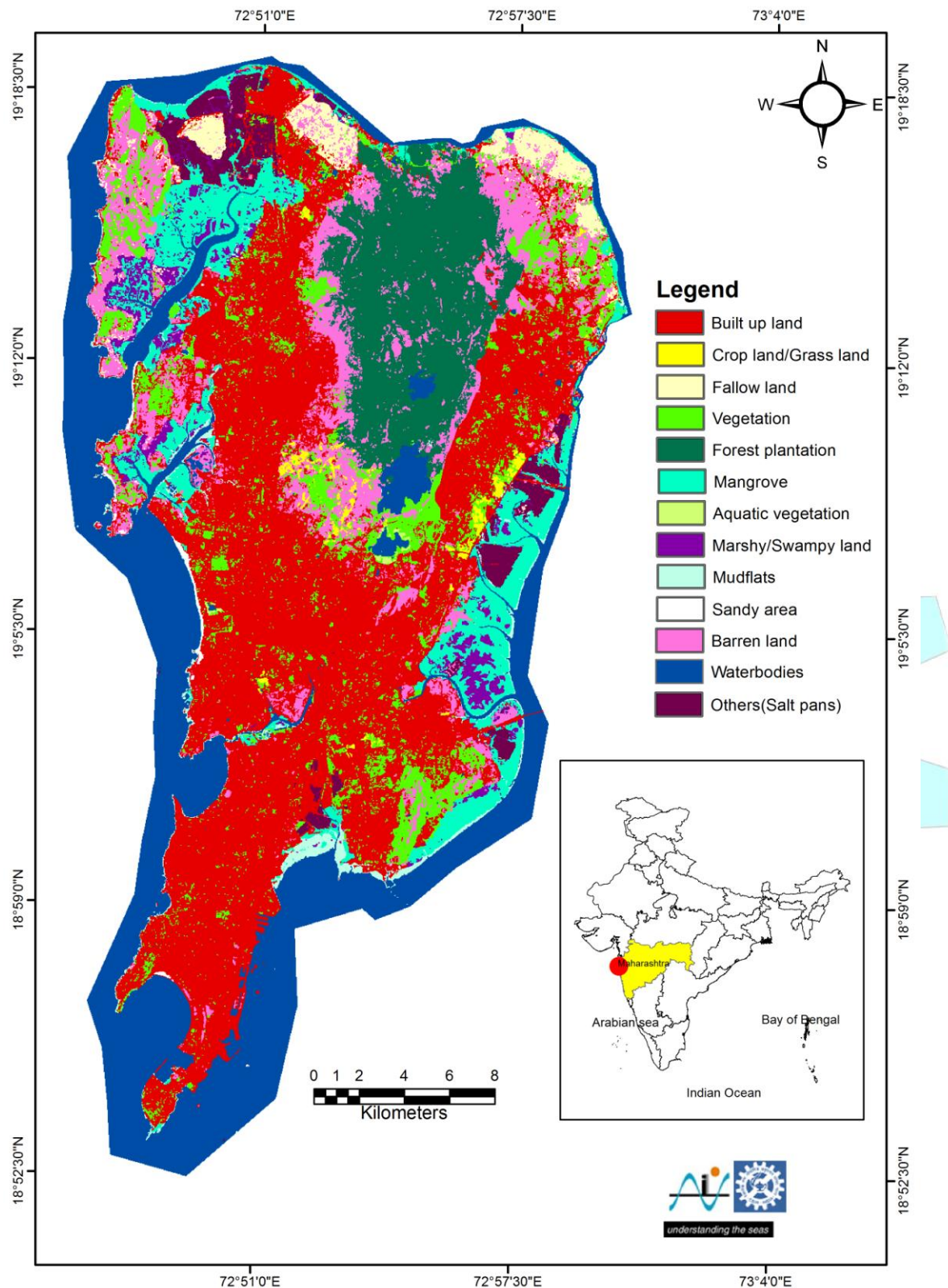


Fig. 3.7. LULC map of 1999

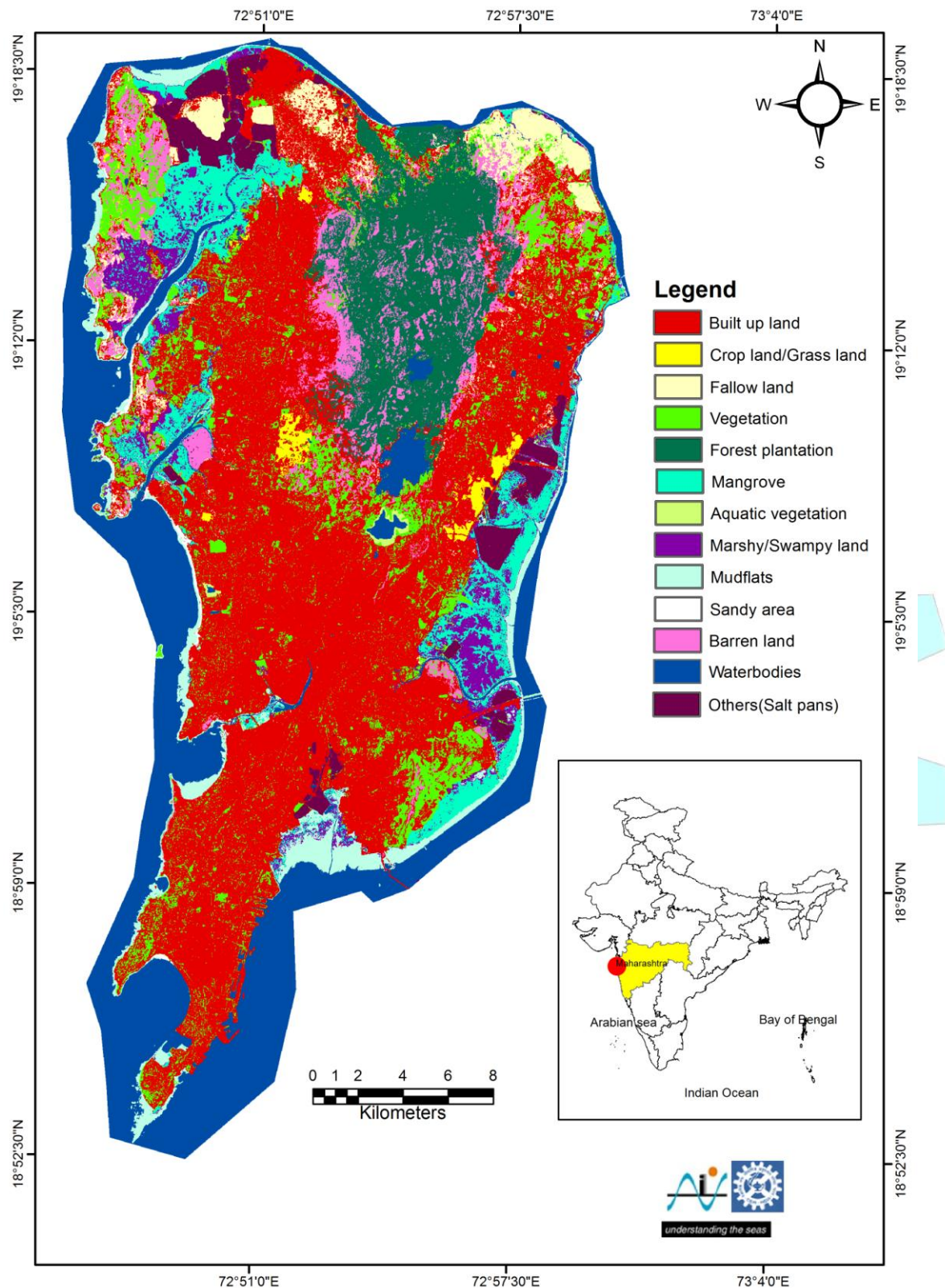


Fig. 3.8. LULC map of 2000

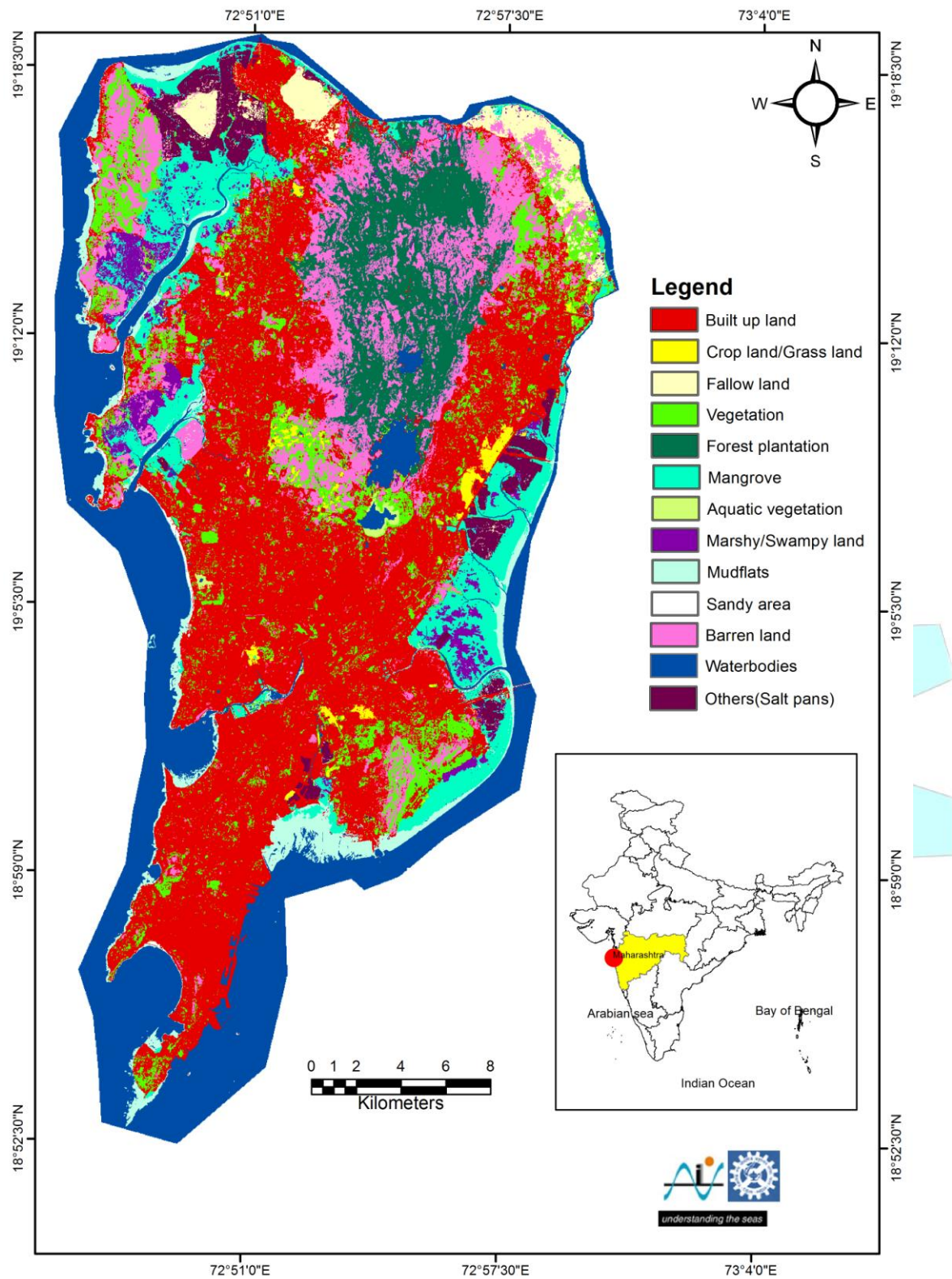


Fig. 3.9. LULC map of 2001

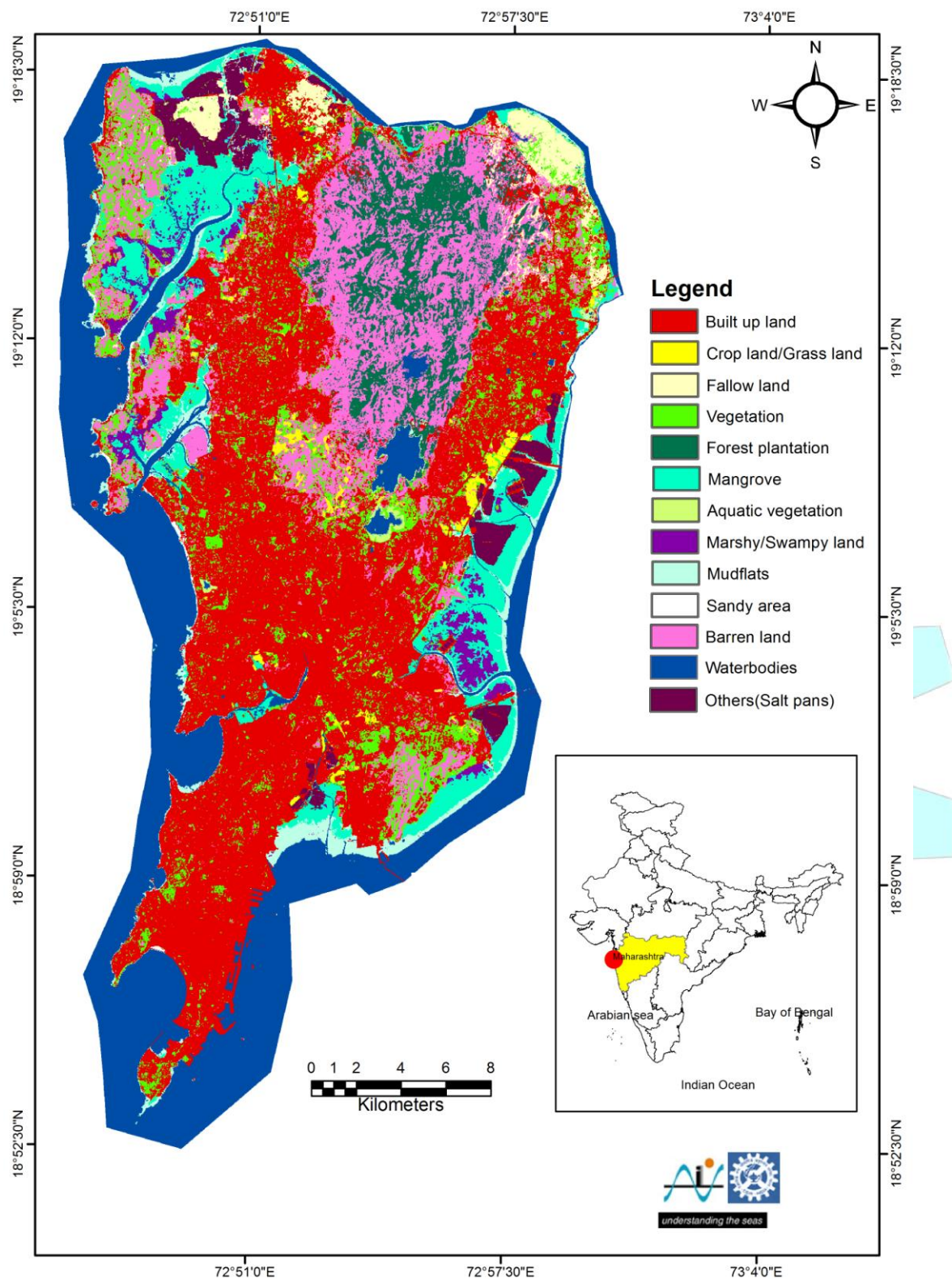


Fig. 3.10. LULC map of 2002

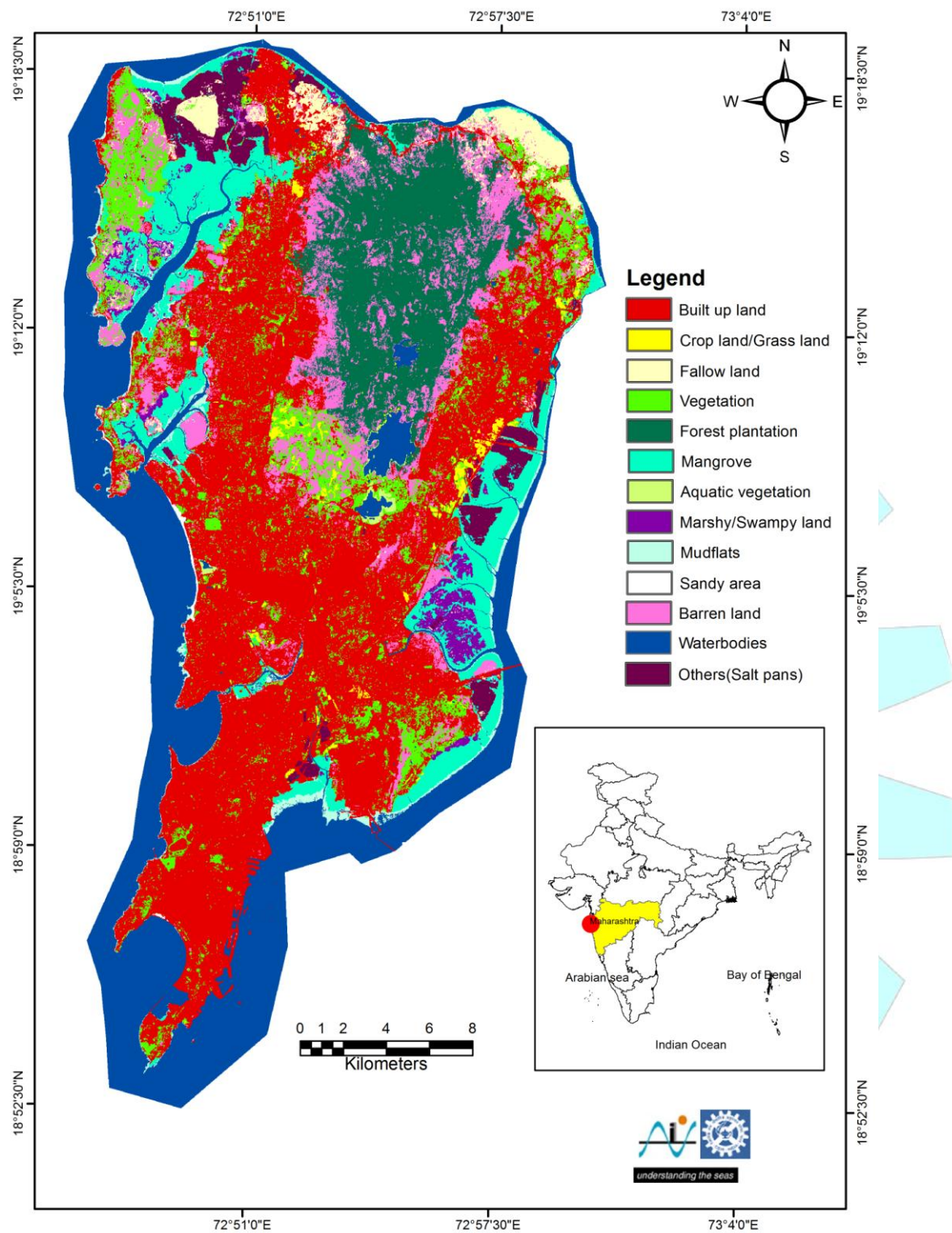


Fig. 3.11. LULC map of 2003

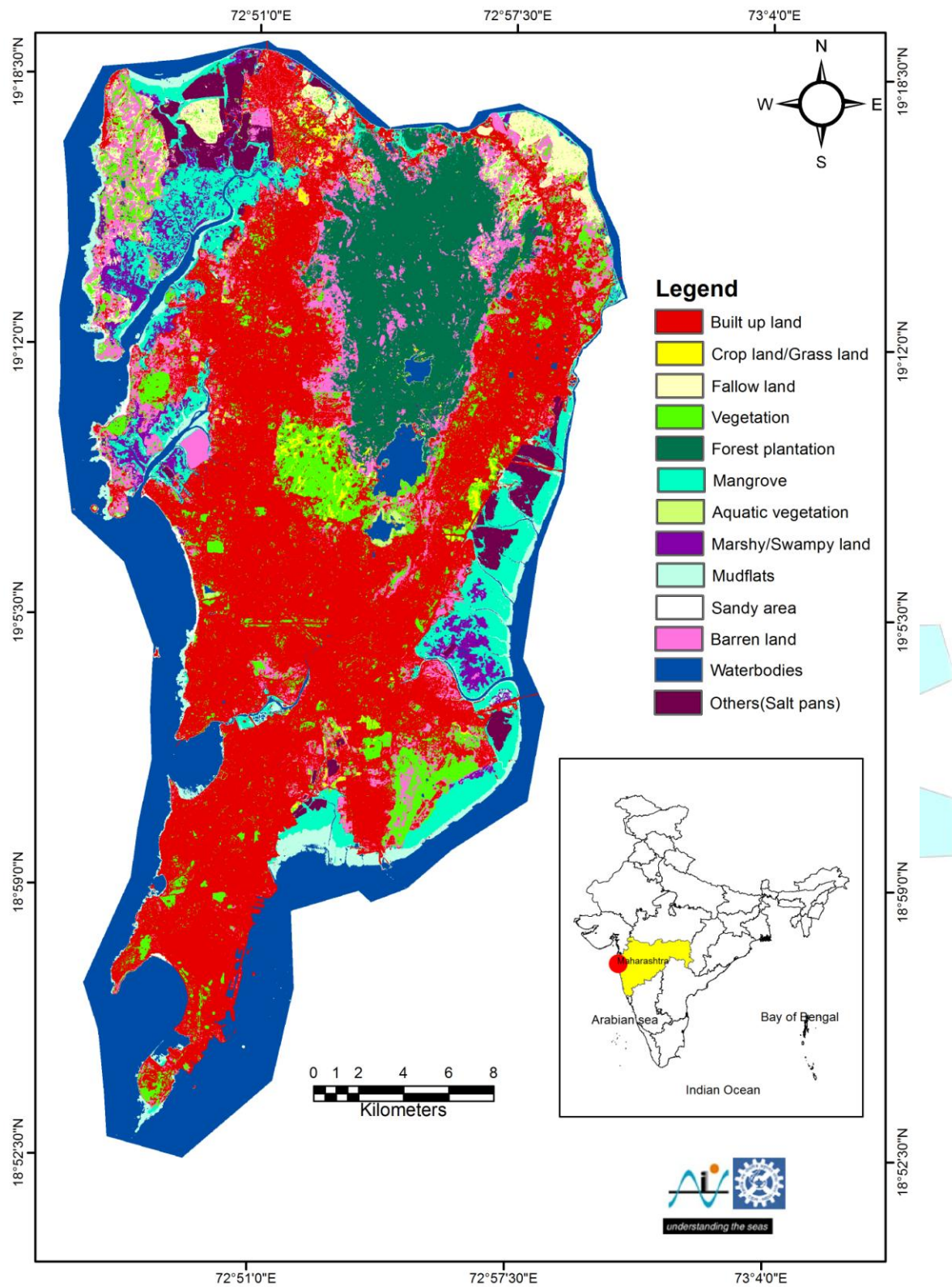


Fig. 3.12. LULC map of 2005

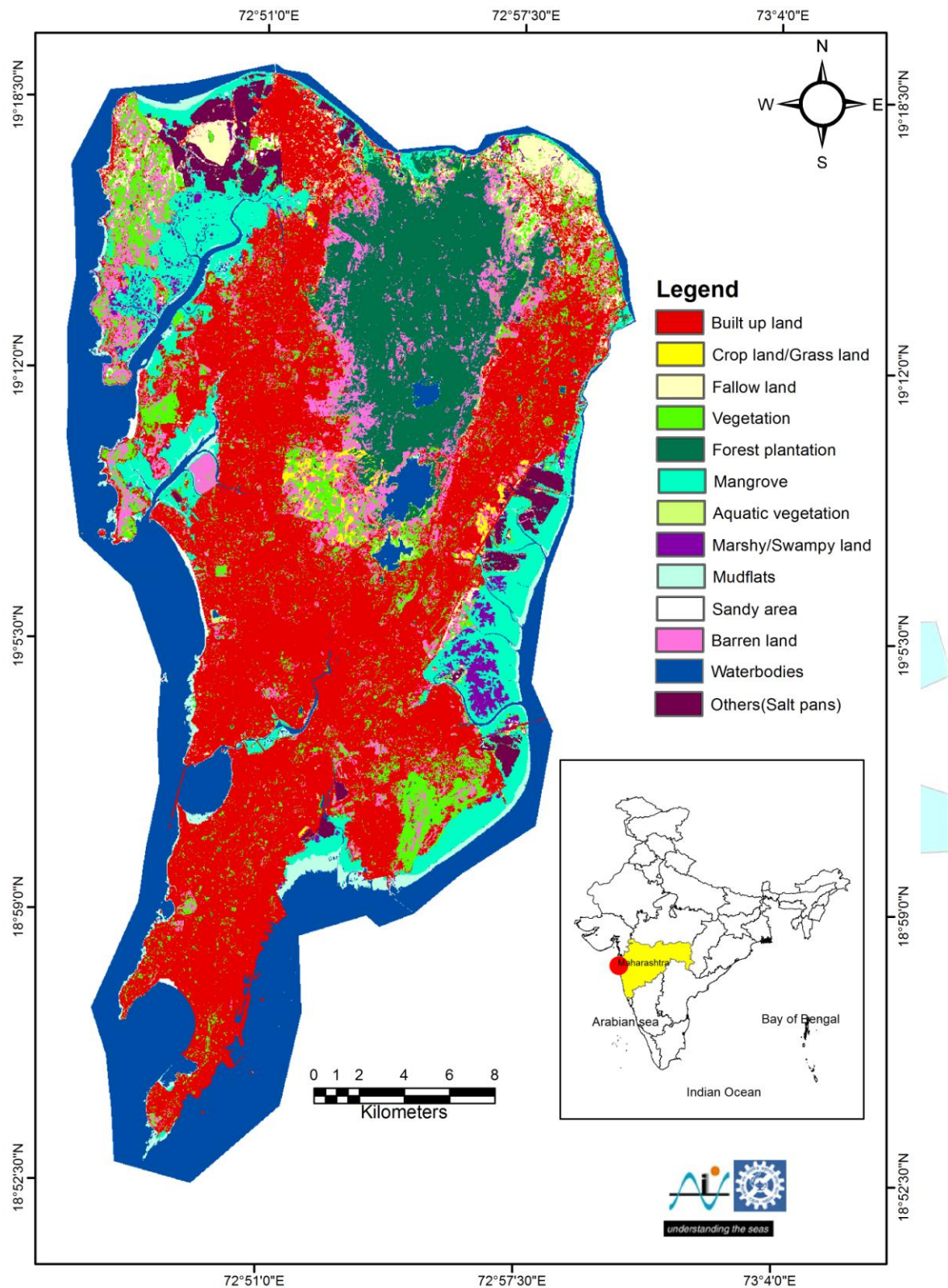


Fig. 3.13. LULC map of 2009

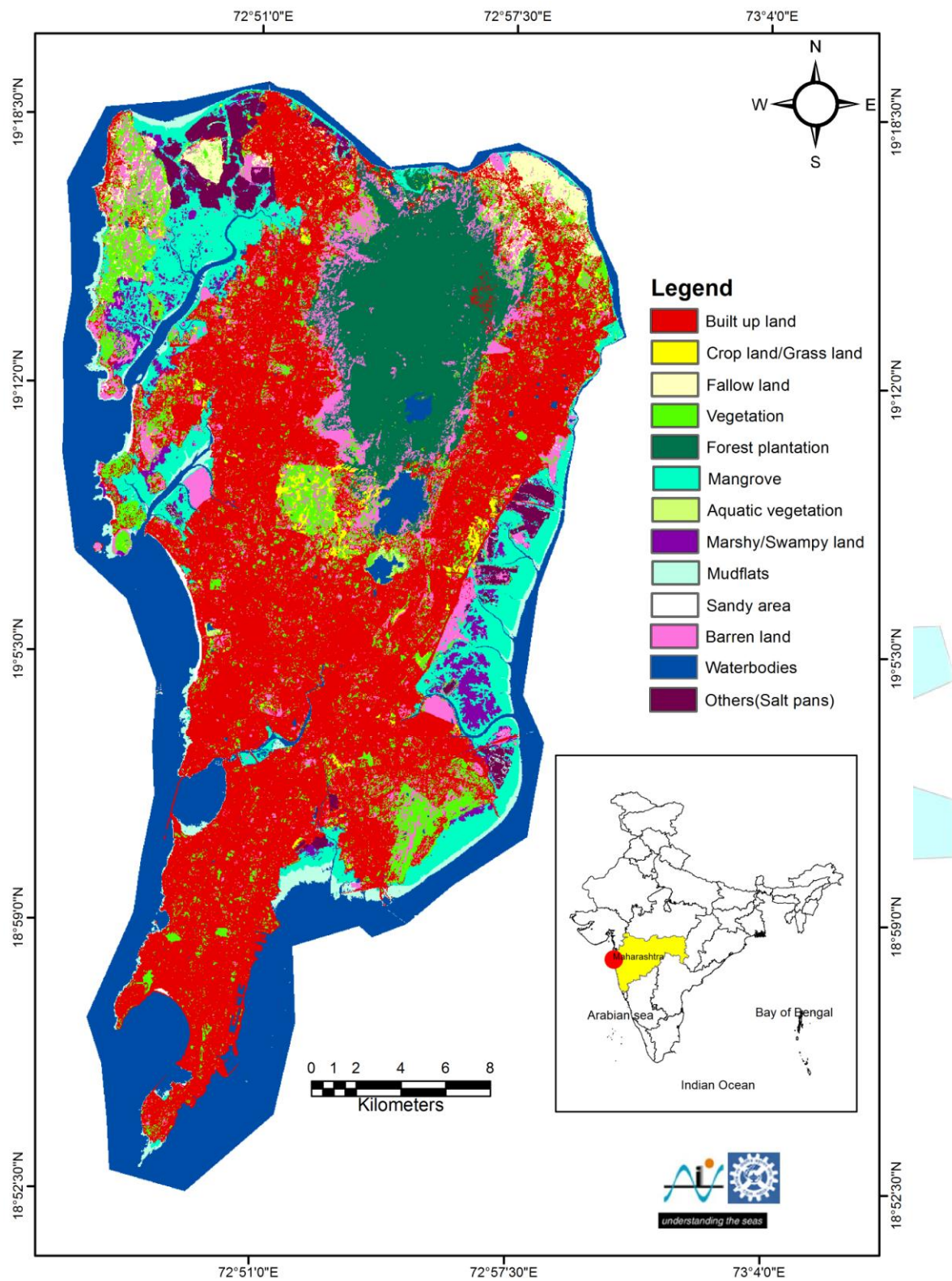


Fig. 3.14. LULC map of 2011

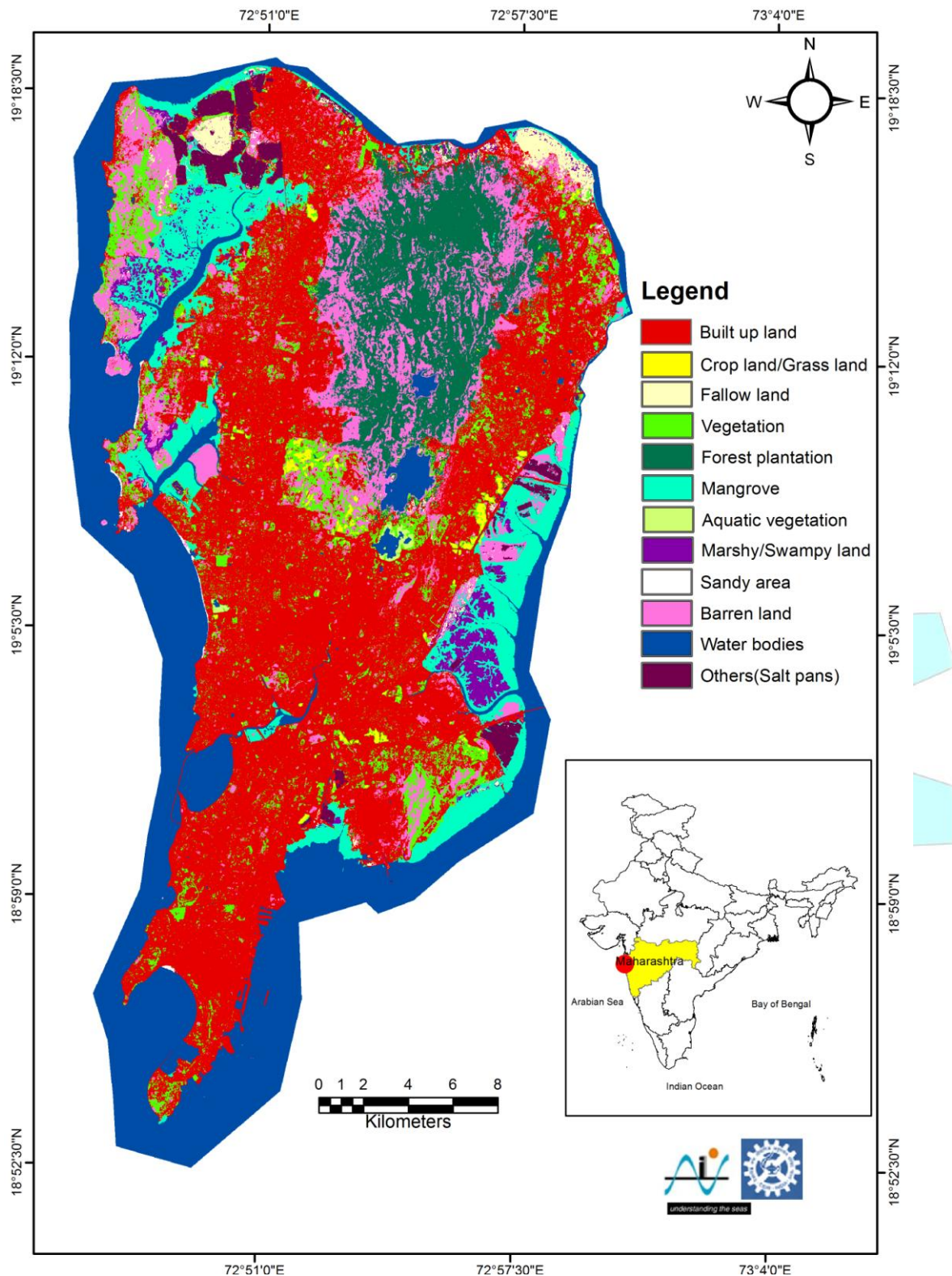


Fig. 3.15. LULC map of 2013

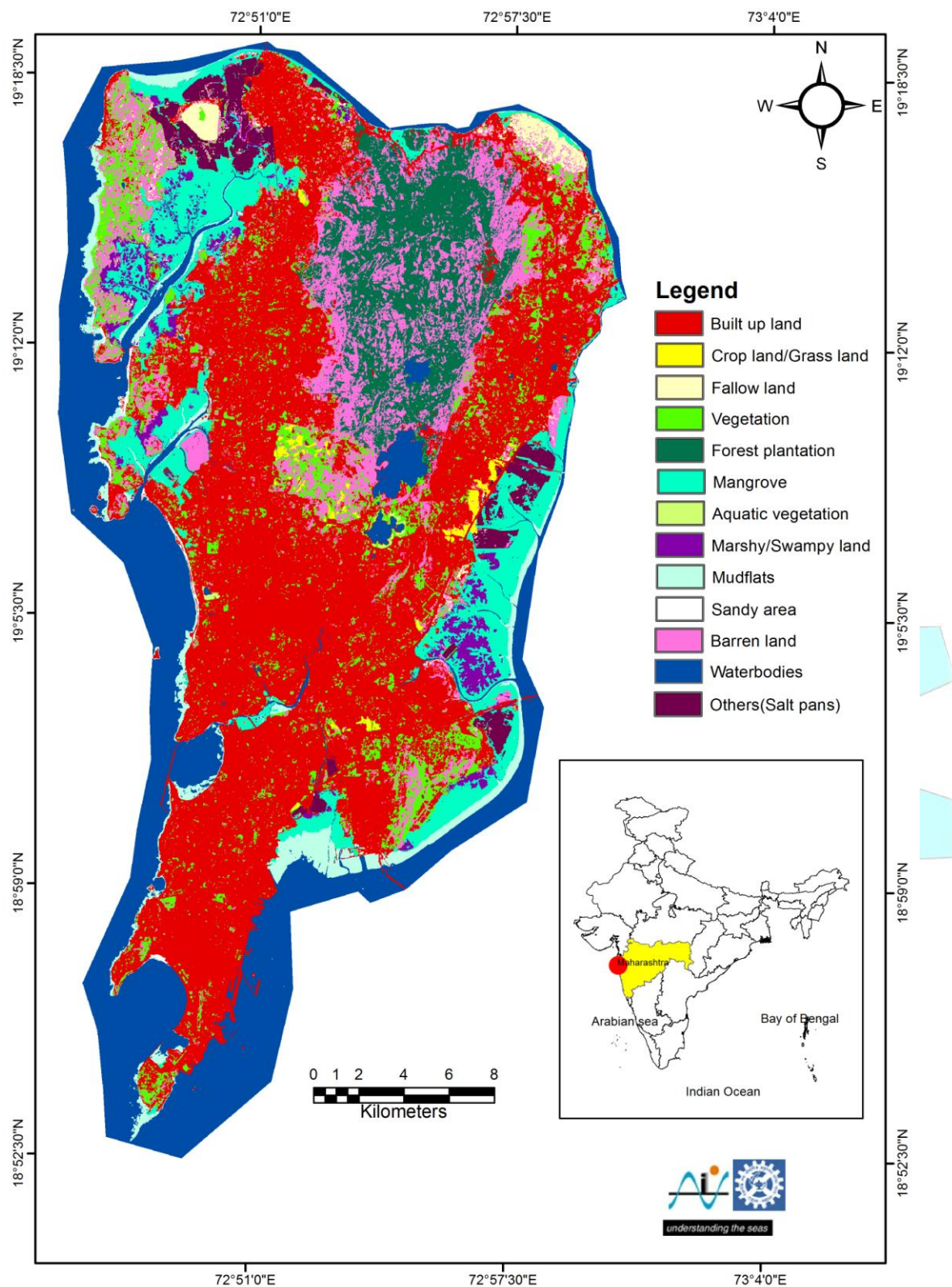


Fig. 3.16. LULC map of February 2014

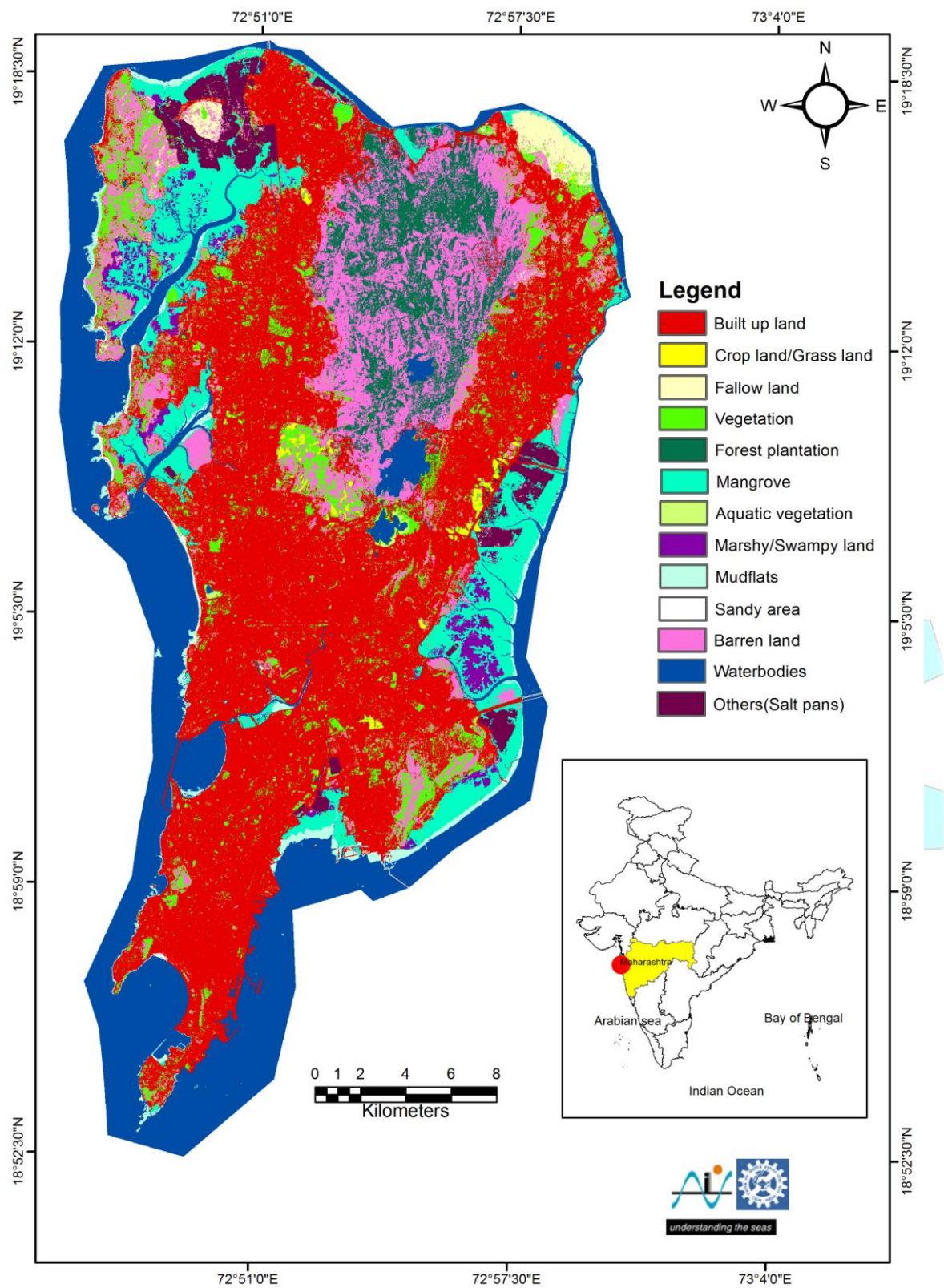


Fig. 3.17. LULC map of March 2014

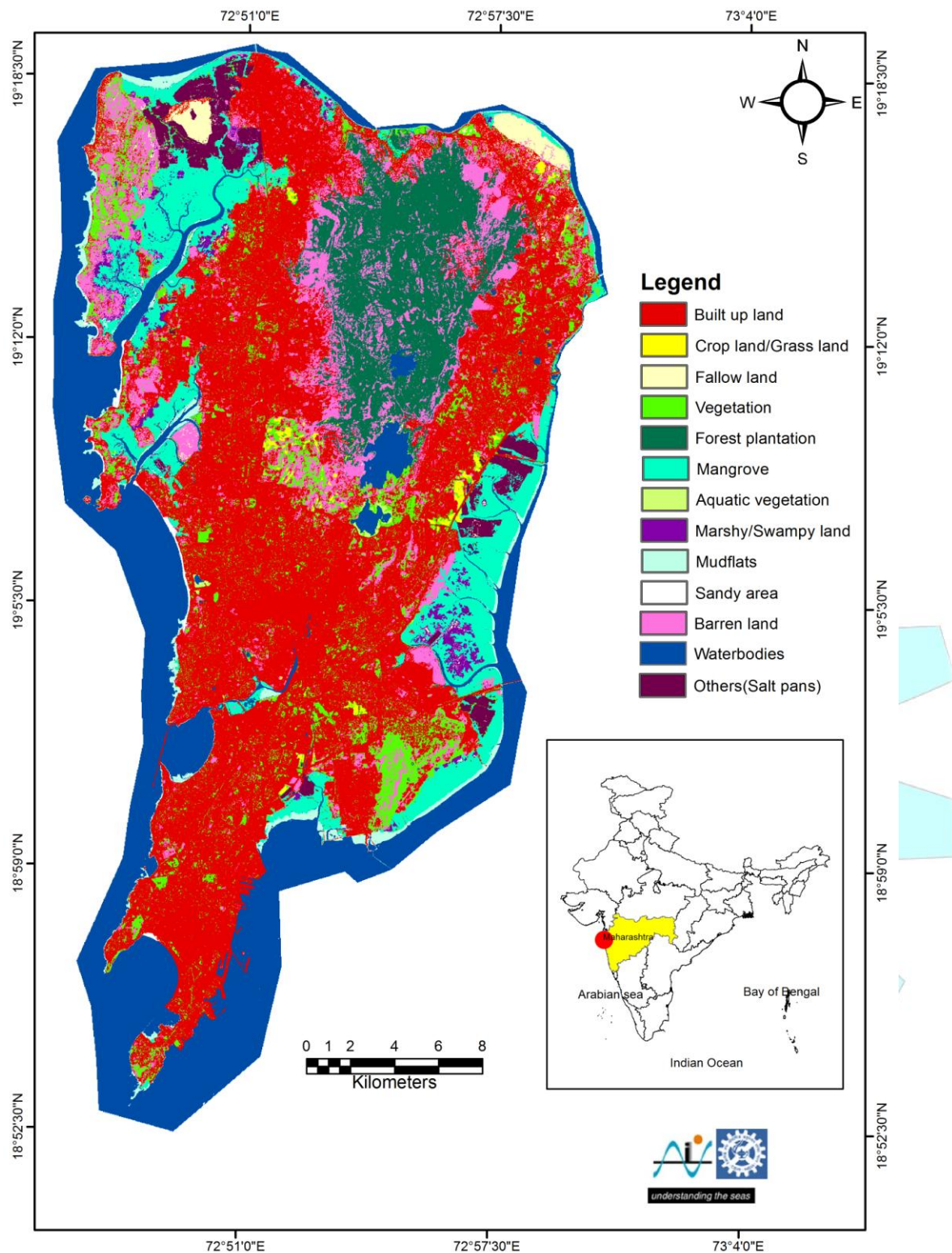


Fig. 3.18. LULC map of 2015

3.5.4 Built up land

It is found that built up land is the main feature of megacity Mumbai. Urban growth over the study area has totally transformed the face of Mumbai. It is evident from the map and the area that built up land has risen from an area of 172.5 sq. km in 1972 to 319.7 sq. km in 2015 in the past 42 years. Rapid urbanization phase is markedly seen from 1972 to 1998. There is a constant increase from 1999 to 2015.

The main transformations to built-up land had happened in the Mumbai sub urban and Thane region of the study area. It can be easily noted from the land use/ land cover map that the fallow land of the Mira Bhayandar area of the North of the study area have changed to built-up area in the following years. The same transformation has also happened in some parts of the Thane region of the study area. Bandra-Worli Sea Link (BWSL) has been constructed in 2009 over the Mahim Bay. Along with the BWSL east- west connectivities, viz. Jogeshwari-Vikroli Kind Road (JVLK), Santacruz- Chembur Link Road (SCLR), Versova- Andheri- Ghatkopar (VAG) Metro and Eastern Freeway, have significantly contributed to the rising built-up area of late.

The transition matrix reveals that 30 sq.km of barren land and 31 sq.km of vegetation have converted to urban land from 1991 to present. Although there are main changes in these two classes, 13 sq.km of fallow land also contributed to the urbanization in Mumbai.

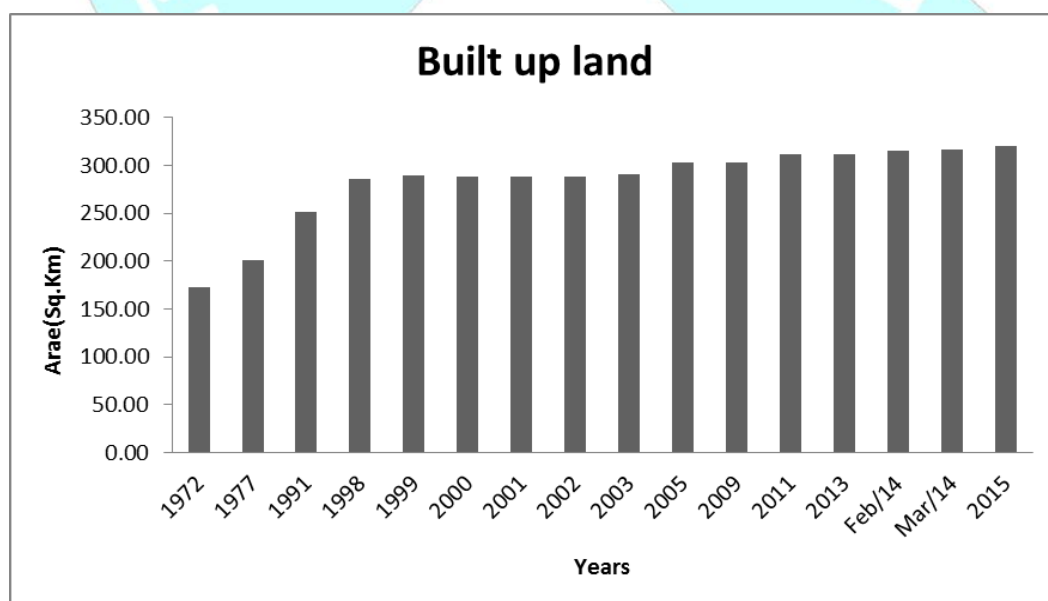


Fig. 3.19. Change in area of Built up land

3.5.5 Crop land/Grass land and Fallow land

Agricultural practices are mainly found in some parts of Goregaon in Mumbai. Crop land is reduced to 3.18 sq. km. Fallow land was found in the Mira Bhayandhar and Thane areas. Fallow land also shows reduction over the years. Conversion of fallow land into urbanization is noticed in the Mira Bhayandar and few parts of Thane. 25.41 sq. km of fallow land was demarcated in 1972 which has been reduced to 8.56 sq. km in 2015. The matrix shows that 13 sq. km of fallow land was converted to built-up land and 4 sq. km to barren land.

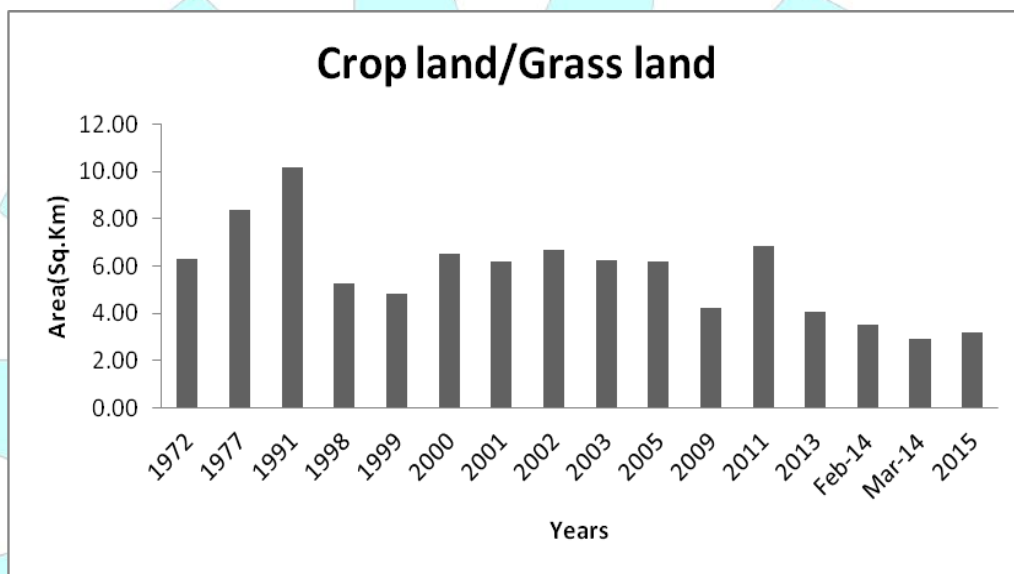


Fig. 3.20. Change in area of crop land/grass land

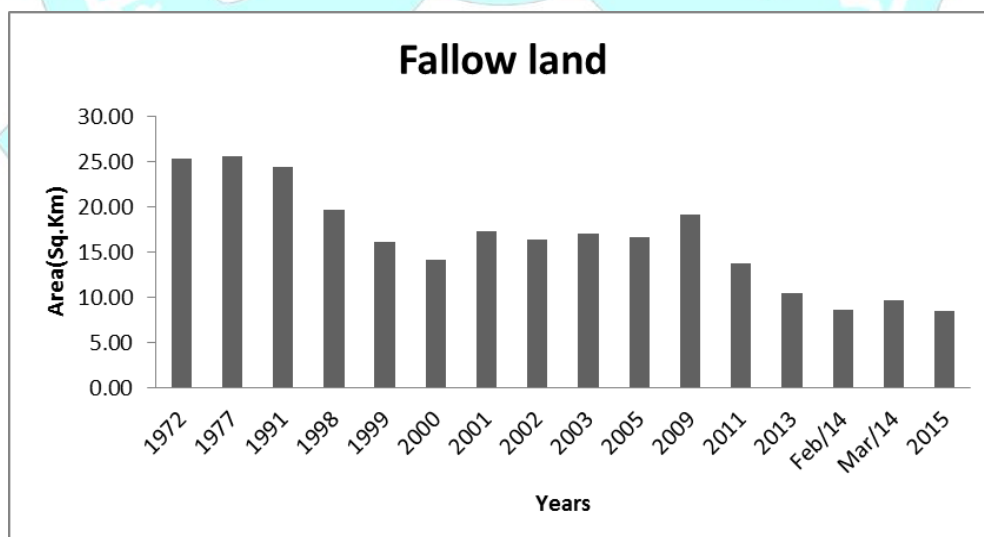


Fig. 3.21. Change in area of fallow land

3.5.6 Vegetation

Vegetation includes the terrestrial plants and trees found over the study area. There is a constant decrease in the vegetation cover from 1991 to 2015. Gradual decrease in area from 73.80 sq km to 54.02 sq km from 1991 to 2015. 52.2 percent of the vegetation have decreased from 1991 to 2015. NDVI analysis shows high density of vegetation in 1972 and then in 1991 and lesser in 1977. This could be due to the seasonal variation. Analysis shows that 31 sq.km of vegetation is transformed to built-up land and 13 sq. km to barren land from 1991 to 2015

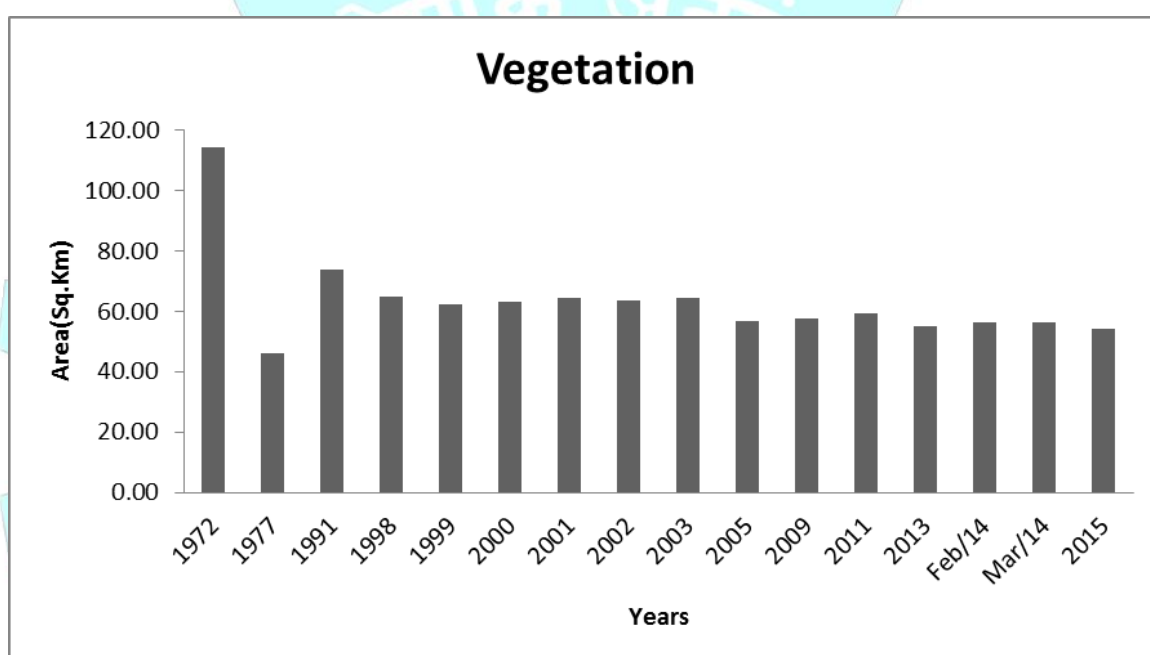


Fig. 3.22. Change in area of vegetation

3.5.7 Forest

Sanjay Gandhi National Park is the forest region found in the study area Mumbai. Forest cover varies with the season. The satellite images chosen for the study contains months from January to April and also October and December. Classified images of March, April and October shows reduction in the forest cover due to shedding of leaves. Forest shows an average area of 65.54 sq. km. The encroachment of built up space over the national park is one of the notable phenomena. Yeoor hills and the north east and western part of the study

area shows the built up cover in the forest area. It is clearly visible from the Google Earth imagery.

Analysis shows that 5 sq km of built up land is converted from the forest region during the period 1991- 2015.

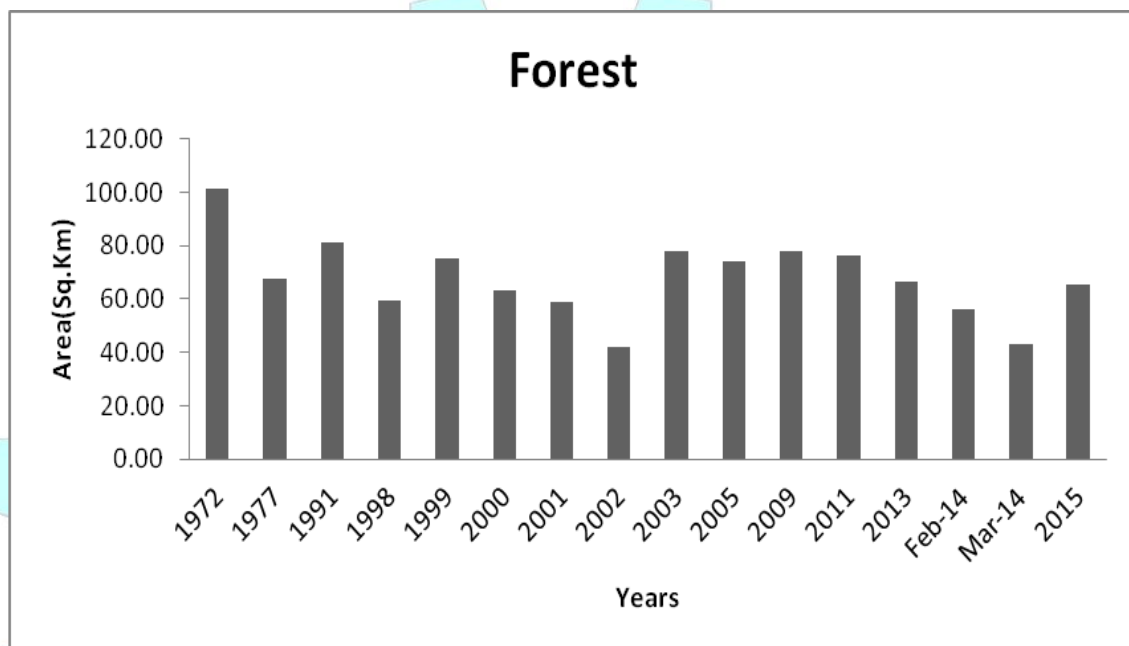


Fig. 3.23. Change in area of Forest plantation

3.5.8 Barren land

Barren land or bare land is one of the important classes where major transformation has happened. Mumbai suburban and Thane region of the study area was covered with the vegetation and barren land with little builtup land in the 1970s to 1980s. There is an increase in the area of barren land during 1972-1977. It was found that the vegetation over the Thane region was turned into barren land in 1977. Transition matrix shows that 30 sq km of barren land has been converted into built up land. Barren land shows an average area of 76.83 sq km. The main transformation in barren land has occurred in the Mumbai suburban and Thane region of the study area.

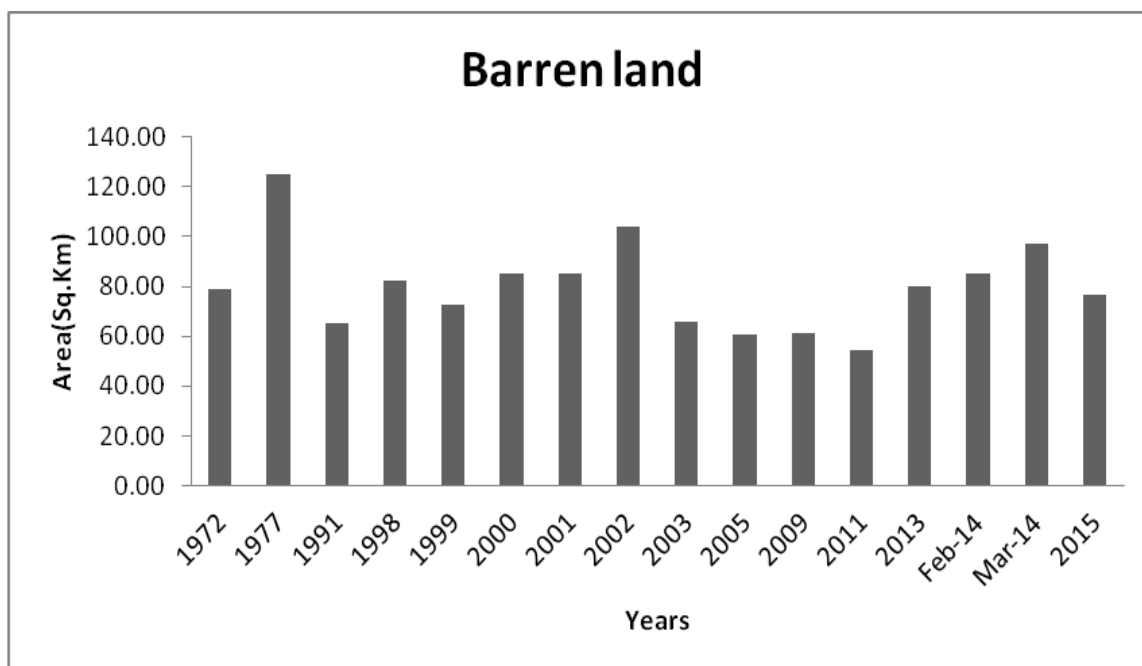


Fig. 3.24. Change in area of barren land

3.5.9 Mangroves

Mangroves are the important land cover along the Mumbai's coastline. Mumbai is rich in mangroves all along the creeks. The major creeks of Mumbai area are the Manori creek, Malad creek, Mahim creek, Mahim creek, Mahul creek, Thane creek and the Vasai creek.

Manori creek was marshy in the 1990s with little patches of mangroves. Later on, marshy areas have become mangroves region. The present condition of the Manori creek is that there are rich mangrove along the creek. Almost same situation has happened with Malad creek. Mahim creek along the sides of the Mithi River also shows the presence of Mangroves. It can be clearly demarcated from the map that the sides of Mithi river with mangroves were converted to built up space in the later stage. Mangroves are present all along the sides of Thane creek. Study showed that the width of the mangroves over the Thane creek have changed. Vasai creek in the northern part of the Mumbai showed an increase in the mangrove cover. Some area on the sides of the Malad creek was transformed into barren land during 1991 to 2015.

Area of mangroves has increased from 56.5 sq. km to 65.9 sq.km during the period 1991 to 2015. Cuffe parade and Versova regions of Mumbai also have mangrove patches. Mangrove

maps of 1991 and 2015 at three specific locations and their changes are shown below with tabulated area.

It is noticed from the land use / land cover classification and the area that 0.06 sq.km of mangroves were present in the Cuffe Parade in 1991. It is decreased to 0.03 sq. km in 2015. Almost 50% reduction in the mangrove cover happened in Cuffe Parade. In case of Mahim, there is a reduction of 39.91 % of mangroves which occurred along the sides of Mithi River. Juhu Moragaon showed an increase of 47.88% of mangroves along the Juhu beach sides.

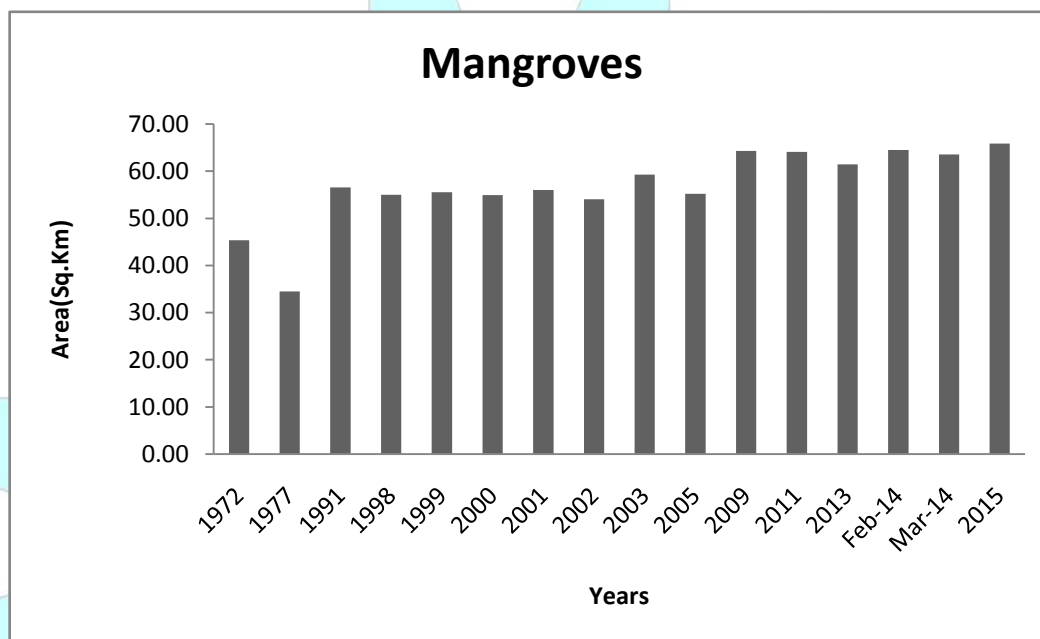


Fig. 3.25. Change in area of mangroves

Table 3.5 Area of mangroves at three different locations

MANGROVES	Area (Sq.km)		Percentage Change
	1991	2015	1991-2015
Cuffe Parade	0.0666	0.03307	-50.338
Mahim	1.2780	0.76792	-39.912
Juhu Moragaon	0.1422	0.21015	47.887

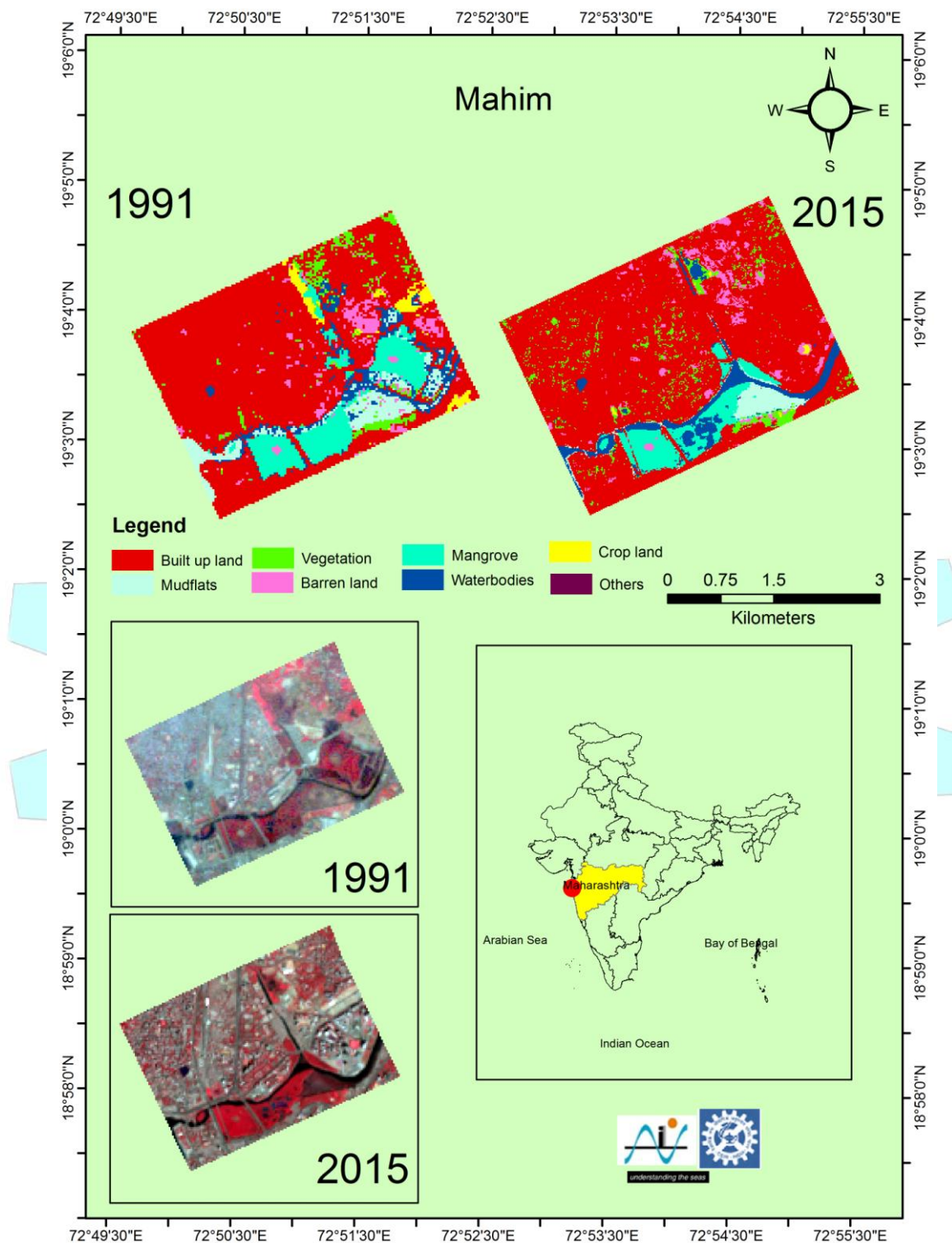


Fig. 3.26. Map showing mangrove change at Mahim

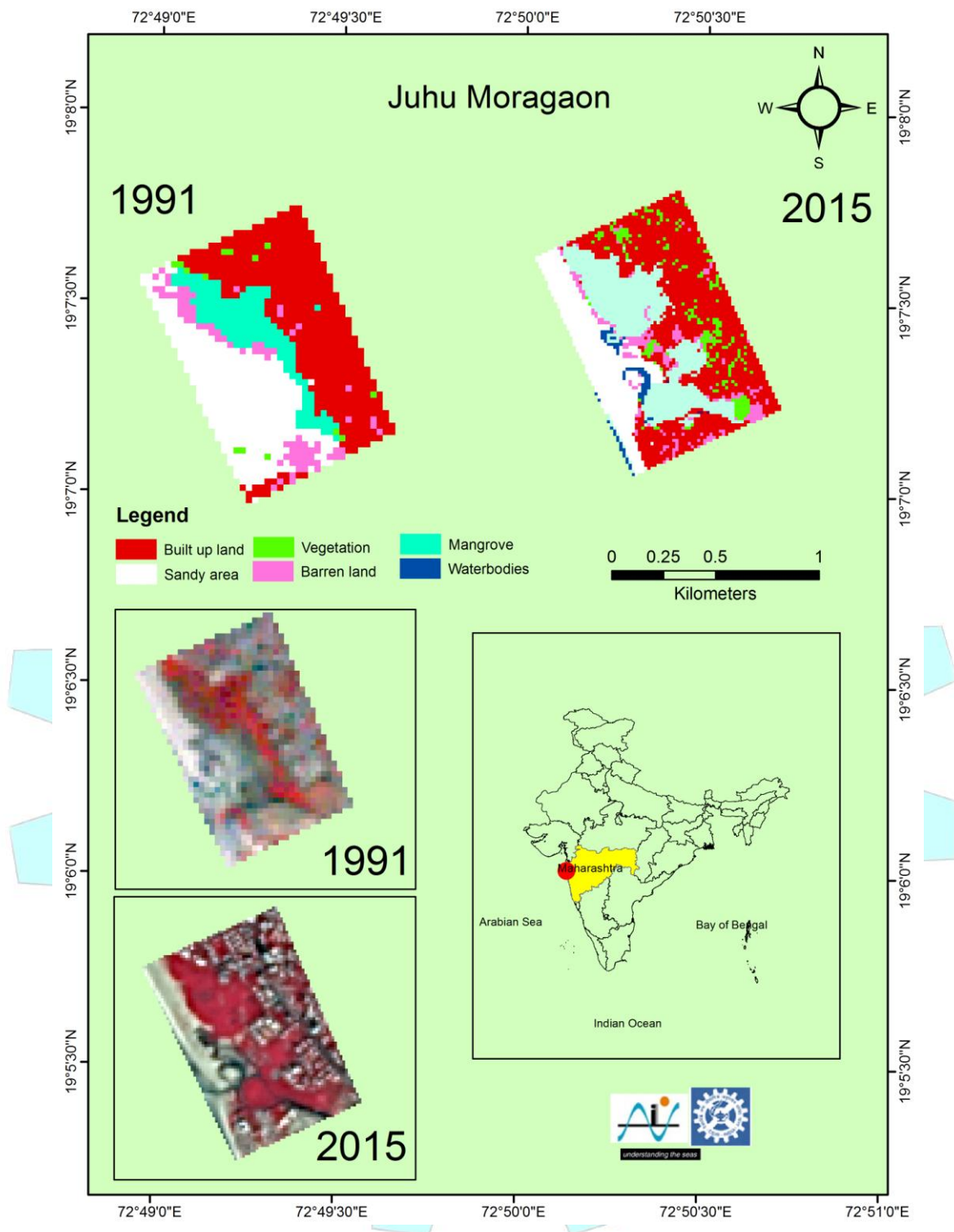


Fig. 3.27. Map showing mangrove change at Juhu Moragaon

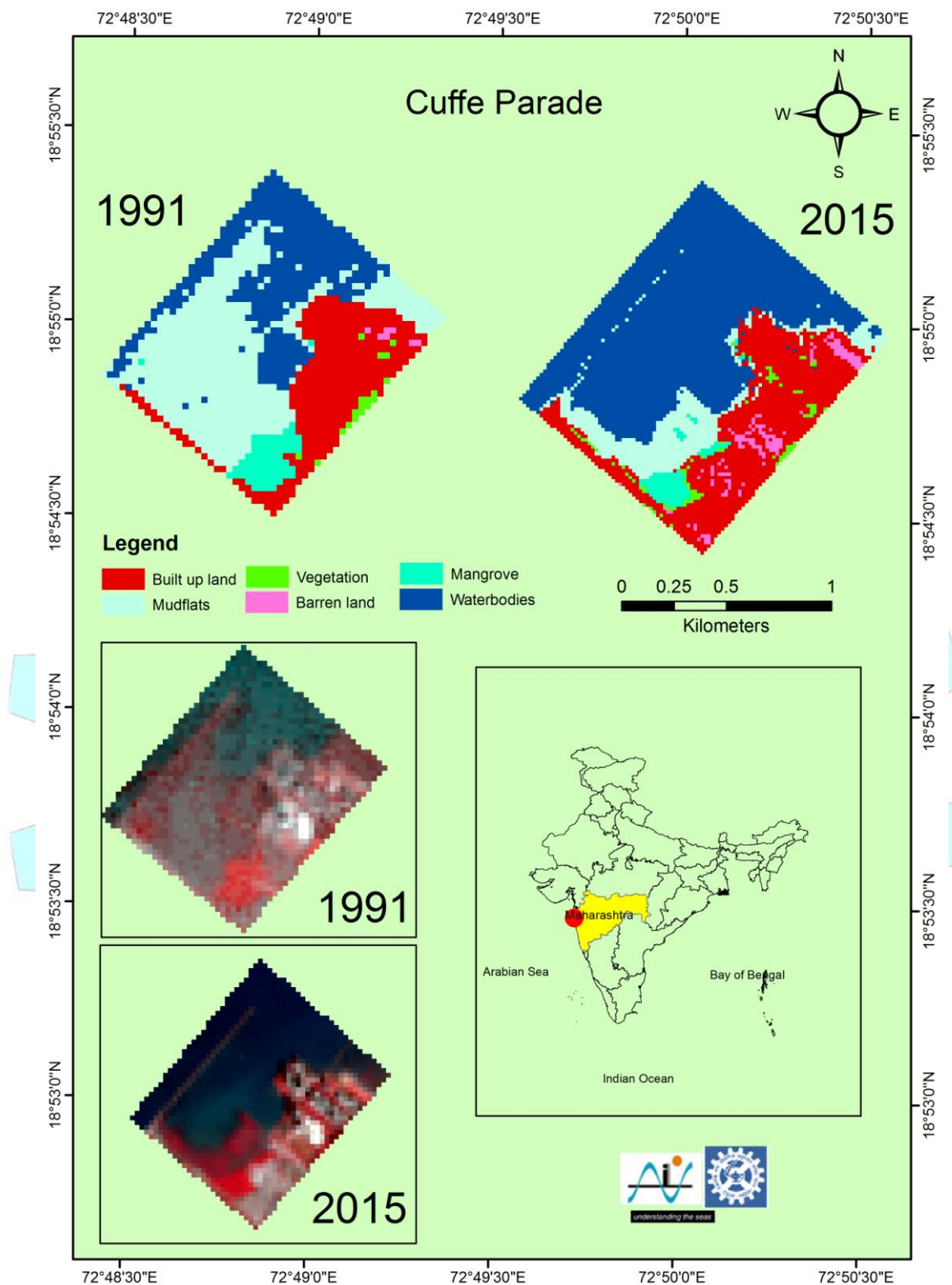


Fig. 3.28. Map showing mangrove change at Cuffe Parade

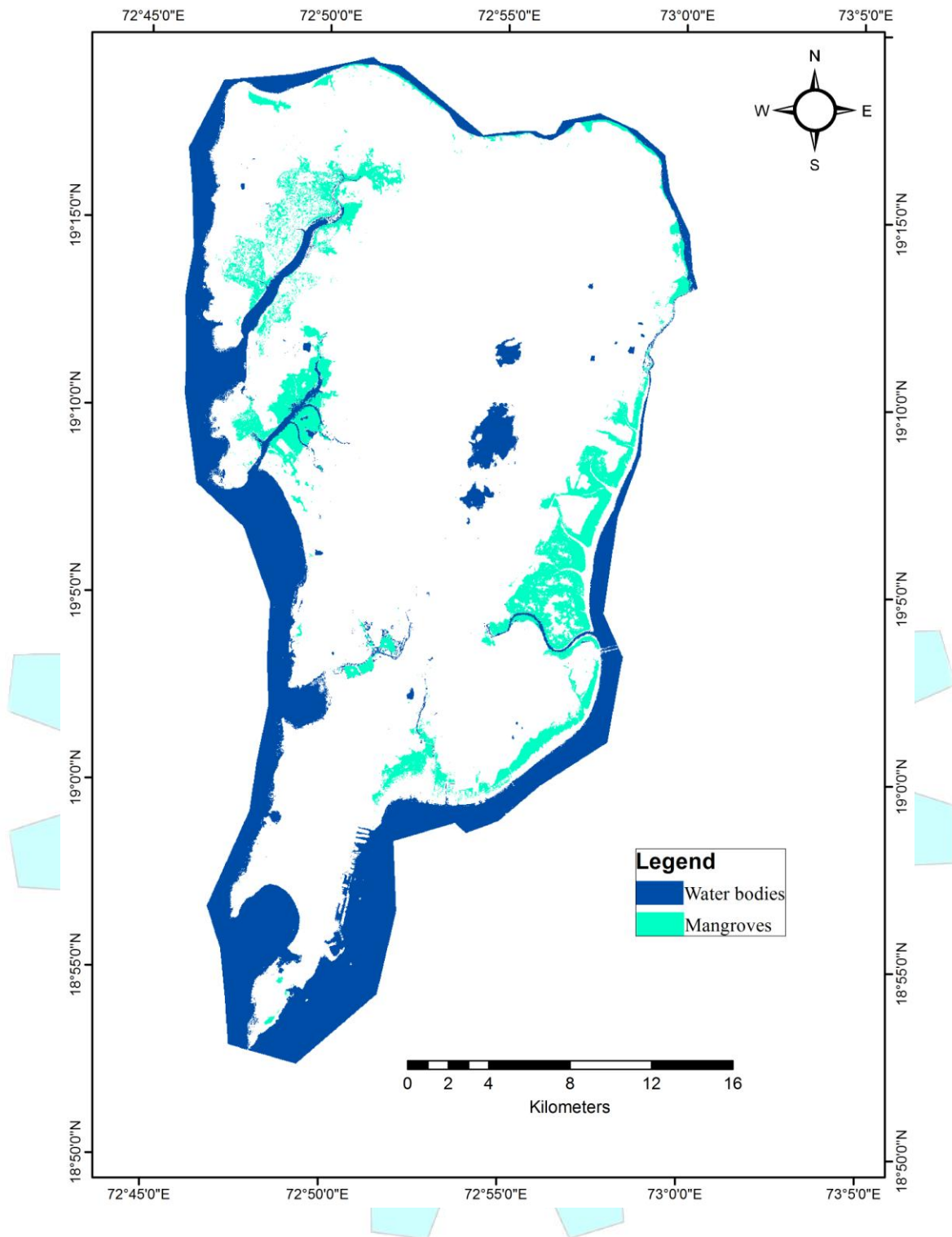


Fig. 3.29. Mangroves map of 1991

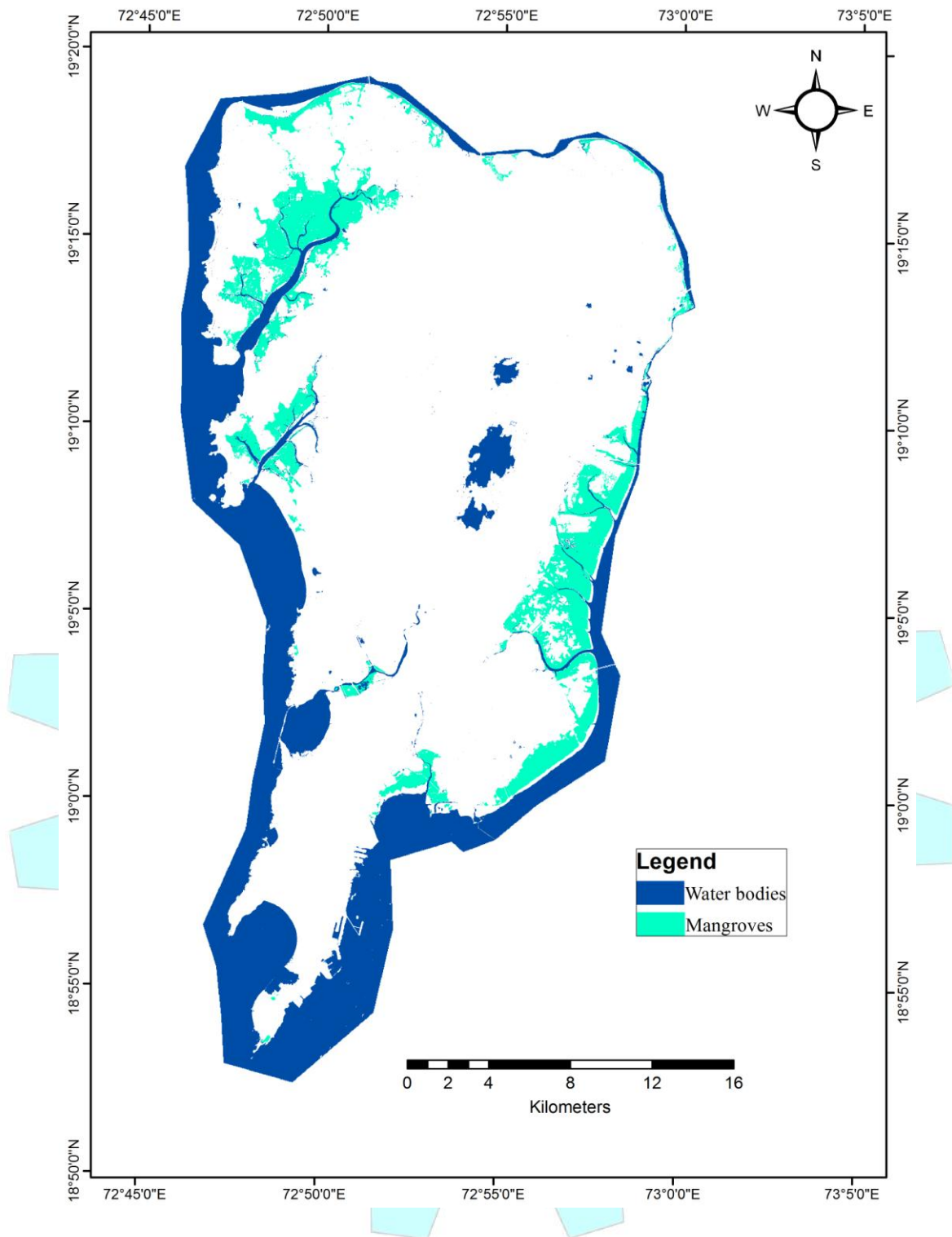


Fig. 3.30. Mangroves map of 2015

3.5.10 Marshy area

Marshy area refers to the wetlands found along with the mangroves. Analysis shows that marshy area increased from around 44 sq km in 1972 to around 55 sq km in 1977. Thereafter it shows a sharp decline over the years to fall to 16.43 sq.km of area in 1991. It has further reduced to 8.47 sq. km in 2015. The decline in marshy area of 8 sq km almost matches with the corresponding increase in mangroves in Mumbai during the period from 1991 to 2015.

A joint study of mangroves and marshy lands shows that prior to 1991, the total land under both categories was about 90 sq km with loss from one as a gain for the other. But by 1991, while the mangroves sharply increased, the marshy area declined more sharply with the total of the two falling to around 72-73 sq km. This indicates conversion of marshy land to mudflats or possibly reclaimed built space.

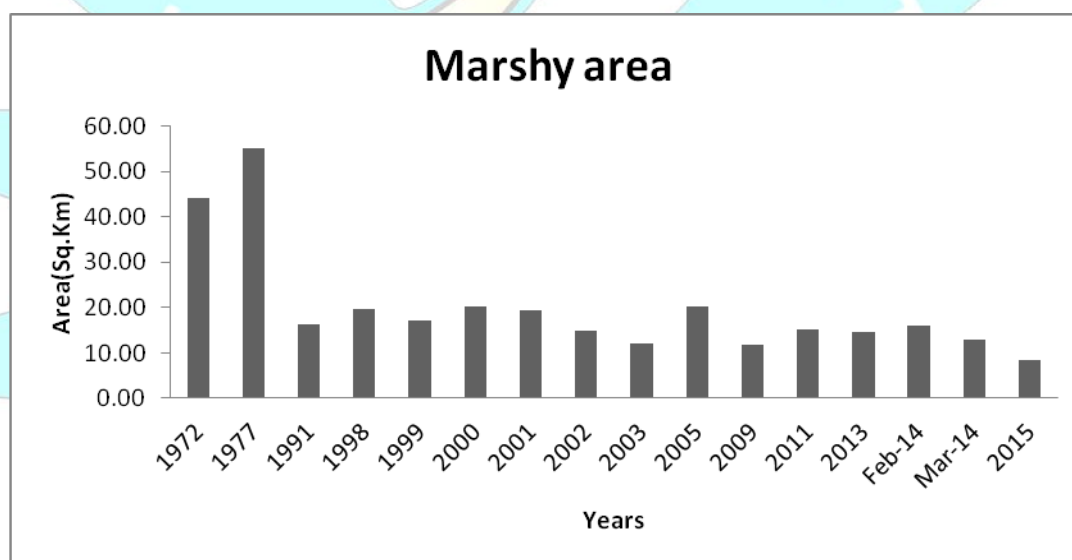


Fig. 3.31. Change in area of Marshy land

3.5.11 Salt Pans and Aquatic vegetation

Salt pans are mainly found along the Thane creek and close to the Vasai creek in the northern part of the study area. Salt pans remained the same from the past with a few changes in it. The main changes noticed in the saltpans are in the Thane region. It was converted to barren land. It has an average area of 22.47 sq. km

Aquatic vegetation is found only in two regions of the study area. One was in the Powai Lake and the other is close to Juhu airport which contributes only 0.68 sq.km of the area.

3.5.12 Mudflats and Water Bodies

The study area boundary was covered by both inland water bodies and the sea. Powai, Vihar and Tulsi lakes are the three main lakes found in the study area. Mithi River is one of the main river flows in the Mumbai city which drains into Mahim bay.

Water bodies showed a maximum of 188.36 sq. km in 2013 and a minimum area of 159.73 sq. km in February 2014. In the year 2013, during high tide time, there were no mudflats. Thus, the areas of water bodies were increased up to 188.36 sq. km. In February 2014, the areas of mudflats were at high of all the years; 25.26 sq. km and thus showed a minimal area of water bodies. The graph showing the area of water bodies and mudflats are given below.

A comparison was made on the tide value and the areas of mudflats, water bodies and marshy land over the creek for the year 2014 February and March. The tide value in February 2014 was 1.16 which showed high area of mudflats and marshy with reduction in water bodies, whereas in March 2014 the tide value was 2.43 which showed a decrease in the area of mudflats and marshy area with increase in the area of water bodies.

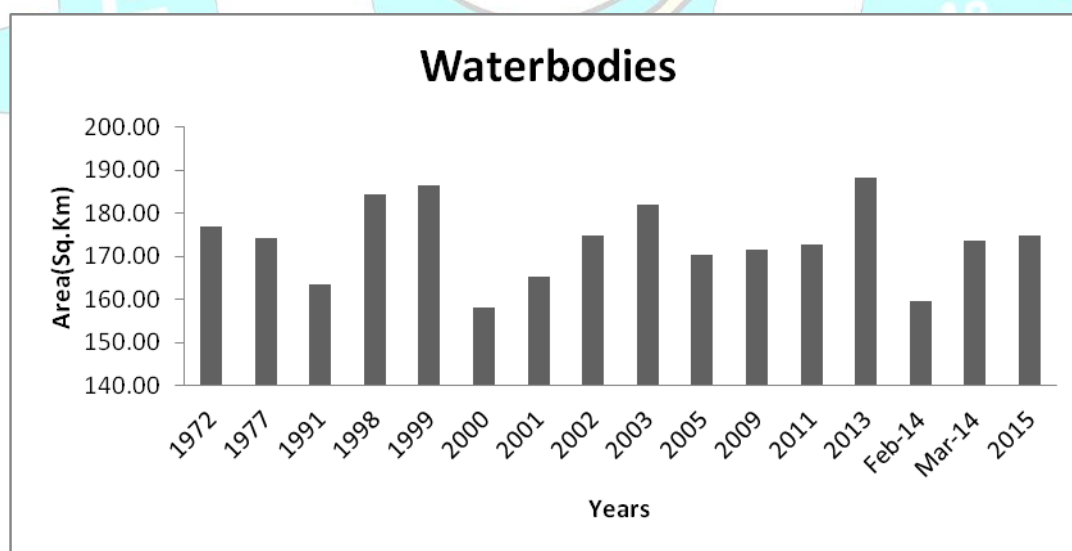


Fig. 3.32. Change in the area of water bodies

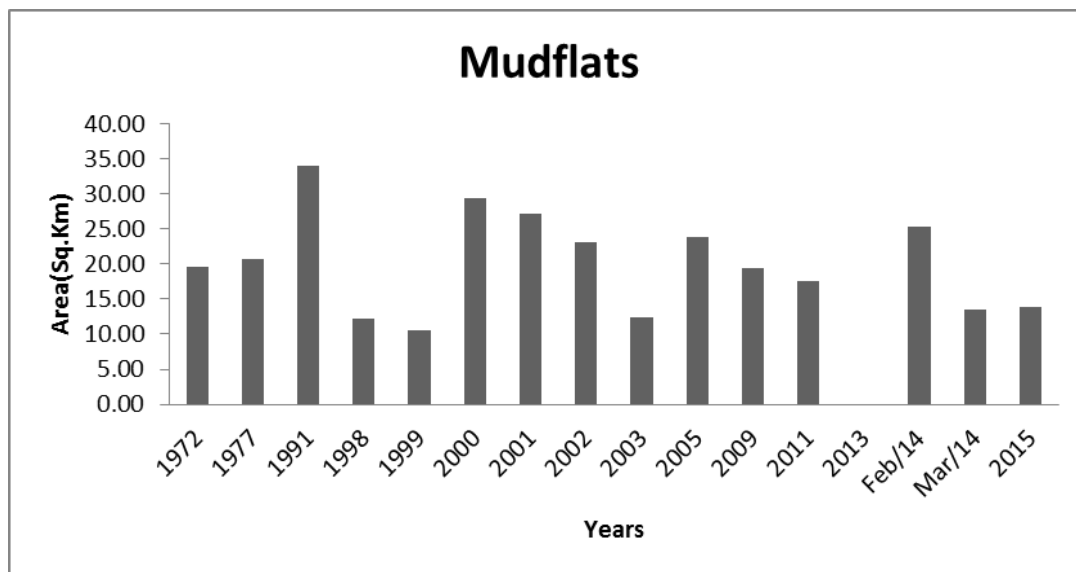


Fig. 3.33. Change in the area of mudflats



3.5.13 Ground Truth Validation

Ground truth validation is conducted all over the study area for the major land use and land cover classes. Land use and land cover type for 58 spots were located within the study area. The GPS locations of those spots are shown in Figure 3.34. The geographic locations of the spot with the identified class in the field and the land use land cover map are shown in the Table 3.6. The spot number marked in the map is in accordance with the serial number of the table.

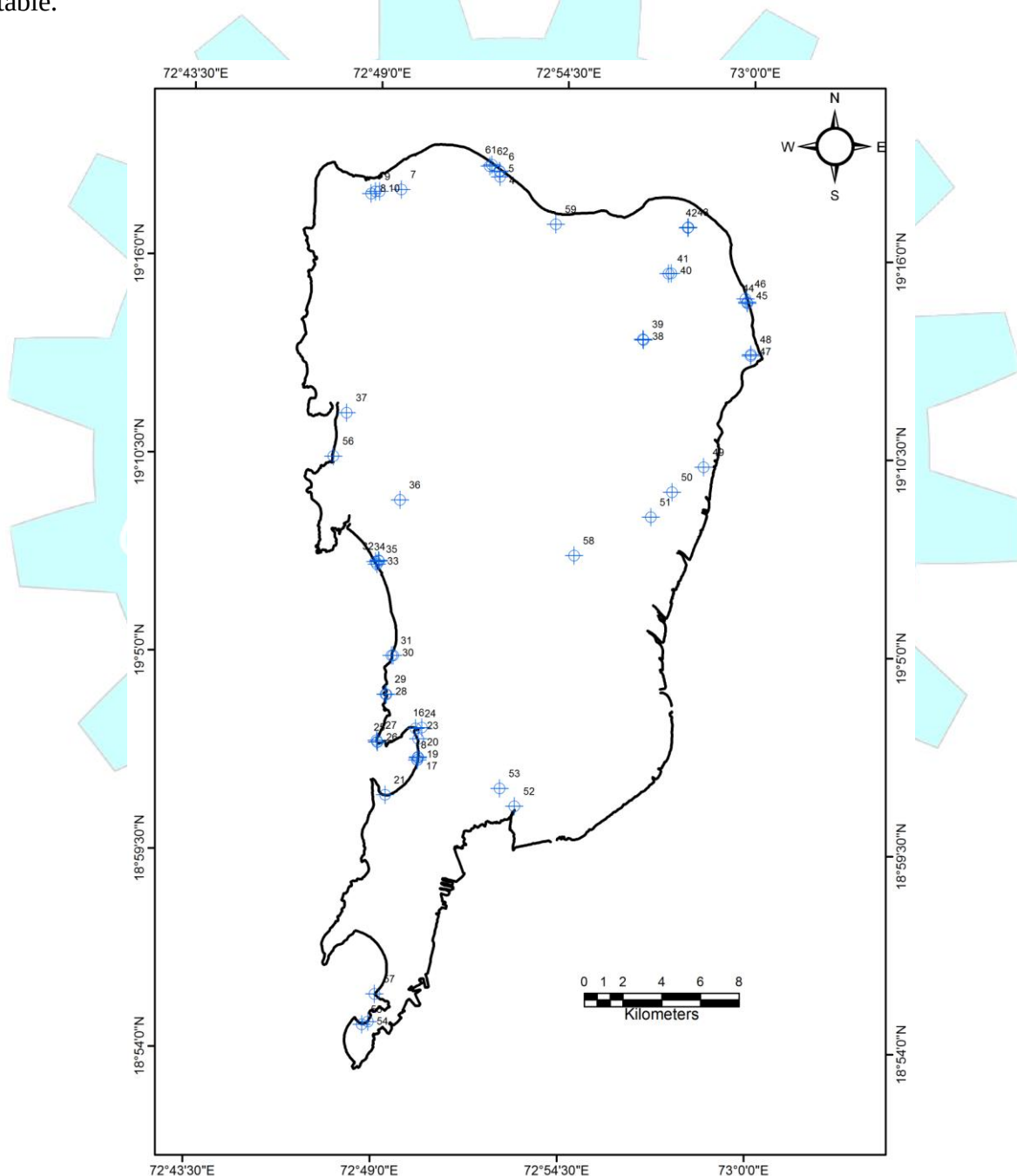


Fig. 3.34. GPS locations

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Table 3.6 GPS locations and class types

Serial Number	Latitude	Longitude	Field	Class
1	19.30	72.88	Salt pan	Salt pan
2	19.31	72.87	Salt pan	Salt pan
3	19.31	72.87	Mangrove	Mangrove
4	19.30	72.83	Fallow land	Fallow land
5	19.30	72.81	Salt pan	Salt pan
6	19.30	72.81	Salt pan	Salt pan
7	19.30	72.82	Mangrove	Mangrove
13	19.05	72.84	Mangrove	Mangrove
14	19.03	72.84	Built up	Built up
15	19.03	72.84	Built up	Built up
16	19.03	72.84	Built up	Built up
17	19.04	72.84	Built up	Built up
18	19.02	72.82	Built up	Built up
20	19.04	72.84	Built up	Built up
21	19.05	72.84	Water bodies	Water bodies
22	19.04	72.82	Built up	Built up
23	19.04	72.82	Built up	Built up
24	19.04	72.82	Built up	Built up

25	19.06	72.82	Mangrove	Mangrove
26	19.06	72.82	Mangrove	Mangrove
27	19.08	72.83	Sandy area	Sandy area
28	19.08	72.82	Sandy area	Sandy area
29	19.13	72.82	Mangrove	Mangrove
30	19.13	72.82	Mangrove	Mangrove
31	19.13	72.82	Sandy area	Sandy area
32	19.12	72.82	Sandy area	Sandy area
33	19.15	72.83	Barren land	Barren land
34	19.20	72.80	Mangroves	Mangroves
35	19.23	72.95	Barren land	Barren land
36	19.23	72.95	Barren land	Barren land
37	19.26	72.96	Built up	Built up
38	19.26	72.96	Built up	Built up
39	19.28	72.97	Fallow land	Fallow land
40	19.28	72.97	Fallow land	Fallow land
41	19.25	73.00	Barren land	Barren land
42	19.25	73.00	Barren land	Barren land
43	19.25	73.00	Mangrove	Mangrove
44	19.22	73.00	Mangrove	Mangrove
45	19.22	73.00	Mangrove	Mangrove

46	19.17	72.98	Dumping	Barren land
47	19.16	72.96	Salt pans	Salt pans
48	19.15	72.95	Grass land	Grass land
49	19.01	72.89	Mangrove	Mangrove
50	19.02	72.88	Mangrove	Mangrove
51	18.91	72.82	Mangrove	Mangrove
52	18.91	72.81	Mangrove	Mangrove
53	19.17	72.79	Sandy area	sandy area
54	19.13	72.91	Aquatic vegetation	Aquatic vegetation
55	19.28	72.90	Built up	Built up
56	19.30	72.87	Mangrove	Mangrove
57	19.30	72.87	Barren land	Barren land
58	18.93	72.82	Built up	Built up

3.5.14 Case study 1- Impact of proposed project in Cuffe Parade

Cuffe Parade lies in the southern part of the Mumbai city where the Nariman point and World Trade Centre and other financial businesses are situated. A Project proposal under the Concept Plan (2012-2052) was suggested for expansion of the Financial District consisted of creating additional reclamation as shown in drawing to re-design shore line near the Nariman Point business district to create attractive water front and enhance business / office areas to accommodate Finance centre if required in near future, as well as facilitate reconstruction of the existing fishing village and infrastructure required fishing activities. The proposed boundary for reclamation covers an overall area of 1.10 sq. km. The area covers mainly existing built up land, small area of barren land, vegetation, mudflats and water bodies and fishing village. The present area covered by each class is shown in the table below.

Major part is covered by built up/urban land which is 0.73 sq.km and water bodies of 0.27 sq. km. Vegetation, Barren land and mudflats areas are 0.04, 0.02 and 0.04 sq.km respectively. Proposed project will transform additional. 0.37 sq. km of area into built up land. The map shown in the figure displays both the present and proposed status of the Cuffe parade.

Table 3.7 Present and proposed area of classes in Cuffe parade

Classes	Present Area (Sq.km)	Impact due to proposed project(Sq.km)
Built up land	0.73	1.1
Water bodies	0.27	0.00
Vegetation	0.04	0.00
Barren land	0.02	0.00
Mudflats	0.04	0.00

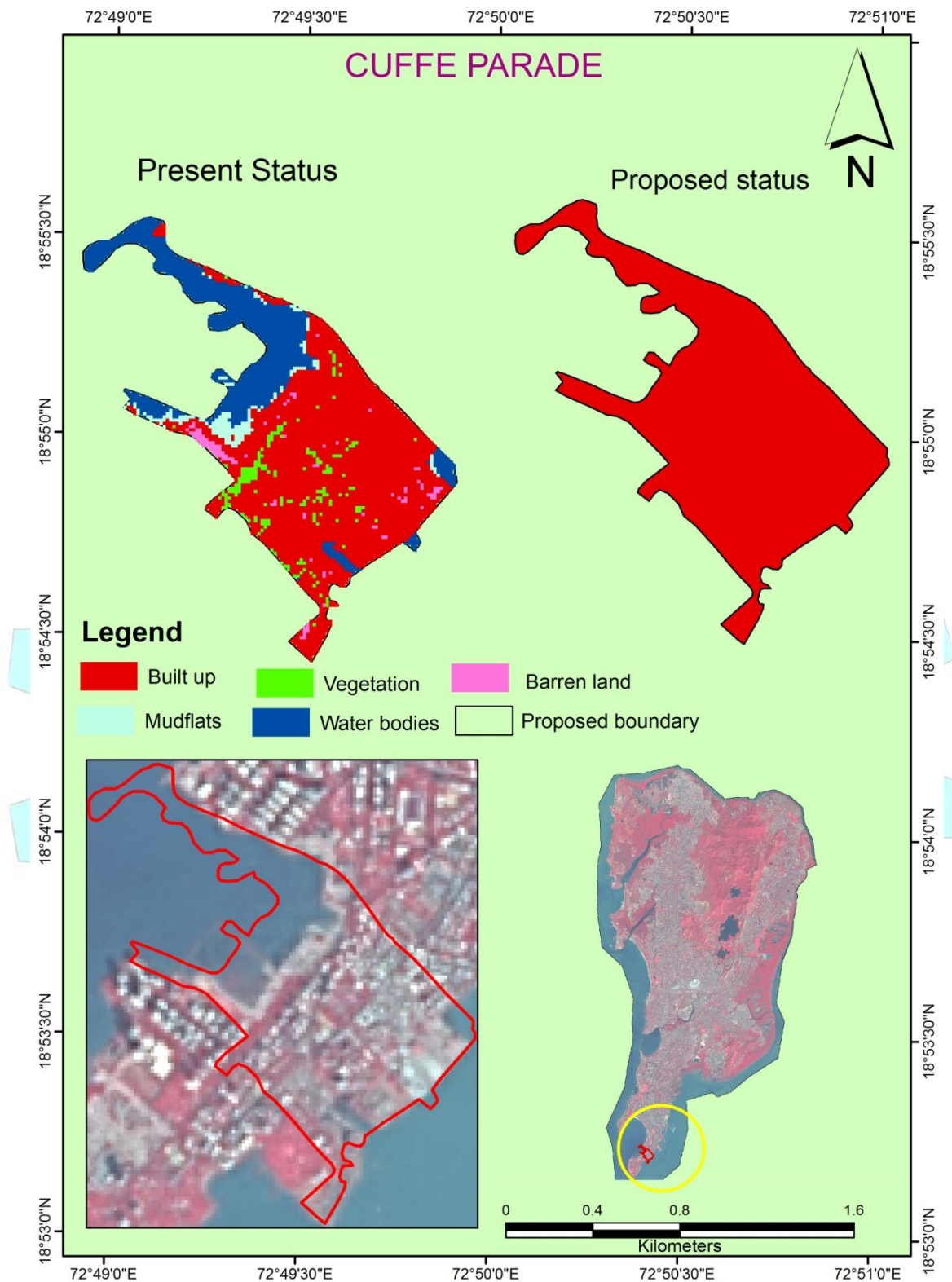


Fig. 3.35. Map showing the present and proposed status of Cuffe parade

3.5.15 Case study 2-Impact of proposed project in Mahim bay

This project was also indicated by the Concept Plan (2012-2052) as along term possibility to augment sweet water capacity for urban use by storing water flowing from Mithi river during Monsoon. The proposed plan is to create a fresh water reservoir in the Mahim bay by constructing bund to stop ingress of sea water into the Mahaim Bay. This change of salt water bay to sweet water lake was expected to affect environment around the bay and also the river banks of Mithi river, consisting of mangroves and mud flats. Presently, 0.30 sq. km area is under water body within the boundary and 0.01 sq. km of area is mudflats. The proposed plan will transform 0.31 sq.km of water body and mudflats into bund construction and reclaimed land for recreation at the mouth of the bay.

The areas of present and proposed status along with their respective classes were shown in the table below.

Table 3.8 Present and proposed area of classes in Mahim bay

Classes	Present Area (Sq.km)	Impact due to proposed project(Sq.km)
Built up land	0.00	0.31
Water bodies	0.30	0.00
Mudflats	0.01	0.00

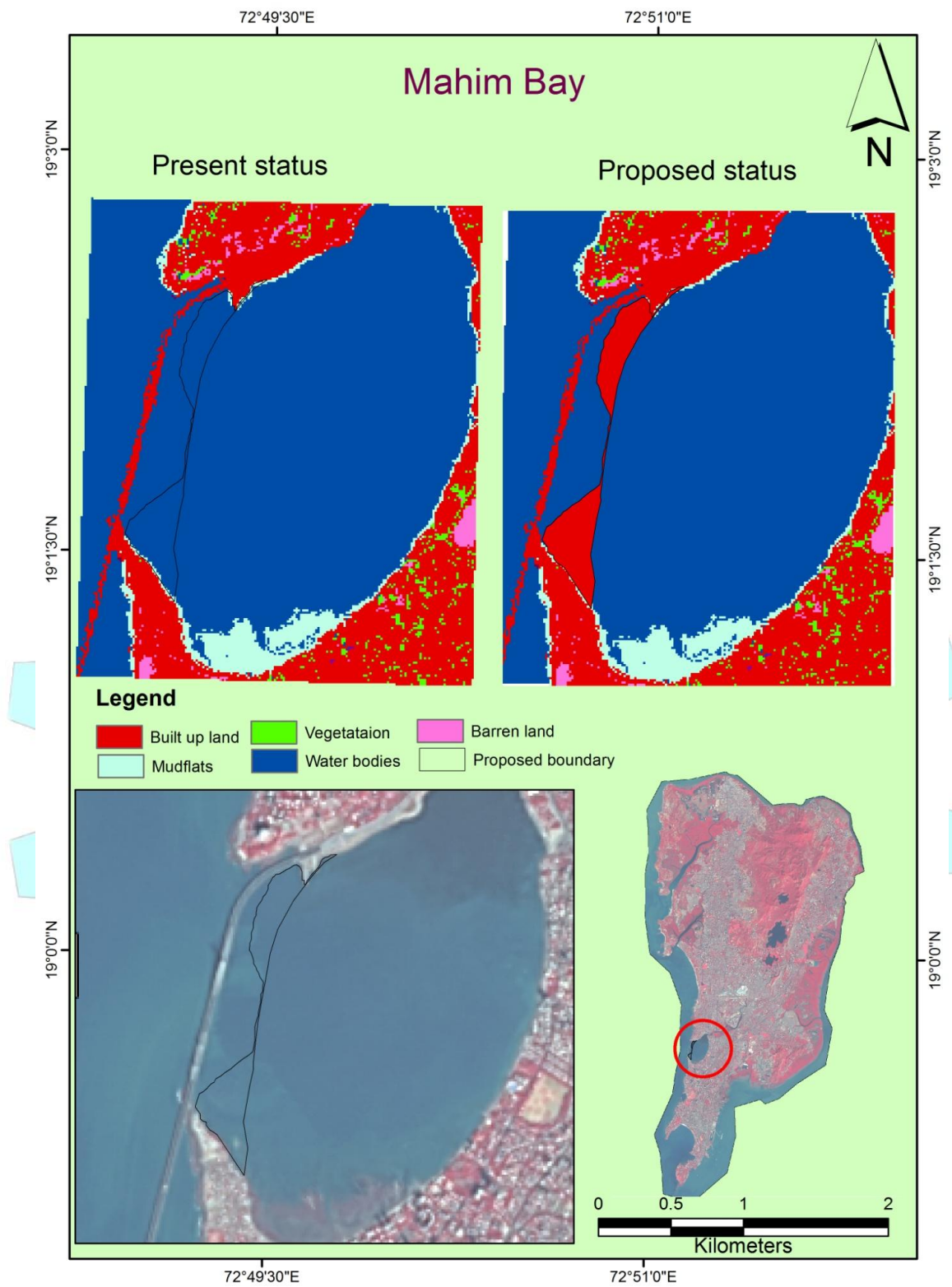


Fig. 3.36. Map showing the present and proposed status in Mahim bay

3.5.16 Case study 3- Impact of proposed project on construction of Coastal Road

A 32 km long coastal road is proposed by MCGM. The original proposal of constructing the road over the bridge on the sea water was converted to coastal road abutting the present shore line to economize the cost. The proposed coastal road extends from Kandivali in the north to the Nariman point in the south. The coastal road would be created by various means i.e. reclaimed land, existing land, bridges over mangroves, tunnel under the Juhu Beach and Malabar hill etc. Hence the areas of water bodies, vegetation, barren land and mudflats are expected to undergo major changes.. The present area covering the respective classes are shown in the given table.

1.32 sq.km of area is expected to be added to the existing land area for construction of coastal road, area of 0.37 sq.km will be reclaimed from mudflats region and 0.93 sq.km from the water bodies. These are the main classes of areas which will be affected by the reclamation as per the draft proposal. In case, the proposal is modified, it has to be re-assessed as per the new proposal.

The map shows status of both the present and proposed of the region.

Table 3.9 Present and proposed area of classes

Classes	Present area (Sq. km)	Impact on area due to proposed project(Sq. km)
Built up land	0.25	1.57
Water bodies	0.93	0.00
Vegetation	0.01	0.00
Barren land	0.01	0.00
Mudflats	0.37	0.00

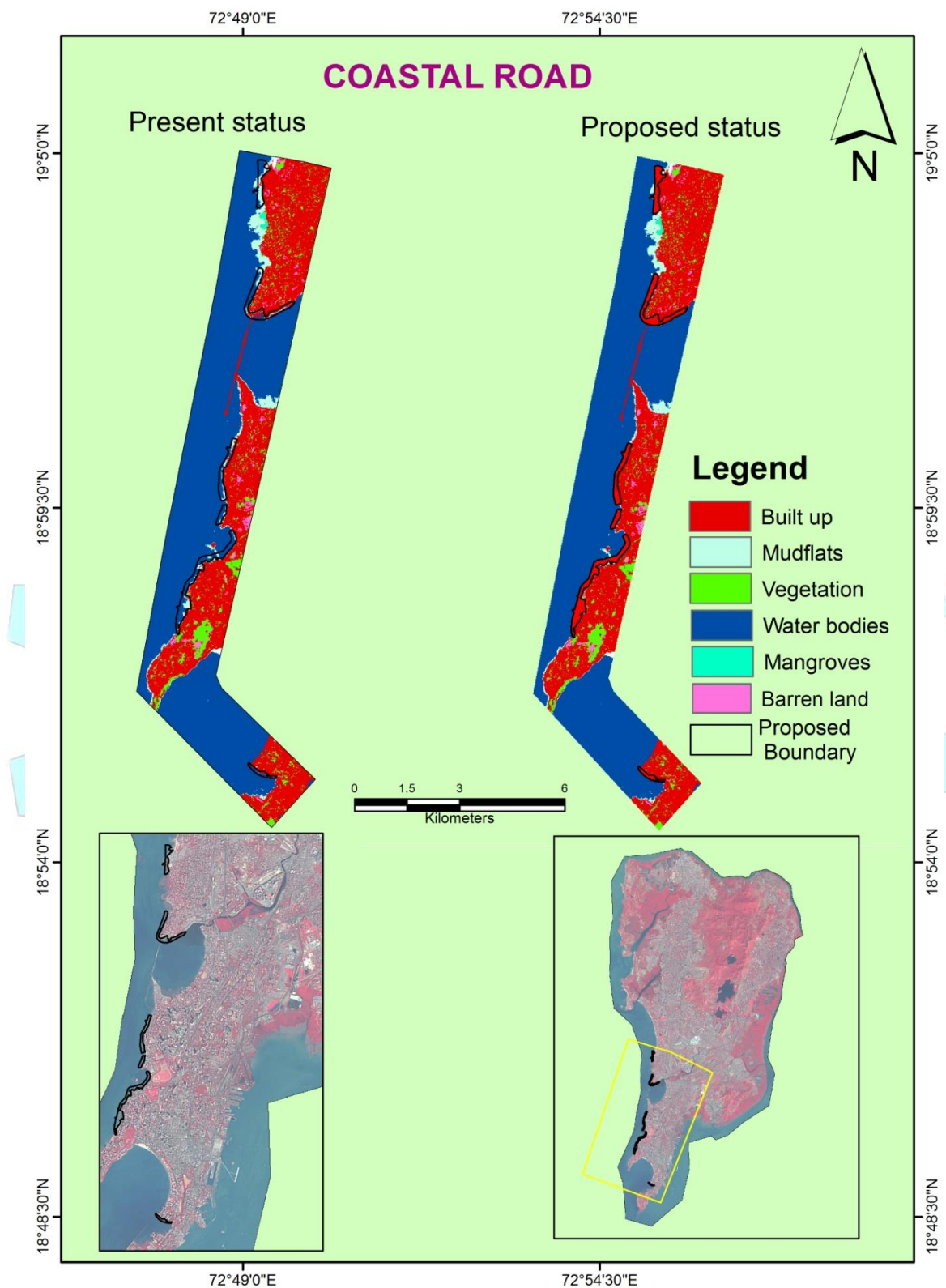


Fig. 3.37. Map showing the present and proposed status of coastal road implementation

3.6 Conclusions

GIS and remote sensing is an effective tool for Land use Land cover classification. LULC changes were significant during the period from 1972 to 2015. The main transformation that happened in the study area of Mumbai are as follows;

- Rapid expansion in the urbanization all over the study area. Significant changes were noticed in the Mumbai suburban and Thane districts of the study area. Urban Area has increased from 172.5 sq. km to 319.1 sq. km during the past 43 years (1972-2015).
- Overall increase of 9.28 sq. km of mangroves during from 1991-2015 over the creeks is noticed while decrease in the marshy land is also noticed. There was a sharper fall in the marshy area during 1972-1991 period.(area=27.6sq.km)
- Manori creek showed the maximum mangrove growth compared to other creeks.(increase in area from 11.79 sq.km in 1991 to 22.12 sq.km in 2015)
- Effect of urbanization through reclamation affected significantly the areas under barren land, vegetation and fallow land. 31 sq.km of vegetation and 13 sq.km of fallow land converted into urban land during 1991 -2015
- Fallow land in the Mira Bhayandar area(14 sq.km in 1977) has totally transformed to urban land during these years
- Development of Built up land in the forest region is also observed. This development is noticed in the northern and north eastern parts of the national park 0.64 sq. Km of built up area is found in the Yeoor hill region of national park. Built up is also observed all along the fringes of the national park.

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