REFORESTING MUMBAI:

AN ANALYSIS OF LAND-USE AND LAND-COVER CHANGE

USING SATELLITE REMOTE SENSING AND GIS

by

APURVA MARATHE

(Under the Direction of Thomas W. Hodler)

ABSTRACT

In this paper land-use land-cover change dynamics was investigated by the combined use of satellite remote sensing and geographical information systems (GIS). The objective of this paper was to determine transition among land-use land-cover types in Mumbai over a period of 28 years from 1973 to 2001, and to access the reasons for this change. Using a Landsat Multi Spectral Scanner (MSS), Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) from 1973, 1992 and 2001 respectively, the three images were classified into six land-use land-cover types: water, wetland, forest, bare land, built-up land and high density built-up land. An accuracy assessment was performed, transition matrices were created and maps were produced depicting the change in all the classes in the three years. The reasons for the change were also analyzed. It was seen that significant changes in land-use land-cover occurred within the area over the study period. As expected, the area showed significant increase in the built-up and high density built-up area. The results also showed change in the land-use land-cover from built-up area to forest area showing the effects of reforestation taking place in the city. The study demonstrates that the integration of remote sensing and GIS was an effective approach for analyzing the land-use land-cover change process.

INDEX WORDS: Satellite Remote Sensing, GIS, Land-use and land-cover, Land-use land-cover Classification, Unsupervised Classification, Accuracy Assessment, Transition Matrix, Reforestation, Slum Redevelopment, Google Earth.

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CHAPTER 1

INTRODUCTION

1.1. Mumbai

Mumbai, previously known as 'Bombay,' is the largest metropolis in India and is one of the fastest growing regions of the country. A rapid growth in population and the process of urbanization have resulted in an increase in demand for land in Mumbai. The mismatch between the supply and demand of land has led to the degradation of environment. Within the existing built-up areas in the city, the uncontrolled growth of population and inadequate infrastructure has caused irreversible losses of trees and open spaces within the city. The improper use of the available land has caused serious problems, due to the unavailability of excess land, to meet the demands of the ever increasing population.

Depletion of the forest cover is one of the major effects of rapid population growth and industrialization. Concerned with the ever growing problems like pollution, and rapid decline in trees and open spaces, various reforestation movements were carried out by the government and various small groups in the 1990's to protect the trees and also to grow more trees in the city.

This paper attempts to show the effects of population growth, urbanization and industrialization on the land-use and land-cover (LULC) of Mumbai. It will also attempt to evaluate the effect of the reforestation movements on the total forest cover in the city.

1.2. Population

The rapid growth of population (see Figure 1.1) and the process of urbanization have resulted in an increasing demand for land in Mumbai, producing what is the most expensive real estate in the country. According to '*The Economic Times*' newspaper, the real estate prices in Mumbai have doubled from 2005 to 2006. A square foot of space in Southern Mumbai in 2006, was about $750. The cost of land in the western suburbs was about $150 per square foot and about $100 per square foot in the central suburbs (Kuber, G. 2006). Increasing population of cities and the physical expansion of the built-up area beyond the city limits, as well as rising demand for more land for various purposes like residence and businesses have induced changes in urban land-use.

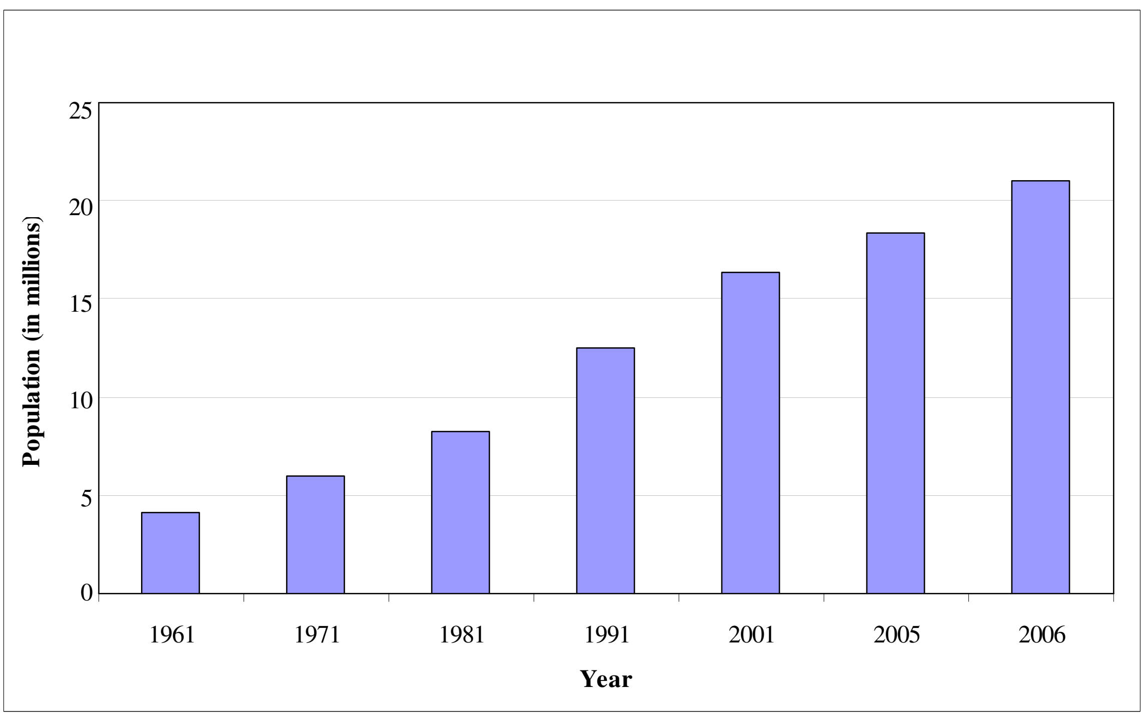

Figure 1.1. Population of Mumbai (Source: Calculated from data contained in Census of India 1961, 1971, 1981, 1991 and 2001)

Mumbai, with a population of around 21 million in 2006, is the eighth most populated city in the world after Tokyo, New York Metro, Sao Paulo, Seoul, Mexico City, Osaka and Manila. It is still, the most densely populated city amongst them all according to the '*City Mayors*' group statistics (City Mayor's Group, 2007), with a population density of 124,000 persons per sq mile.

1.3. Area

Mumbai is situated on the west coast of India between 18.96° N latitude and 72.82° E longitude and is surrounded by the Arabian Sea from all sides. Figure 1.2 shows the location of Mumbai within India.

The city of Mumbai originally consisted of seven islands, namely Colaba, Mazagaon, Old Woman's Island, Worli, Mahim, Parel, and Bombay with a combined area of not more than 50 sq miles (see Figure 1.3). This group of islands has since been joined together by a series of reclamations, the first one that occurred in 1708. It took over 150 years to join the original seven islands of Mumbai. Today the city (see Figure 1.4) covers an area of about 169 sq miles. The study area is classified as the metropolis of Mumbai, under the jurisdiction of the Brihanmumbai Municipal Corporation. The Metropolis consists of the city, its suburbs and also the cities of New Bombay and Thane.

Figure 1.2. Geographic position of Mumbai within India

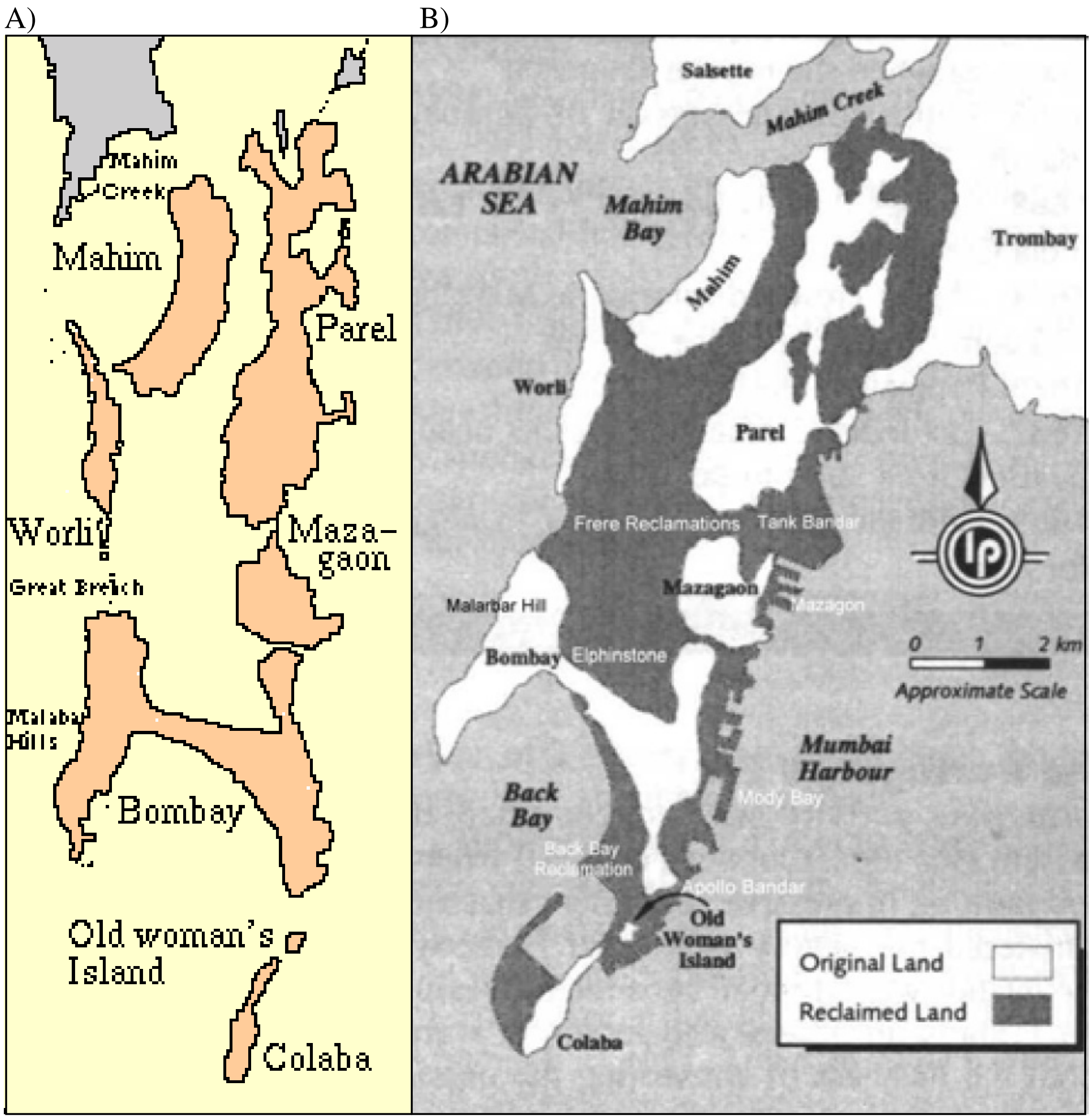

Figure 1.3. Seven islands of Mumbai. A) identifies the individual islands while B) identifies the area of land reclamation

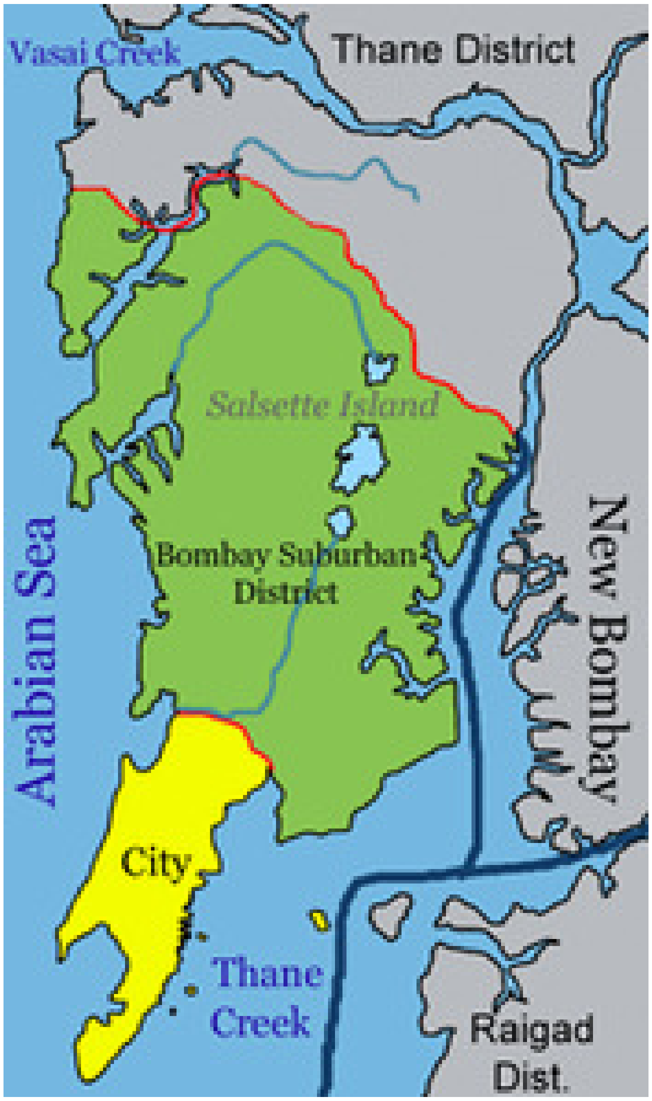

Figure 1.4. Metropolis of Mumbai

Much of Mumbai is just above the sea level where the average elevation is 13 meters. The annual temperature ranges from a high 38°C (100°F) to a low 11°C (52°F). Mumbai's weather is divided in four seasons: Winter (December - February); Summer (March – May); Monsoon (June – September) and withdrawal of monsoon season (October – December).

1.4. Class Difference and Distribution

There is a major cultural and class difference in the population across the metropolis of Mumbai. Almost 48% of the people in Mumbai live in slums. According to '*Rediff India Abroad*' (Rediff India Abroad, 2004), Mumbai was ranked first as the market city with the highest total prosperity (per capita prosperity multiplied by population) in the country. It is the financial capital of India, housing the primary stock exchange and serves as cooperative headquarters for many large cooperations like the Tata Group, Reliance Industries, Aditya Birla Group Hindustan Petroleum, Bharat petroleum, and others with a total revenue of 28.90, 28.34, 24.12 and 18.10 billion US$ respectively. It is also the primary center for the arts and the entertainment industry. On the other hand, in 2006, according to the '*Time Asia'* magazine (Perry 2006), the town of Dharavi in Mumbai that spreads across one square mile in the heart of Mumbai is the largest contiguous slum in the world, and has a population of between 600,000 and a million. Figure 1.5 shows the LULC in Dharavi. Dharavi is one of the world's largest slums, and is also by far the most prosperous one too. It is a thriving business centre propelled by thousands of micro-entrepreneurs who have created an invaluable industry like leather, jewellery and pottery (Ramanathan 2007). Thus the class difference is very pronounced in Mumbai.

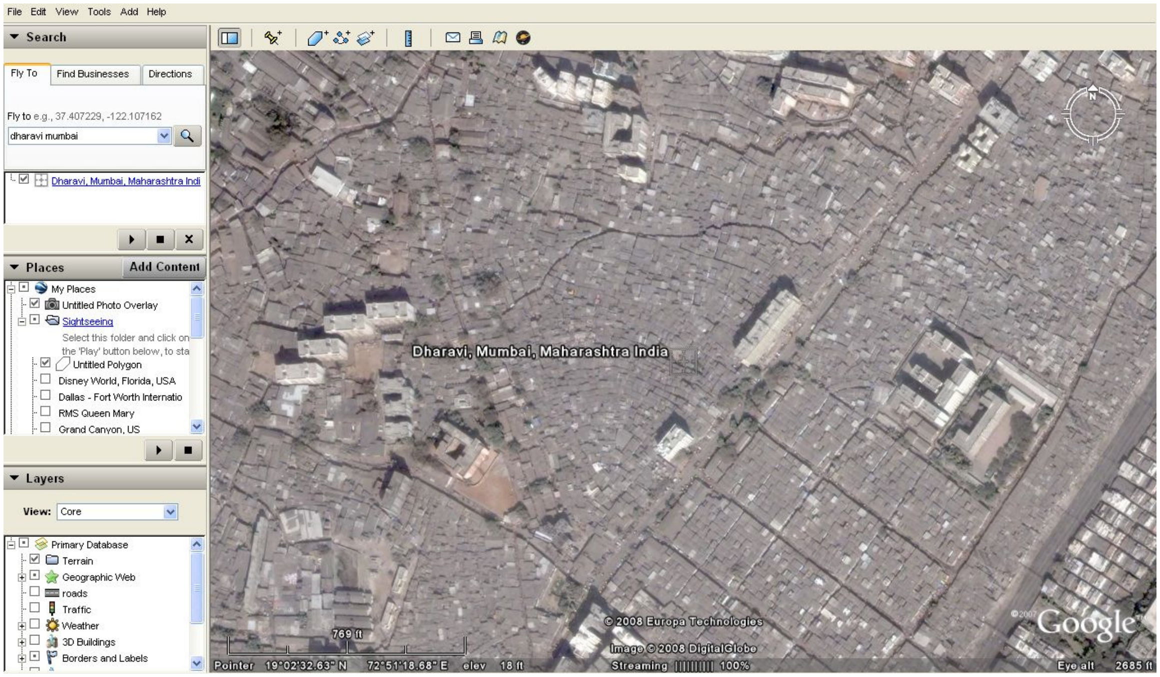

Figure 1.5. Dharavi

1.5. Reforestation Movements

To accommodate the increasing population due to immigration of people from all over the country to Mumbai, and the rapid industrialization, it was observed that there was a rapid decline in the forest cover in the city. Concerned with the alarming rise in pollution levels, lack of cleanliness and the rapid disappearance of trees and open spaces, reforestation movements were started by the government and also by some concerned small groups. The "Action for Good Governance and Networking in India" (AGNI) collaborated with college and school students and the '*Times of India*' group to take up 'Cleaning and Greening Mumbai.' The project began with a two-day workshop at Lonavala in November 2000, involving 150 college students and program officers besides AGNI volunteers. Detailed plans and commitment schedules were prepared. A "Clean and Green Mumbai" week (18th - 24th Jan 2001) was conceived at the workshop and launched at a mass meeting. Volunteer groups were set up in eleven Wards to spread awareness during the first phase of the project. The second phase was an exercise in cleaning, greening and vermi-composting in and around Mumbai.

Several other drives took place in Mumbai before and after this movement. In 1998-99, a "Grow more trees campaign" was started where the Brihanmumbai Municipal Corporation (BMC) gave away 100,000 saplings at a nominal rate of Re. 1 (about 2.50 cents) per plant to schools, colleges, factories, housing societies and individuals for planting. Since then many more groups have come up to try and be a helping hand towards growing more trees. Thus small groups played a very important role in reforesting Mumbai.

The Maharashtra Preservation of Trees Act of 1975 prohibits any person from cutting or damaging a tree without permission, even in a private premise. Every act of chopping at different points of time, whether it is the same tree or different trees, constitutes a separate offence. A penalty includes a minimum fine of Rs. 1,000 ($ 25) and maximum of Rs. 5,000 ($ 125) with possible imprisonment ranging from a week to a year.

1.6. Remote Sensing and GIS

Rapid land-use land-cover (LULC) change has taken place in many regions of India, especially in the city of Mumbai due to accelerated industrialization and urbanization. In this study, LULC change dynamics will be investigated through the combined use of satellite remote sensing and geographical information systems (GIS). Transition among LULC types in Mumbai over a period of 28 years from 1973 to 2001 is going to be determined, and the reasons for this change are going to be evaluated. The analysis will be performed using three images obtained from the Global Land-Cover Facility (GLCF) website. The first 1973 image is a Multi Spectral Scanner (MSS), the second 1991 image is a Landsat Thematic Mapper (TM) and the third 2001 image is a Landsat Enhanced Thematic Mapper Plus (ETM+). These three images will be classified into six land-use types namely: water, wetland, forest, bare land, low density built-up land and high density built-up land.

1.7. Objectives

The purpose of this study is to reconstruct 28 years of LULC change in Mumbai from 1973 to 2001 with the help of three satellite imageries from the years 1973, 1992 and 2001. Mumbai is the fastest growing metropolis in India, which is why it is very important to explore the LULC change taking place in this region. There are seven objectives set forth in this research. They are:

1. Classify the LULC in six classes namely water, wetland, forest, bare land, high density urban and low density urban for each of the three images of 1973, 1992 and 2001;
2. Determine how accurate the whole LULC classification process really was. For this purpose an accuracy assessment will be carried out on all the three images;
3. Identify and compare the direction of change in the LULC in the desired area from (a) 1973 to 1992, (b) 1992 to 2001 and (c) collectively from 1973 to 2001 with the help of LULC transition matrices;

4. Create maps to visually see the changes in different classes spatially across Mumbai from 1973 to 1992, from 1992 to 2001 and also from 1973 to 2001;

5. Determine if Mumbai has actually increased the forest cover due to the various reforestation movements;

6. Observe the effects of population growth and urbanization on the LULC of the area;

7. Explain the effects for the changing LULC in the area.

CHAPTER 2

LITERATURE REVIEW

2.1. Anderson's Land-use Land-cover (LULC) Classification Overview

Anderson's LULC classification system was developed in 1972 to meet the needs of Federal and State agencies for an up-to-date overview of LULC throughout the United States. The basis of the classification scheme is to produce uniform categorization at the more generalized first and second levels and that would be receptive to data from satellite and aircraft remote sensors (Anderson 1972).

In this study, the design and LULC scheme will be developed from an Anderson Level II classification scheme. This classification scheme is most appropriate for statewide and interstate regional LULC compilation and mapping and provides flexibility in developing categorization at detailed levels. Users can also develop their own categories according to the utility to their particular needs (Anderson 1976). Thus several modifications will be made in this classification scheme in order to include only those classes that are relevant to the study area. Some categories like tundra and perennial snow or ice are omitted because they are not applicable to the area. Built-up area has been divided into low density built-up area, and high density built-up area (Table 2.1).

Table 2.1. Land-use and land-cover classification scheme specific to the Mumbai metropolitan region

Level I	Level II
1. Water	11. Sea 12. Lakes and Ponds 13. Streams
2. Wetland	21. Mangroves
3. Forest	31. Deciduous Forest 32. Mixed Forest 33. Segregated Tree Cover
4. Bare Land	41. Stadiums 42. Highways 43. Airfields
5. Low Density Built-Up	51. Sparsely Built Residential and Commercial Buildings
6. High Density Built-Up	61. Slums 62. Closely Packed Residential and Commercial Buildings

2.2. Classification of Land-use and Land-cover

2.2.1. Satellite Imagery

Changes in the LULC have become recognized over the last 15 years as important global environmental changes in their own right (Turner 2002). Globally, the landscape is being altered by direct human use. Remote sensing has been an important contributor in documenting the actual change in LULC on regional and global spatial scales from the mid-1970s (DeFries *et al*. 2004, Lambin *et al*. 2003).

Remote Sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with object, area, or phenomenon under investigation (Lillesand and Kiefer 1987). Today remotely sensed image data of the Earth's surface acquired by spacecraft platforms are readily available in digital form. Digital remote sensing systems convert electromagnetic energy (color, light, heat, etc) to a digital format. Spatially, the data are composed of discrete picture elements, or pixels, and radiometrically quantised into discrete brightness levels. Remote sensing has become an important tool applicable to developing and understanding the global, physical processes affecting the Earth. As current trends continue, additional, higher resolution satellites will become available providing the means to produce more accurate LULC maps characterized by finer levels of detail.

The two main factors limiting urban applications of the available satellite imagery are spatial resolution and geometric accuracy. Spatial resolution of the sensor refers to the size of the smallest possible feature that can be detected. A higher resolution, yields to a more detailed sharper image. Spatial resolution is usually expressed in meters. Thus, a 30 meter resolution image is more detailed than a 60 meter resolution image. The constraints of Landsat MSS imagery include a low spatial resolution of about 60 meters versus a high spatial resolution of about 30 meters for a Landsat TM and Landsat ETM+ image, and a relatively coarse spectral resolution of 4 bands while the latter has a 7 band multispectral sensor. The Landsat ETM+ also includes a broadband panchromatic channel at a 15 meter resolution. Spectral resolution is determined by the band widths of the channels used.

Higher classification accuracy will be obtained from TM and ETM+ images than from the MSS image. To get high classification accuracy for the MSS image, it is necessary to regroup MSS classified image into more classes in order to increase classification accuracy (Alavi Panah and Ehsani 2004).

Satellite remote sensing has the advantages of large area coverage, repeated viewing capability, and ease of integration with GIS. When the environment in a large metropolitan area experiences rapid suburbanization, it needs to be monitored constantly. The use of remote sensing has demonstrated more advantages than the traditional field surveying. In such areas, human induced land-use land-cover changes can be substantial but are difficult to grasp when they occur on such a high extent and large scale. Mapping from a time series of satellite data, has successfully revealed dynamics of urban land characteristics for large metropolitan areas (Lo and Shipman 1990; Lo 1998; Masek *et al*. 2000).

3.2.2. Classification Approach

In contemporary LULC change mapping studies, LULC classes are often derived from satellite imagery by utilizing computer-assisted image classification techniques. Within the scope of the study, image classification is defined as the extraction of distinct classes or themes from the satellite imagery, with the help of similar digital number values, into LULC classification categories. There are two primary methods of image classification utilized by image analysts: unsupervised and supervised classification.

Unsupervised image classification is a method in which the image interpreting software separates the pixels in an image, based upon their reflectance values into as many classes or clusters as the analyst wants. Once this process is completed, the image analyst determines the land-cover type for each class, based on image interpretation, ground truth information, maps, field reports, or other information sources and assigns each class to a specified category.

Supervised image classification is a method in which the analyst defines small areas, called training sites, on the image which are representative of each desired land-cover category. The delineation of training areas representative of a cover type is most effective when an image analyst has knowledge of the geography of a region and experience with the spectral properties of the cover classes (Skidmore 1989). The image analyst then “trains” the software to recognize spectral values or signatures associated with the training sites. After the signatures for each land-cover category have been defined, the software then uses those signatures to classify the image pixels.

CHAPTER 3

METHODOLOGY

3.1. Satellite Imagery

Landsat data files which were radiometrically and geometrically corrected were obtained from the "Global Land-Cover Facility" (GLCF) website. Three images, a Landsat MSS image acquired on 9th January 1973, a Landsat TM image acquired on 9th November 1992 and a Landsat ETM+ image acquired on 25th October 2001 were used in this study. The Landsat MSS had four bands (1-4) and had a resolution of 60 meters. The Landsat TM and Landsat ETM+, each had six bands (1-5 and 7) and had a resolution of 30 meters. The original three Landsat MSS, Landsat TM and Landsat ETM+ images are shown respectively in Figures 3.1, 3.2 and 3.3.

Figure 3.1. Landsat MSS Image of 1973

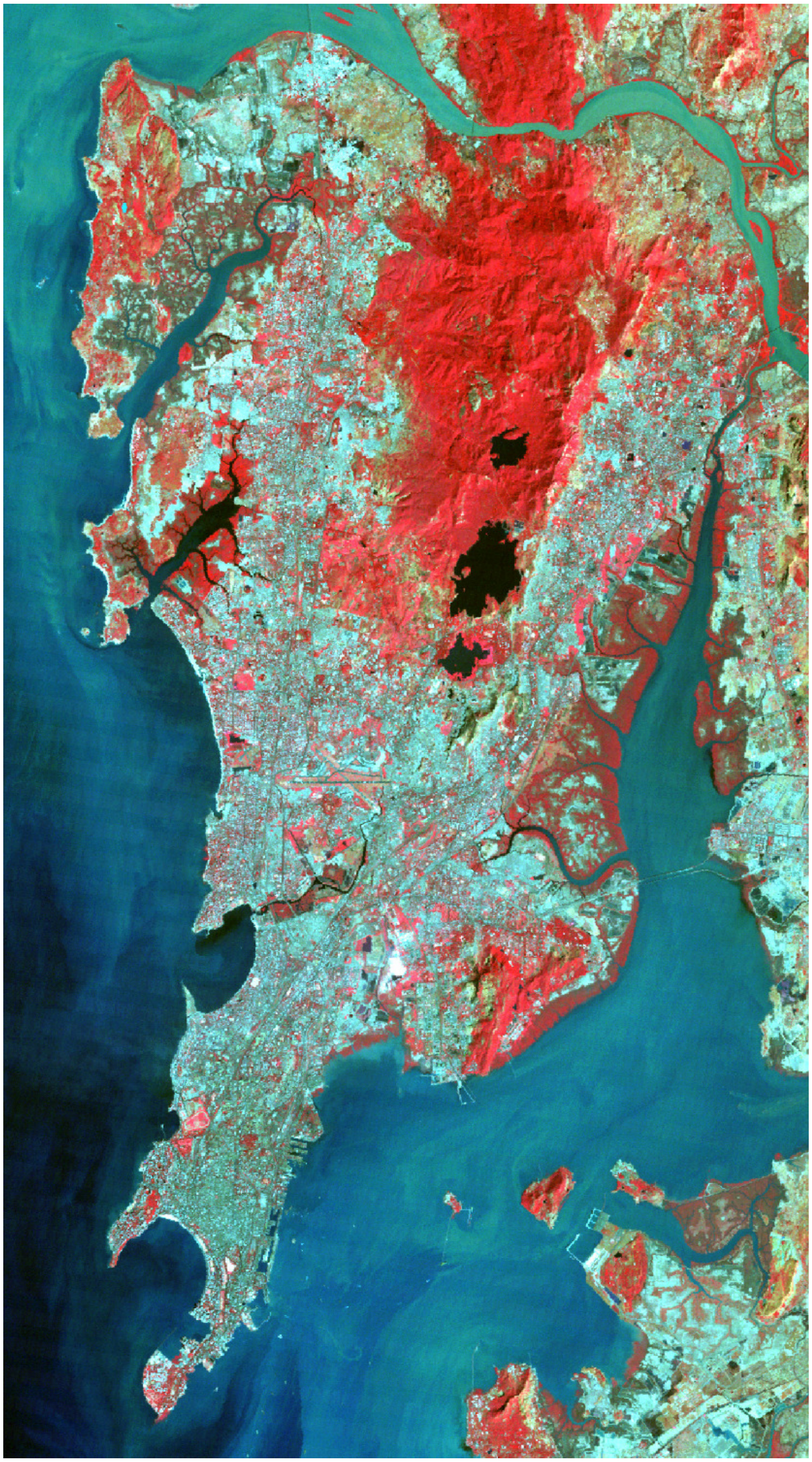

Figure 3.2. Landsat TM Image of 1992

Figure 3.3. Landsat ETM+ Image of 2001

3.2. Processing Techniques Summarized

A subset was created around the area of interest (AOI) from the three images. An unsupervised classification will be carried out on each of the three images in which six different classes will be identified: water, wetland, forest, bare land, built-up land, and high density built-up land. An accuracy assessment of the three images will be conducted. LULC transition matrices will be created to show the direction of change in the study area. The change in total area within each class for each of the three years will be observed with the help of maps.

3.3. Satellite Imagery Selection

The images used were obtained free of cost from the Global Land Cover Facility (GLCF) website, for the years 1973, 1992 and 2001. These years were selected as they depicted a broad time frame of 28 years. While looking for a satellite image, a few things were taken into consideration like moderate resolution (60 meters and 30 meters) and zero cloud cover.

3.4. Image Resolution

Spatial resolution specifies the pixel size of satellite images covering the Earth's surface. The higher the resolution, the more detailed is the image. The Landsat MSS image has a low spatial resolution (30 - >1000 m) and the Landsat TM and Landsat ETM+ have a medium spatial resolution (4 – 30 m). A sensor's spectral resolution specifies the number of spectral bands in which the sensor can collect reflected radiance. The three images acquired, in this research are of medium spectral resolution (3 – 15 bands).

The characteristics of these three images are shown in Table 3.1.

Table 3.1. Characteristics of the satellite data used for land-use land-cover change mapping in the Mumbai area

Date	Path/Row	Type of Imagery	Landsat Number	Spatial Resolution	Bands
9 Jan 1973	159/047	MSS	1	60 meters	1,2,3 and 4
9 Nov 1992	148/047	TM	5	30 meters	1,2,3,4,5 and 7
25 Oct 2001	148/047	ETM+	7	30 meters	1,2,3,4,5 and 7

3.6. Classification Procedures

3.6.1. Creating a Subset

Bands 1-5 and 7 for the Landsat TM and ETM+ image and bands 1-4 for the Landsat MSS image were layer stacked on each other in the Erdas Imagine software in order to produce a subset around the Metropolis of Mumbai. This process was carried out for all three images of 1973, 1992 and 2001. The spatial extent of the Area of Interest (AOI) was as follows:

Upper Left X: 263910.00 Lower Right X: 291298.50

Upper Left Y: 2138383.50 Lower Right Y: 2088993.00

3.6.2. Computer Assisted Land-use Land-cover Classification

These subsets were used to perform an unsupervised classification starting with 15 classes for Landsat TM and ETM+ and 20 classes for Landsat MSS to gain better classification accuracy due to its lower resolution. After that, the maps were recoded with just six land-use land-cover (LULC) classes namely: water, wetland, forest, bare land, low density built-up area and high density built-up area. Recoding is done in order to reduce the number of classes from the original high number of unsupervised classification classes. The process of ground truthing was done with the help of Google Earth. Figures 3.4 and 3.5 are taken from the city of Thane, and they depict images from Google Earth showing low density built-up land. Figures 3.6 and 3.7 are from the towns of Ghatkopar and Govandi respectively, and show examples of high density built-up land. A comparison of these four figures provides visual insight into the differences in land-use land-cover densities.

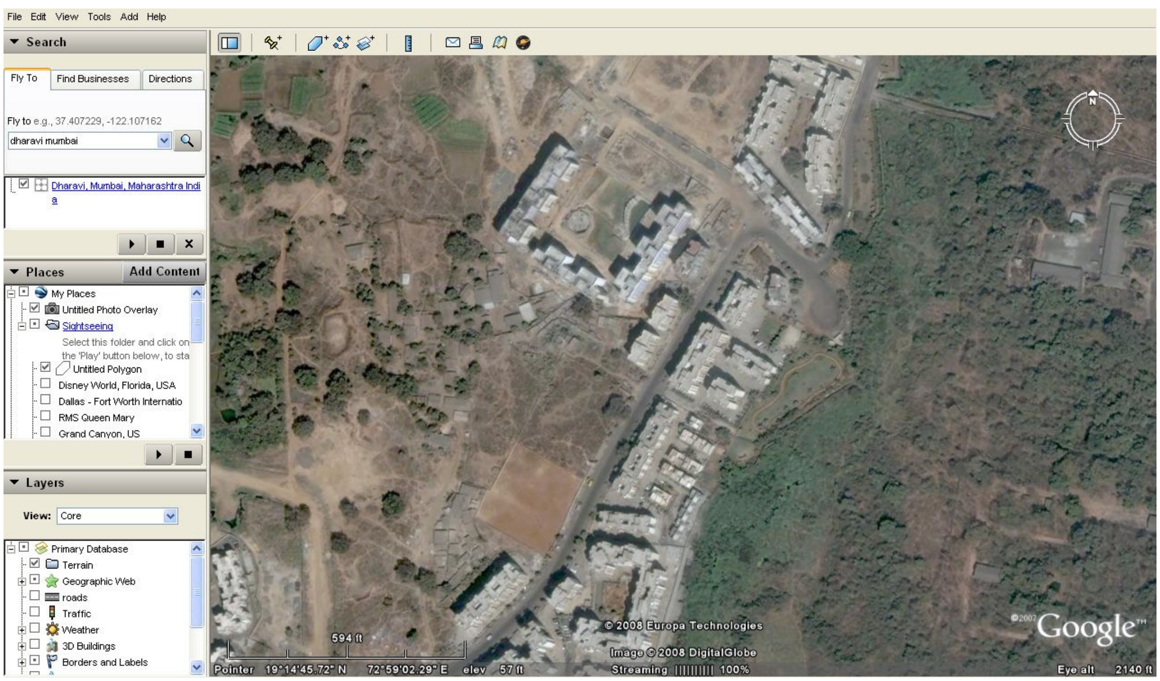

Figure 3.4. Low density built-up land

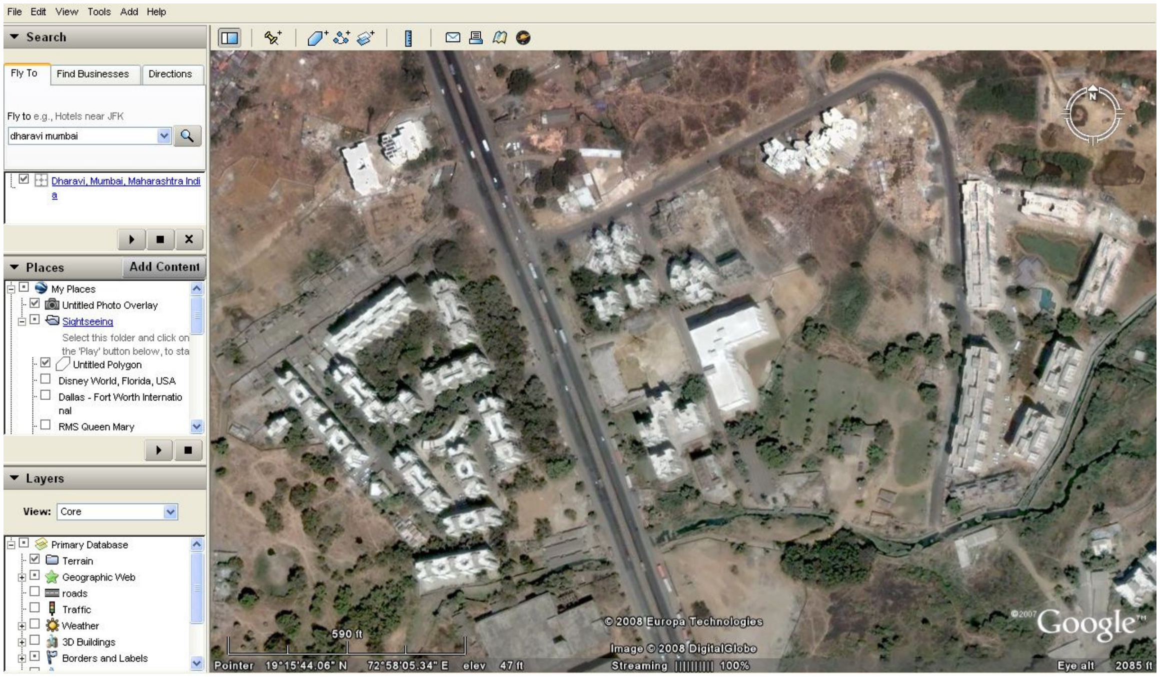

Figure 3.5. Low density built-up land

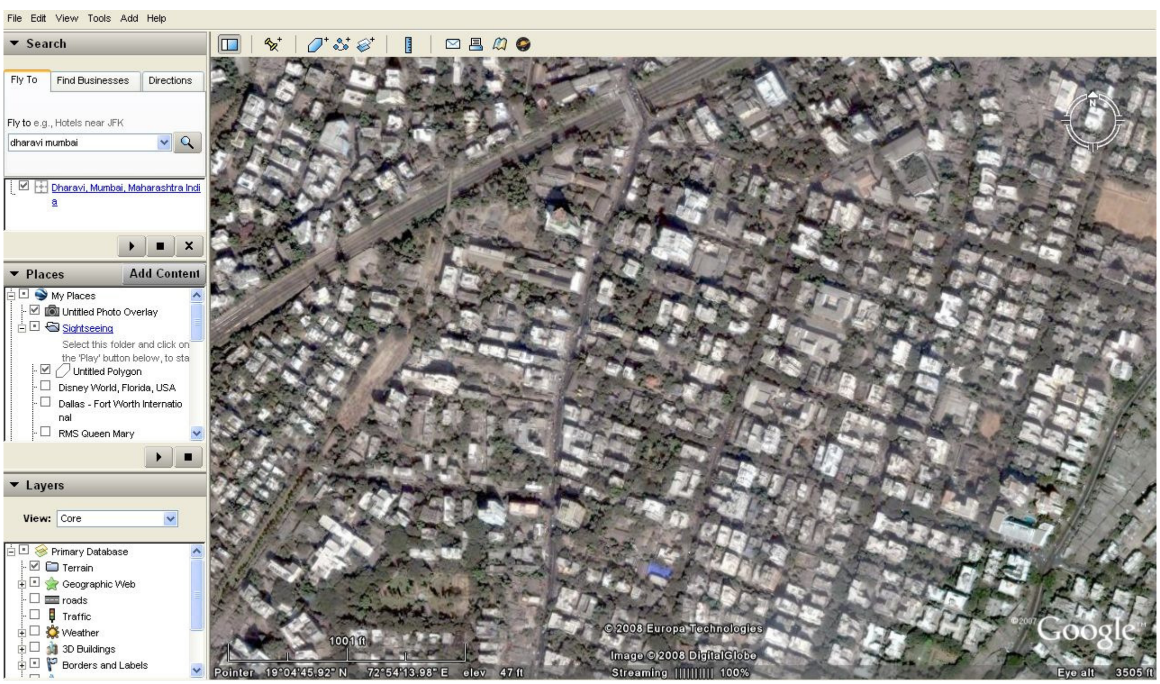

Figure 3.6. High Density built-up land

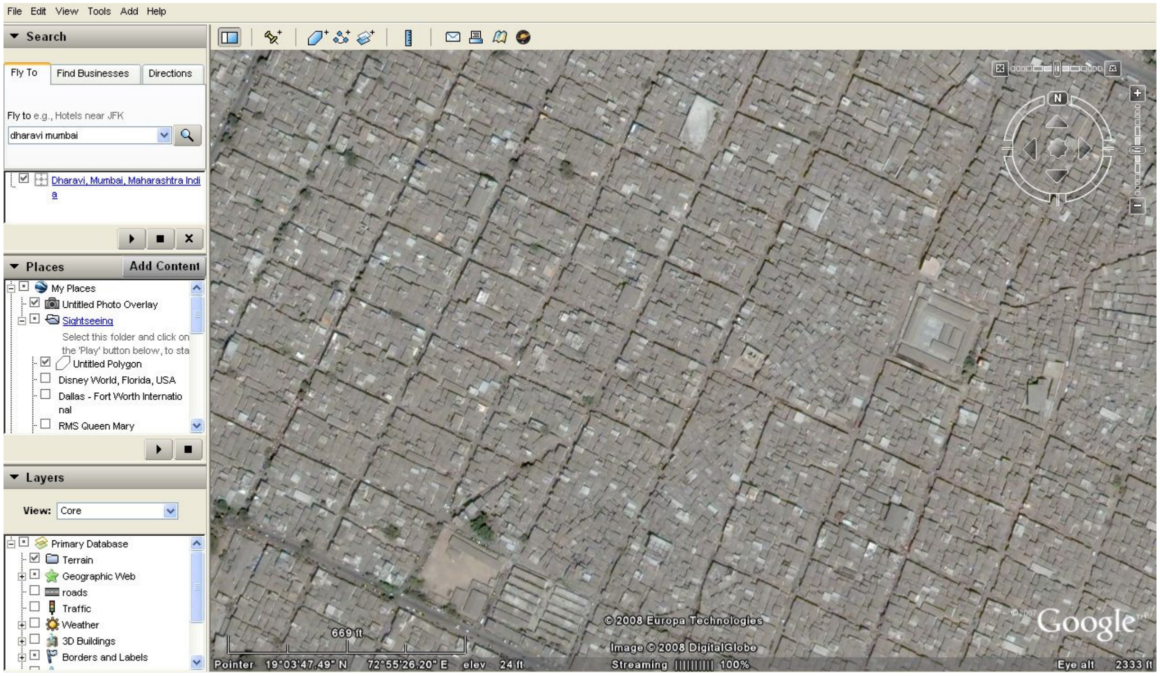

Figure 3.7. High Density built-up land

3.6.3. Accuracy Assessment

The accuracy of spatial data can be simply defined as, the measure of the number of ground truth pixels classified correctly. A classification is not complete until its accuracy is assessed (Lillesand *et al*. 2004). Accuracy assessment or validation is an important step in the processing of remote sensing data. It determines the information value in percentage, of the resulting data to a user. Productive utilization of geographical data is only possible if the qualities of the data are known. Furthermore, integrated processing of different types of geographical data cannot be effective if the data quality is not known. The classification accuracy and kappa coefficient have become a standard means of assessment of image classification accuracy. This method of determining image classification accuracy re-samples classified imagery against ground truth field samples, often obtained with a Global Positioning System (GPS). If field samples are not available, an image source of higher resolution may be employed. In this case Google Earth was used as a reference source.

3.6.4. Creation of Land-use Land-cover Transition Matrix

The LULC transition matrix gives information on the main types of change (direction) in the study area. The matrix can be generated by having at least two identical LULC maps from different time periods. In this study three LULC transition matrices were produced depicting the change in all classes from 1973 to 1992, from 1992 to 2001 and collectively from 1973 to 2001.

3.6.5. Maps Produced from Imagery

Twelve maps were produced depicting the LULC change in different classes from 1973 to 1992, 1992 to 2001 and 1973 to 2001 (Table 3.2).

Table 3.2. Maps to be produced

Year	Class
1973 to 1992	Overall change in all classes
1973 to 1992	Change in built-up
1973 to 1992	Change from low density built-up to high density built-up
1973 to 1992	Change in forest
1992 to 2001	Overall change in all classes
1992 to 2001	Change in built-up
1992 to 2001	Change from low density built-up to high density built-up
1992 to 2001	Change in forest
1973 to 2001	Overall change in all classes
1973 to 2001	Change in built-up
1973 to 2001	Change from low density built-up to high density built-up
1973 to 2001	Change in forest

3.7. Google Earth

After preparing the LULC change maps, snapshots from Google Earth with an example of the area that had been changed from one class to another from 1992 to 2001 and from 1973 to 2001, were shown with the help of Arc View and Google Earth. Points were marked on the LULC change maps and new shapefiles were created. The WGS 1984, UTM Zone 43N projection were assigned to the maps and these points were exported to Google Earth as .KMZ file. Once these points were reprojected on Google Earth, snapshots were taken to show examples of areas that have been changed from one class to another.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Land-use and Land-cover Composition

Individual maps displaying the land-use land-cover (LULC) composition of Mumbai are shown in Figures 4.1, 4.2 and 4.3. These maps are classified in six classes namely water, wetland, forest, bare land, low density built-up land and high density built-up land.

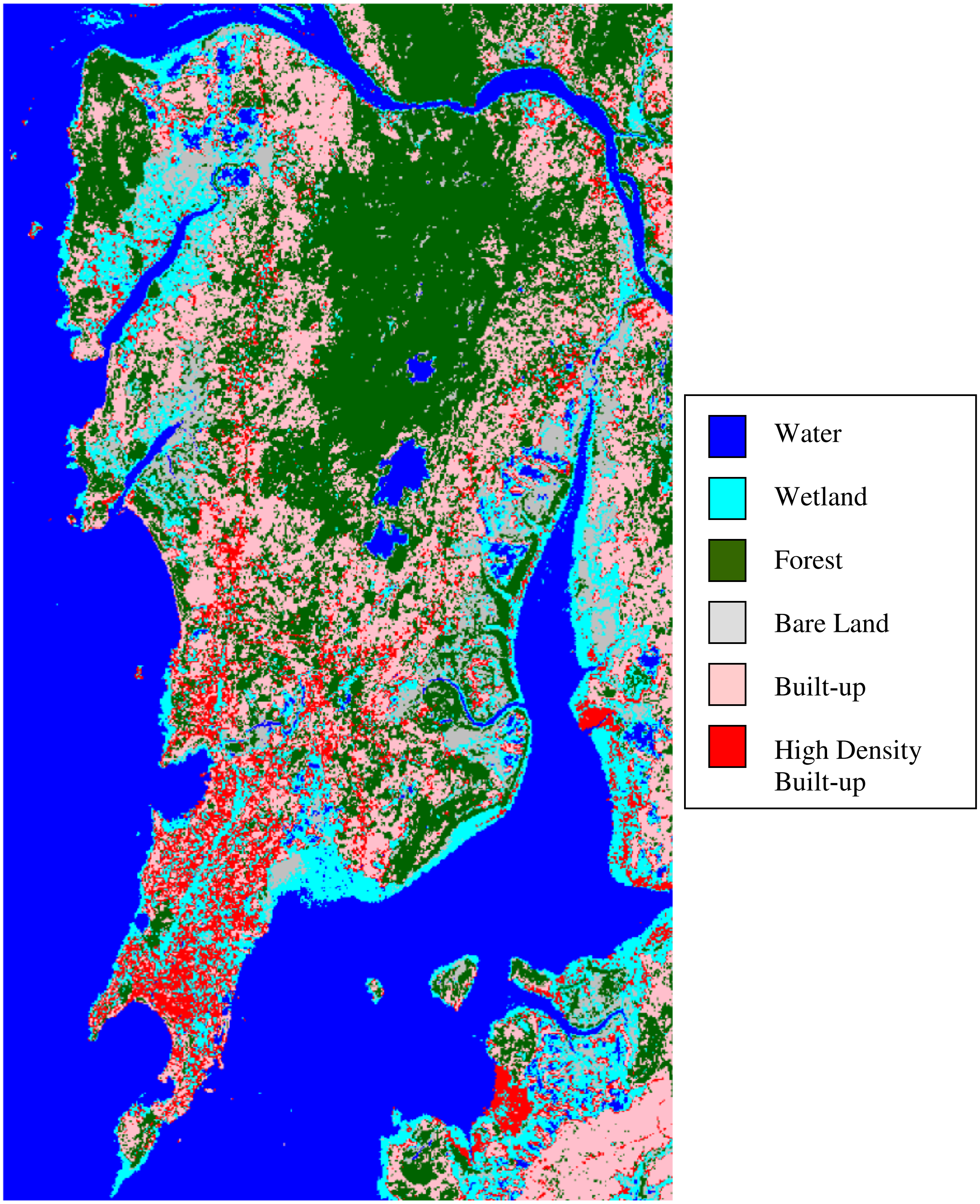

Figure 4.1. Land-use and land-cover of Mumbai for 1973

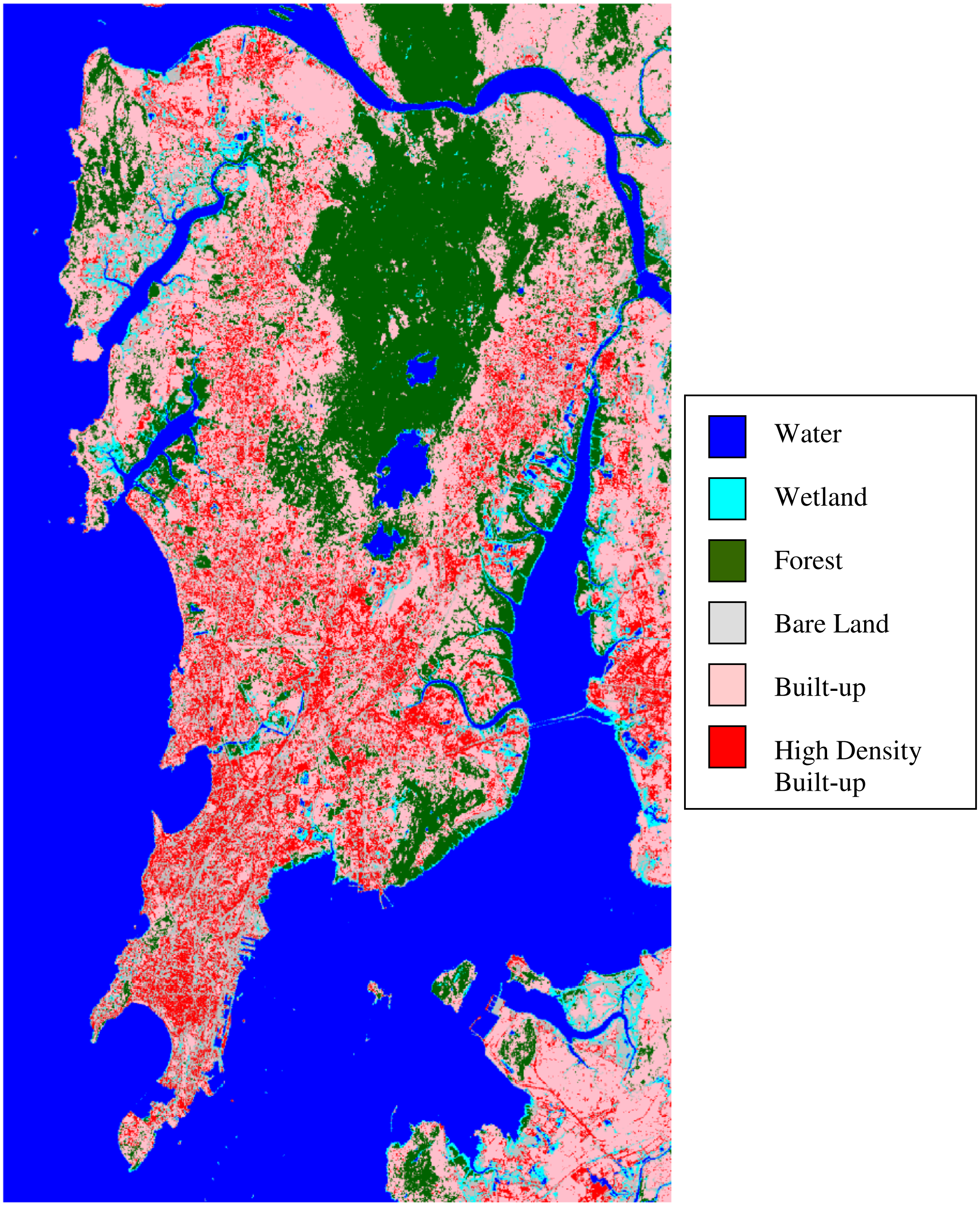

Figure 4.2. Land-use and land-cover of Mumbai for 1992

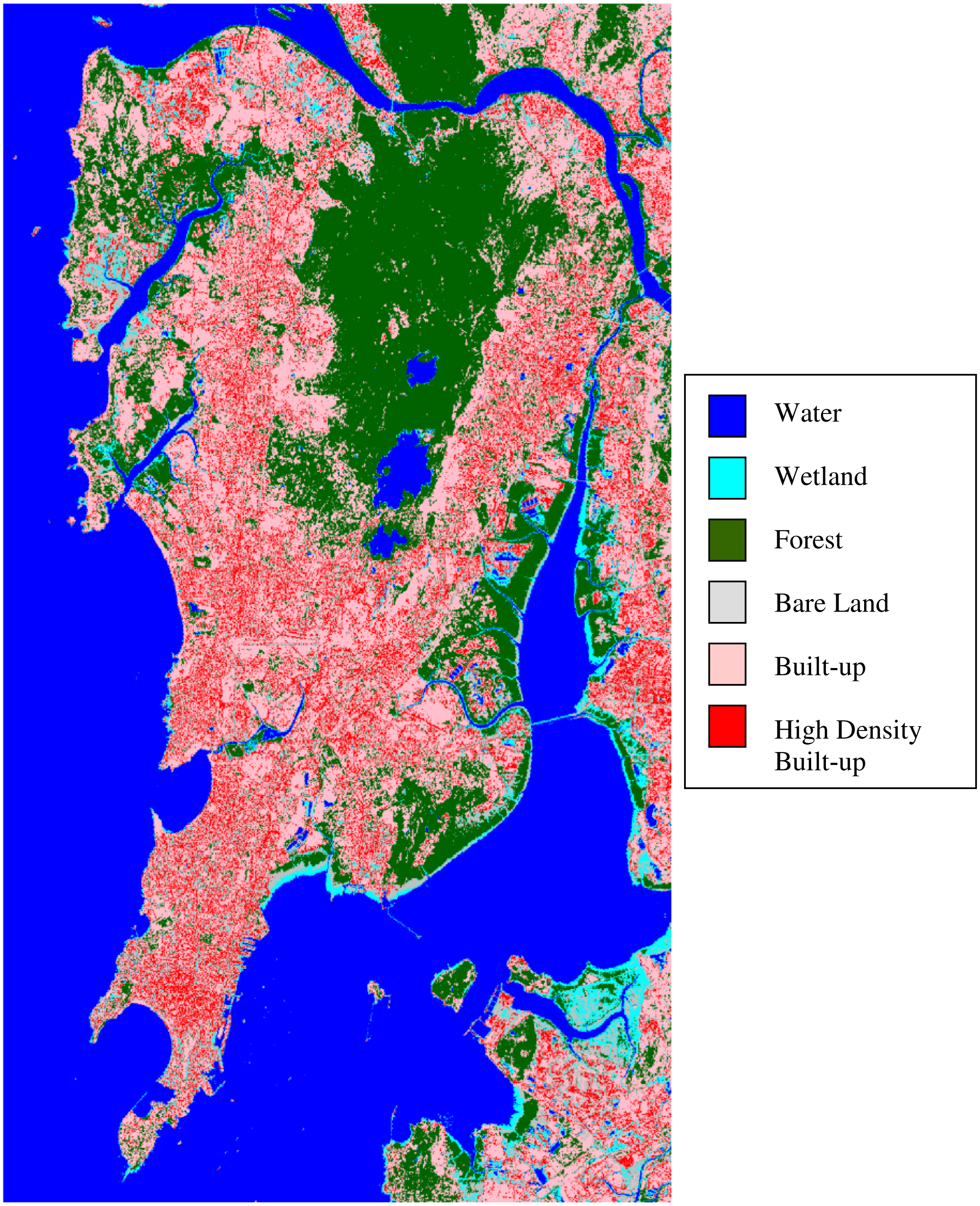

Figure 4.3. Land-use and land-cover of Mumbai for 2001

The weight in each category of LULC class can be best seen with the help of the summary statistics depicted in the histograms in Figures 4.4, 4.5 and 4.6

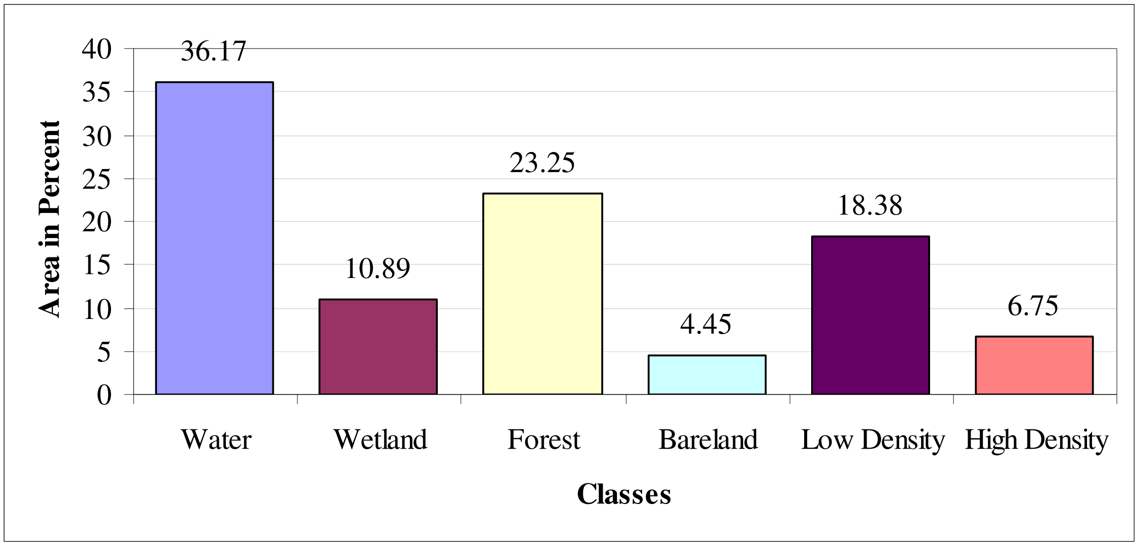

Figure 4.4. Land-use and land-cover statistics for 1973

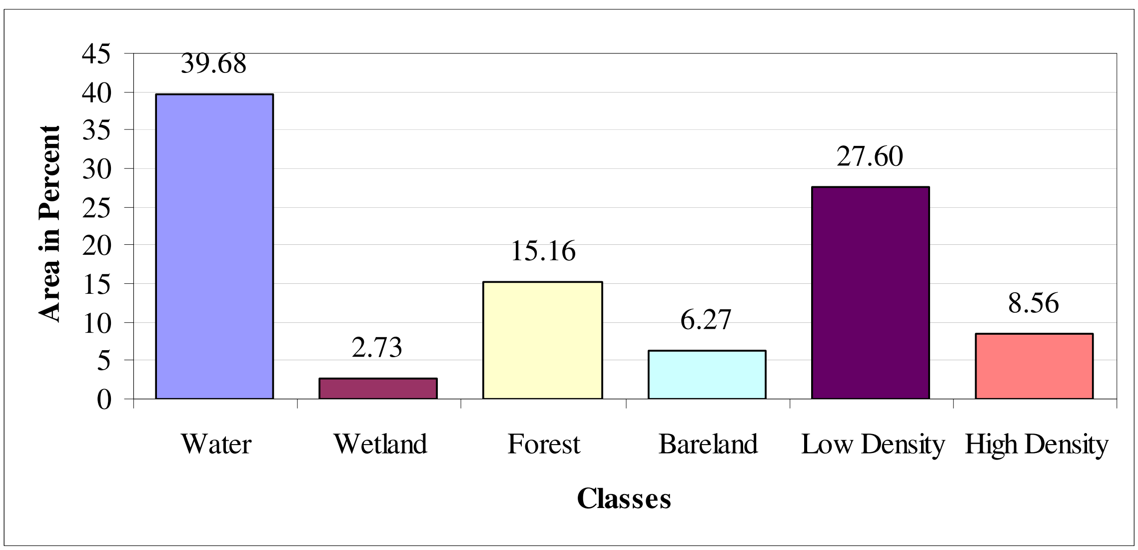

Figure 4.5. Land-use and land-cover statistics for 1992

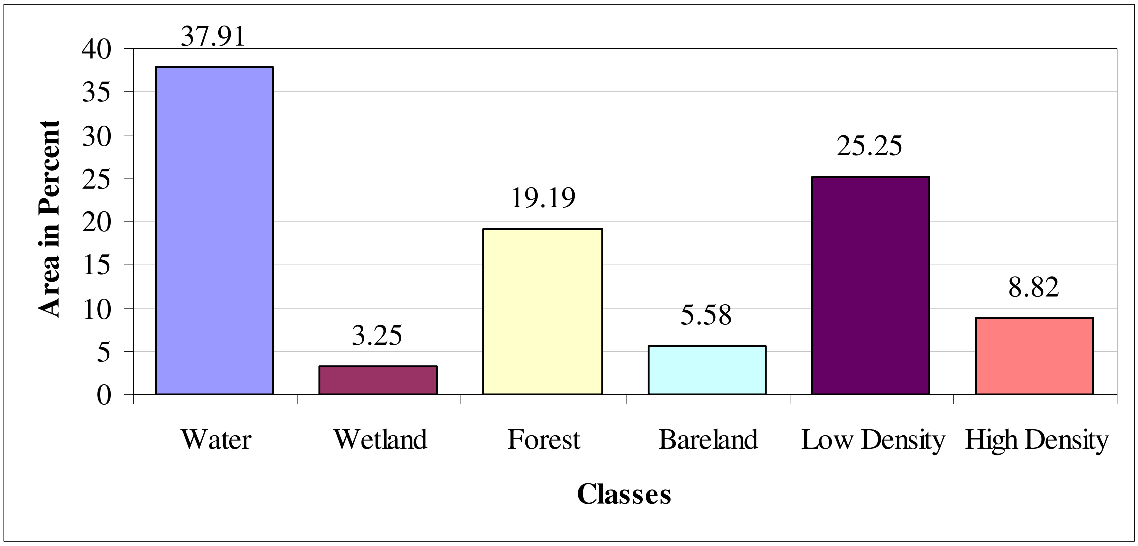

Figure 4.6. Land-use and land-cover statistics for 2001

The comparative statistics for the LULC for the three years is shown in Figure 4.7.

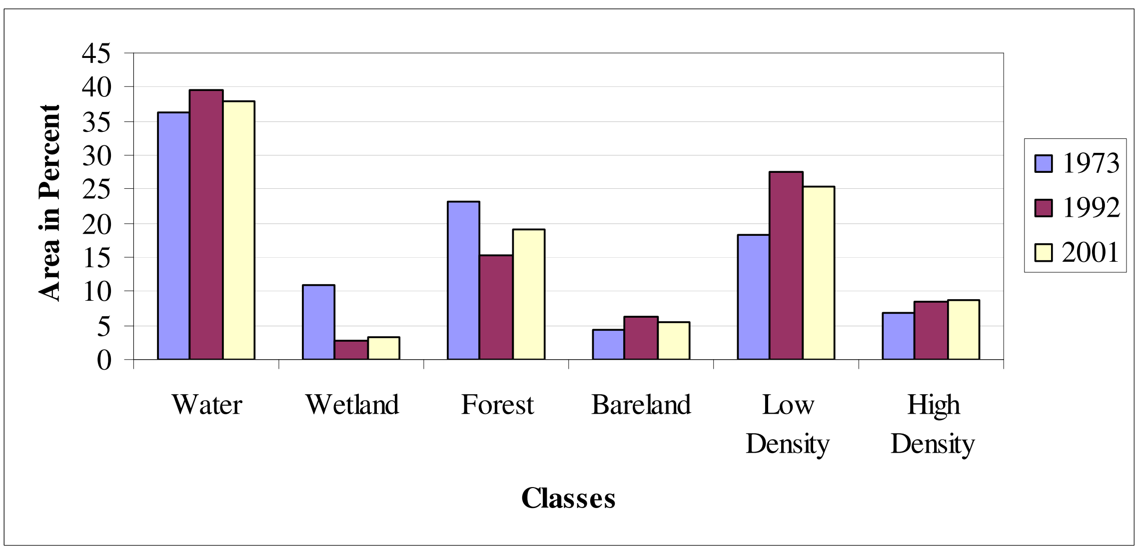

Figure 4.7. Comparative statistics for land-use and land-cover for 1973, 1992 and 2001

The total study area of the metropolis of Mumbai ranges between 523.14 sq miles to 524.83 sq miles. Table 4.1 is a summary of the area distribution in square miles among categories for the three periods considered in this study.

Table 4.1. Area distribution in square miles for all categories in each year of study

Category	1973	1992	2001
Water	189.81	207.60	198.33
Wetland	57.16	14.30	17.02
Forest	122.04	79.31	100.39
Bare land	23.36	32.80	29.17
Low Density built-up	96.46	144.38	132.08
High Density built-up	35.40	44.76	46.14
Unclassified	0.60	0	0
Total Area	524.83	523.14	523.14

Although the study area was classified in six classes, the Landsat MSS image of 1973 shows an unclassified area of about 0.6 sq miles which will not be considered in further analysis.

From Table 4.1 and Figure 4.6 it can clearly be seen that there is a substantial increase in the total low density built-up land from 1973 to 1992 (96.46 sq miles to 144.38 sq miles) but here is a decrease in that class from 1992 to 2001 (144.38 sq miles to 132.08 sq miles).

There is an increase in the high density built-up land (35.40 sq miles to 44.76 sq miles) from 1973 to 1992. It can also be seen that the high density built-up land continues with a modest increase until 2001 (46.14 sq miles).

A considerable amount of decrease can also be seen in the forest cover from 1973 to 1992 (122.04 sq miles to 79.31 sq miles). This is due to deforestation to accommodate the urbanization and increase in population due to the constant immigration of people in Mumbai. Although the total forested area has decreased overall from 1973 to 2001 (122.04 sq miles to 100.39 sq miles), an increase in the forest cover is seen from 1992 to 2001 (79.31 sq miles to 100.4 sq miles) This is an unexpected increase as the trend from 1973 to 1992 shows that there was a rapid deforestation in the city due to urbanization. This shows that the reforestation movements taking place throughout Mumbai have actually helped in increasing the forest cover in the metropolis.

4.2. Accuracy Assessment

An accuracy assessment was performed on the three classified images (Figure 4.1, 4.2 and 4.3). The accuracy assessment tool evaluates the correctness of the unsupervised classification by generating a list of random sample points, extracting the classes for those points from the image and then comparing those classes with values provided by the user through interpretation of the image. The cell array for this utility lists two sets of class values for the random points in the classified file. A total of 100 points were used for this assessment. One set of class values is automatically assigned to these random points as they are selected, and the other set of class values (reference values) are input manually by the user with the help of ground truthing. Ground truthing refers to a process in which a pixel on a satellite image is compared to what is there in reality (at the present time) in order to verify the contents of the pixel on the image. In the case of the classified images, ground truth comparisons of actual LULC activities are compared to the predicted LULC classification of the pixels. This comparison of known LULC to the predicted LULC allows us to determine the accuracy of the overall classification. Such accuracy provides us with an assessment of the validity of our final analysis and the conclusions drawn in that analysis. In this study, as a ground truth reference for the 2001 image, Google Earth and the original satellite image of 2001 were used because the 2003 Google Earth images most closely approximate the 2001 image. As a ground truth reference for the 1992 image, the 2001 classified image, the original 1992 satellite image and Google Earth was used. Lastly, the ground truth reference for the 1973 image included the 1992 classified image, and the original satellite image of 1973. Using Google Earth for the 1973 image was unrealistic because of a broad time gap of 30 years between them.

The results of the accuracy assessment for the LULC classification for the 1973 Landsat MSS image showed an overall accuracy of 85%. This is the result of the accuracy of each class weighted by the proportion of test samples for that class in the total training or testing sets. It also shows an overall kappa statistic of 0.8046. The Kappa statistic represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Foody, 1992). This means that the kappa value of 0.8046 represents a probable 80% better accuracy than if the classification resulted from a random assignment instead of the employed maximum likelihood classification. The kappa statistic lies typically on a scale between zero and one, where one indicates complete agreement. It is often multiplied by 100 to give a percentage measure of classification accuracy. A value greater than 0.8000 represents strong agreement, a value between 0.4000 and 0.8000 represents moderate agreement, and a value below 0.4000 represents poor agreement (Congalton, 1996). The Overall classification accuracy for the 1992 Landsat TM image was 87% and an overall kappa statistics of 0.8243. The 2001 Landsat ETM+ image showed an overall classification accuracy of 90% and also an overall kappa statistic of 0.8668. Thus the classification process in this study shows high classification accuracy and a strong agreement. The overall classification accuracy and kappa statistics for all the three years is given in Table 4.2.

Table 4.2. Overall classification accuracy and kappa statistics

Year	Overall Classification Accuracy	Kappa Statistics
1973	85%	0.8046
1992	87%	0.8243
2001	90%	0.8668

4.3. Land-use and Land-cover Change Analysis

4.3.1. Analysis of Land-use and Land-cover Change from 1973 to 1992

To detect the LULC change in the study area from 1973 to 1992, a LULC transition matrix was produced. Quantitative area data of the overall LULC changes as well as gains and losses in each category between 1973 and 1992 were compiled. Table 4.3 is a LULC transition matrix which gives information on the main types of change (direction) from 1973 to 1992 in the study area.

Table 4.3. Land-use land-cover transition matrix from 1973 to 1992 (square miles)

To 1992 / From 1973	Water	Wetland	Forest	Bare land	Low density	High density
Water	**182.88**	1.27	0.42	1.28	2.13	1.14
Wetland	15.94	**5.32**	4.48	9.85	14.91	6.59
Forest	1.23	1.74	**59.19**	4.17	47.07	8.36
Bare land	1.76	2.74	6.67	**2.50**	8.29	1.38
Low density	1.37	1.60	7.22	7.47	**60.43**	18.08
High density	4.22	1.62	1.32	7.53	11.49	**9.19**

From Table 4.3 it can be seen that approximately 21.5 sq miles have been converted from wetland to low density built-up land and high density built-up land while 55.43 sq miles have been converted from forest to built-up land from 1973 to 1992.This shows a high volume of both reclamation of wetland and deforestation in Mumbai to accommodate the increasing population. An indication of the tremendous population growth in Mumbai is that 18.08 sq miles have been converted from low density built-up land to high density built-up land.

To visually understand the spatial distribution of LULC in the study area, several maps were created. Figure 4.8 displays the overall change in all classes from 1973 to 1992. Figure 4.9 displays the change to low density built-up land and high density built-up land from all other classes. Figure 4.10 displays specifically the areas that have changed from low density built-up land to high density built up land. Figure 4.11 displays the overall change in the forested area. It depicts areas which have been converted from water, wetland and bare land to forest and areas that have been converted from low density built-up land and high density built-up land to forest. It also depicts areas that have changed from forest to low density built-up land and high density built-up land.

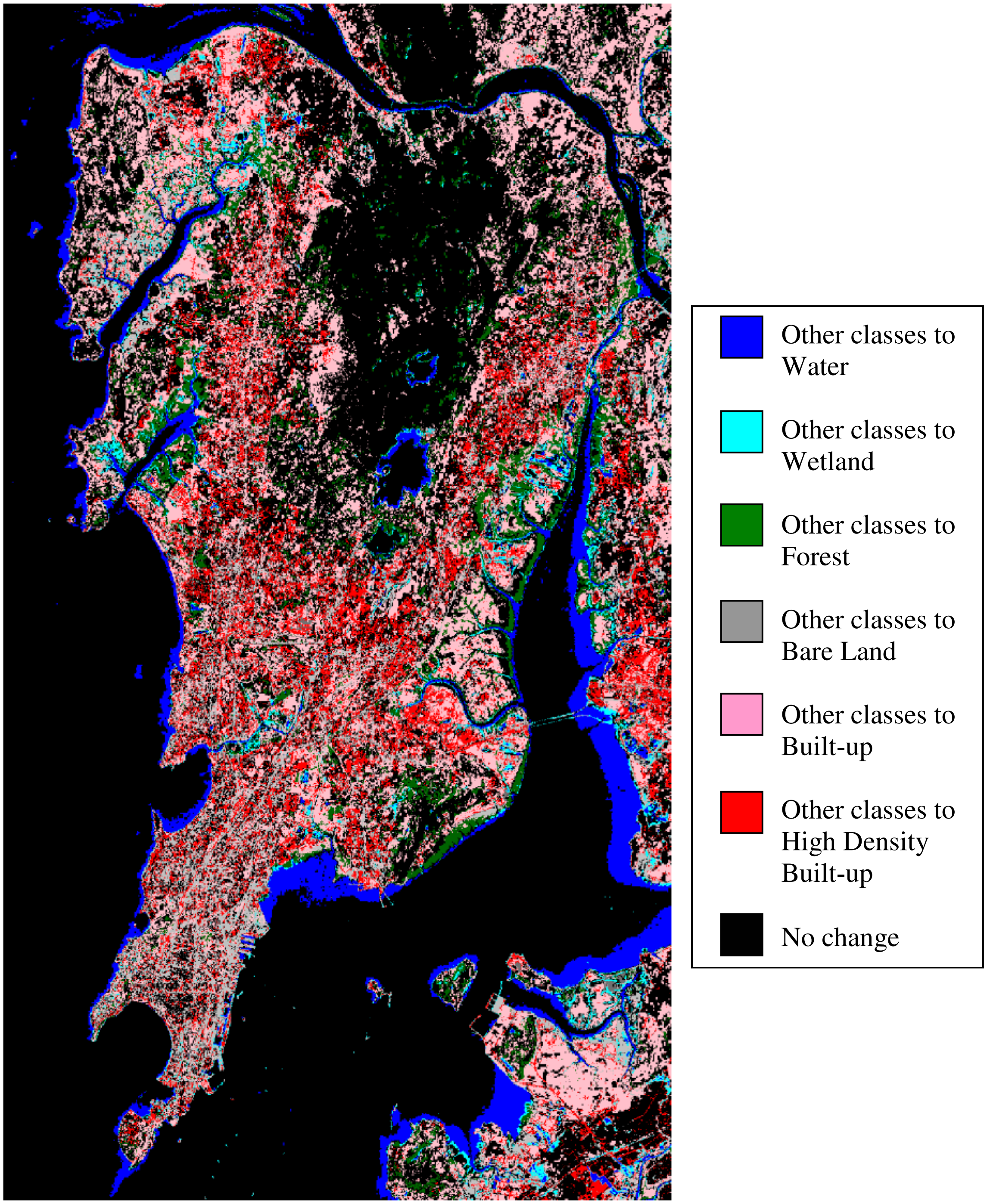

Figure 4.8. Overall change in all classes, 1973 to 1992

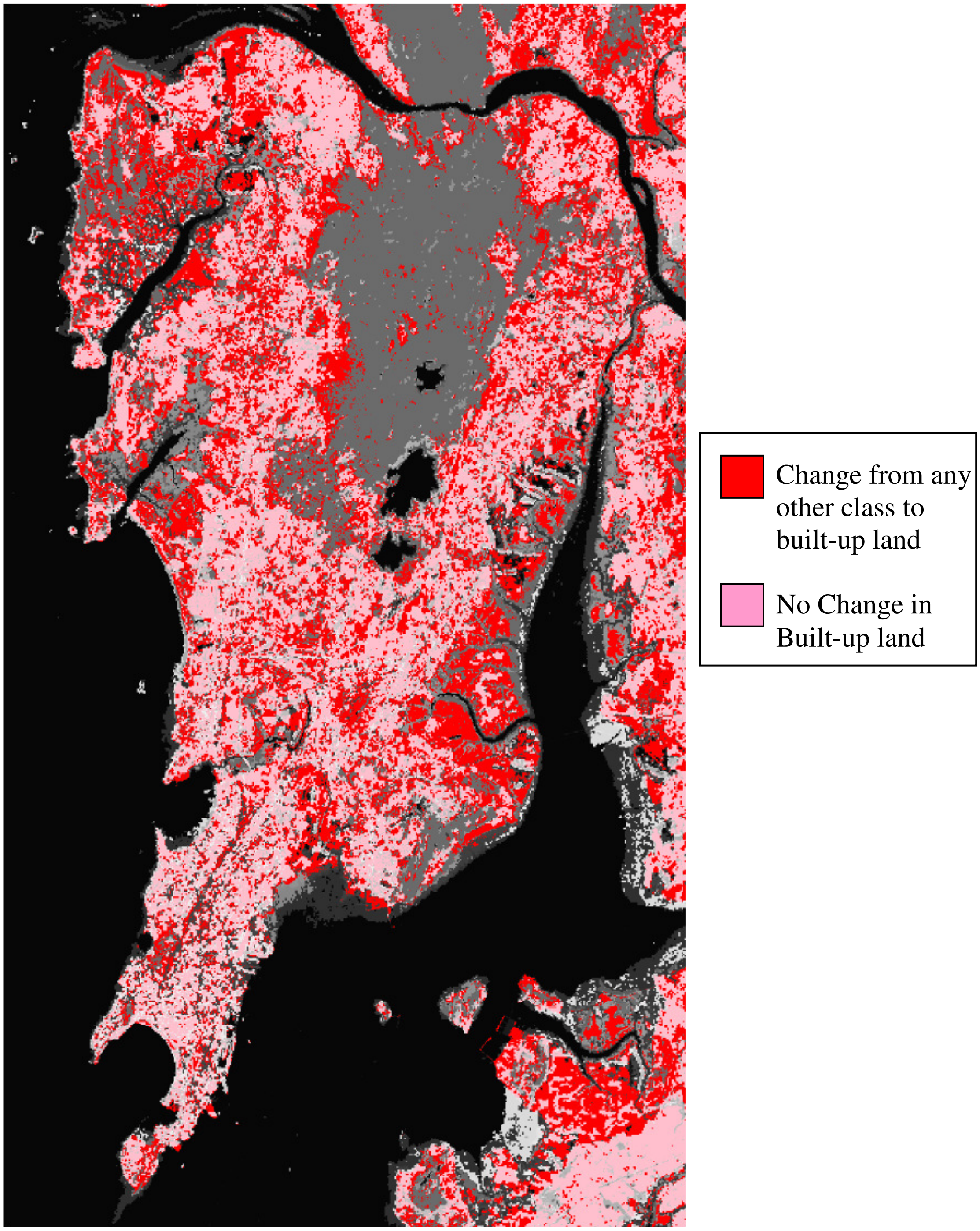

Figure 4.9. Change in Built-up area, 1973 to 1992

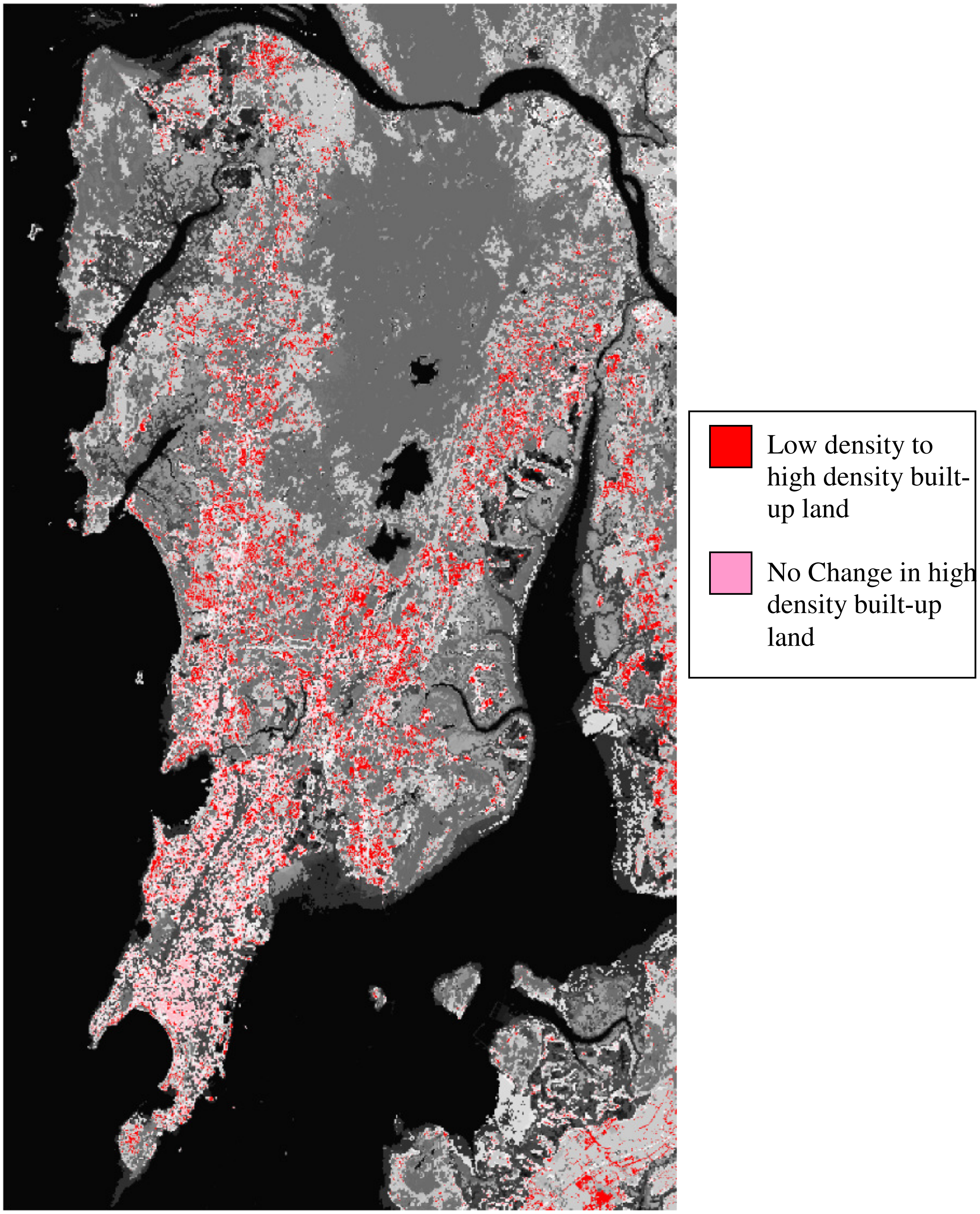

Figure 4.10. Change from low density to high density, 1973 to 1992

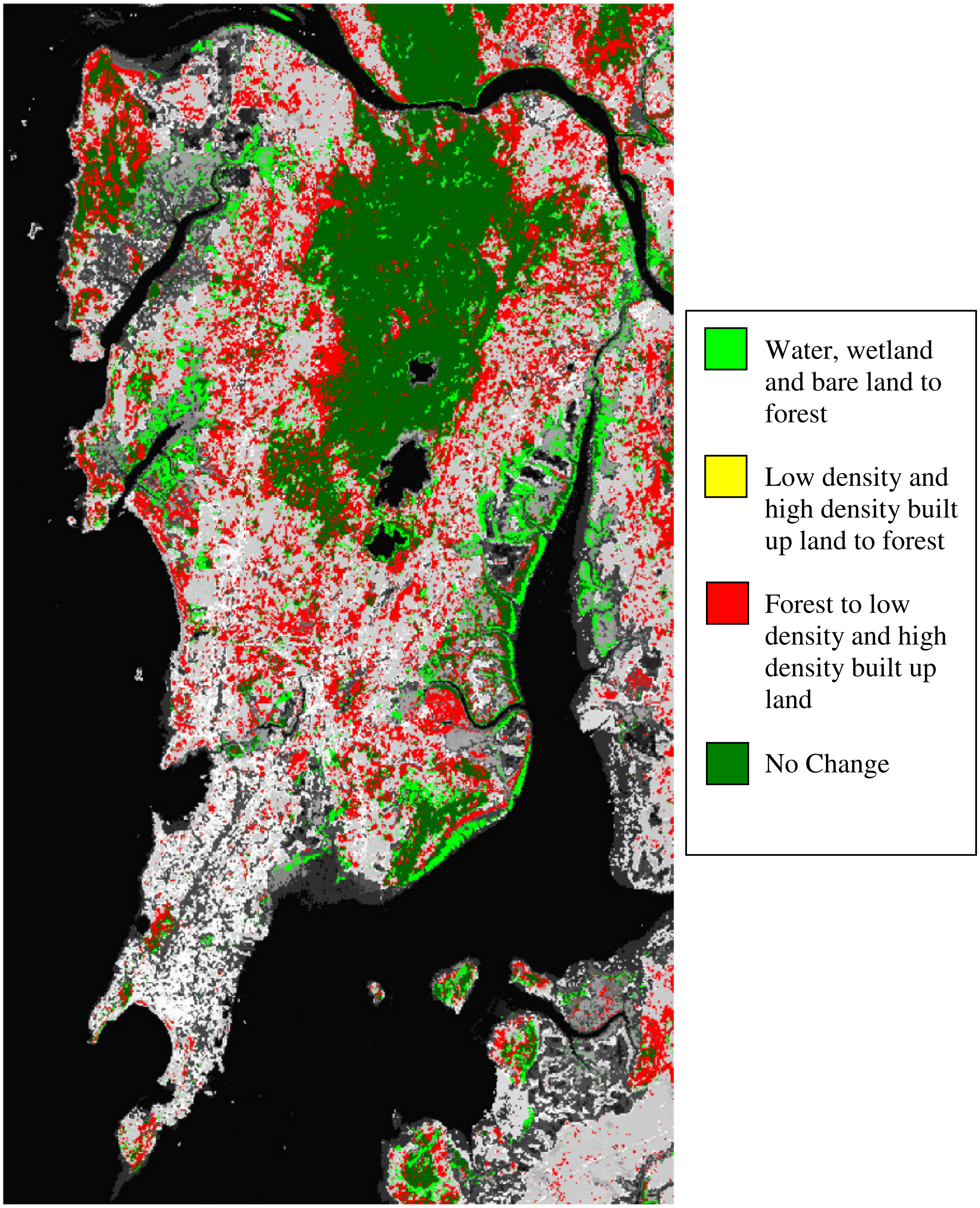

Figure 4.11. Change in forest area, 1973 to 1992

4.3.2. Analysis of Land-use and Land-cover Change from 1992 to 2001

Table 4.4 shows the LULC transition matrix from 1992 to 2001. It shows the change in individual classes, to all other classes.

Table 4.4. Land-use land-cover transition matrix from 1992 to 2001 (square miles)

To 2001 / **From 1992**	**Water**	**Wetland**	**Forest**	**Bare land**	**Low density**	**High density**
Water	**195.56**	5.59	2.45	2.61	0.88	0.50
Wetland	1.26	**4.11**	4.62	1.75	1.87	0.71
Forest	0.18	0.90	**66.48**	0.88	9.76	1.11
Bare land	0.44	2.83	3.67	**9.90**	7.84	8.13
Low density	0.67	2.86	22.40	9.69	**88.34**	20.43
High density	0.22	0.75	0.78	4.35	23.40	**15.26**

From this table it can be seen that 10.87 sq miles have been converted from forest to a combination of low density built-up area and high density built-up area. Figure 4.12 shows an example of an area from the town of Mulund that was converted from forest to low density built-up area from 1992 to 2001. This is an indicator of deforestation taking place in the city.

Figure 4.12. Area converted from forest to low density built-up land from 1992 to 2001

A total of 15.96 sq miles have been converted from bare land collectively to low density built-up land and high density built-up land from 1992 to 2001. Figure 4.13 shows an example of area from the town of Goregaon that has changed from bare land to built-up land from 1992 to 2001. This is also an indication of uncontrolled growth in population in Mumbai.

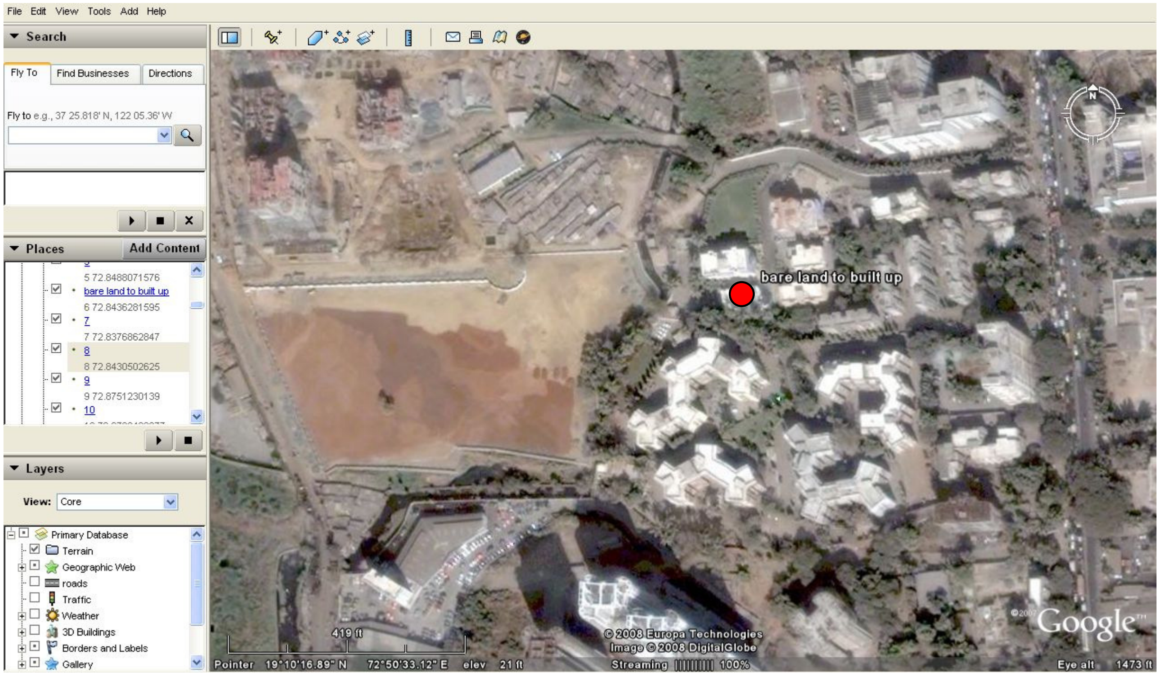

Figure 4.13. Area converted from bare land to built-up land from 1992 to 2001

A total of 20.43 sq miles have been converted from low density built-up land to high density built-up land from 1992 to 2001. An example of that area is shown in Figure 4.14. The snapshot is taken from the town of Dadar. This shows a high volume of population growth and inadequate infrastructure in the area.

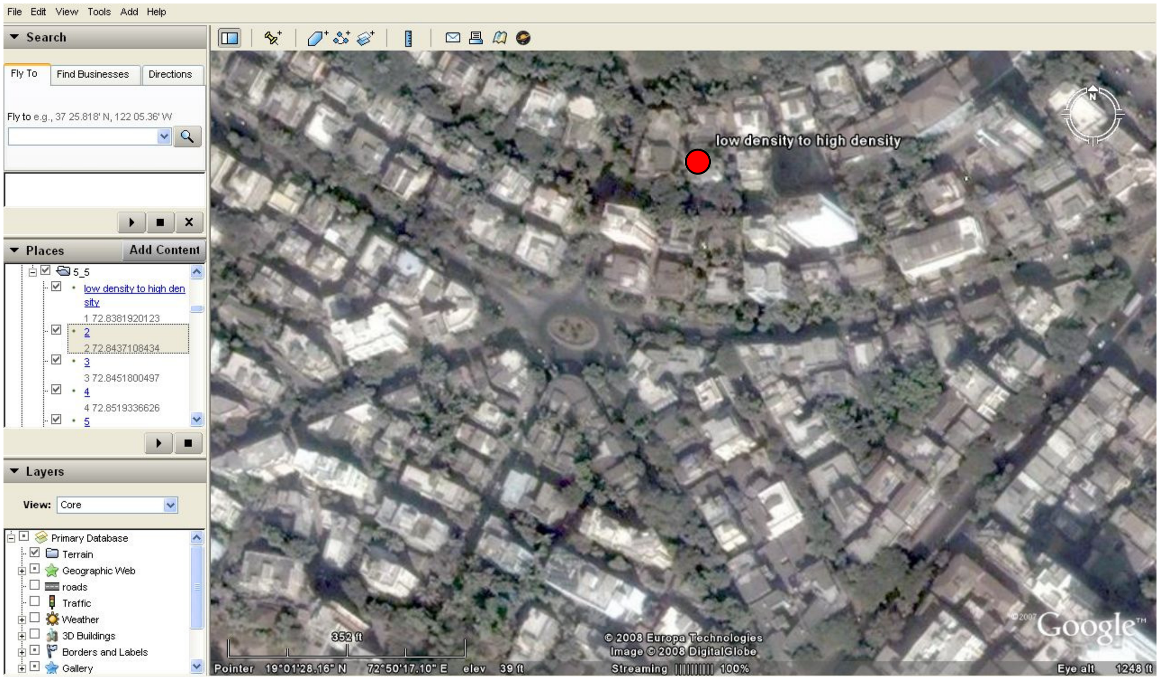

Figure 4.14. Area converted from low density built-up land to high density built-up land from 1992 to 2001

An overall 23.4 sq miles have been converted from high density built-up area to low density built-up area. High density areas constitute slum areas. The reason for this change from high density built-up area to low density built-up area might be because of the Slum Redevelopment Program (SRP). In the mid-1980s, the state government of Maharashtra, India, introduced a Slum Upgrading Program (SUP) in Mumbai with the support of the World Bank. It was a pilot project which involved the demolition of existing slums and the redevelopment of new, medium-rise apartment blocks, including, entirely cross-subsidized housing for the original slum dwellers. In the early 1990’s it was extended to the entire city of Mumbai. By August 1998, 367 proposals to redevelop the slums with 75,689 households of slum dwellers had been approved by the Government (Slum Rehabilitation Authority, 1998). Figure 4.15 is a snapshot taken from the town of Borivali and is an example of an area that was converted to low density built-up area in 2001 from a high density built-up area in 1992.

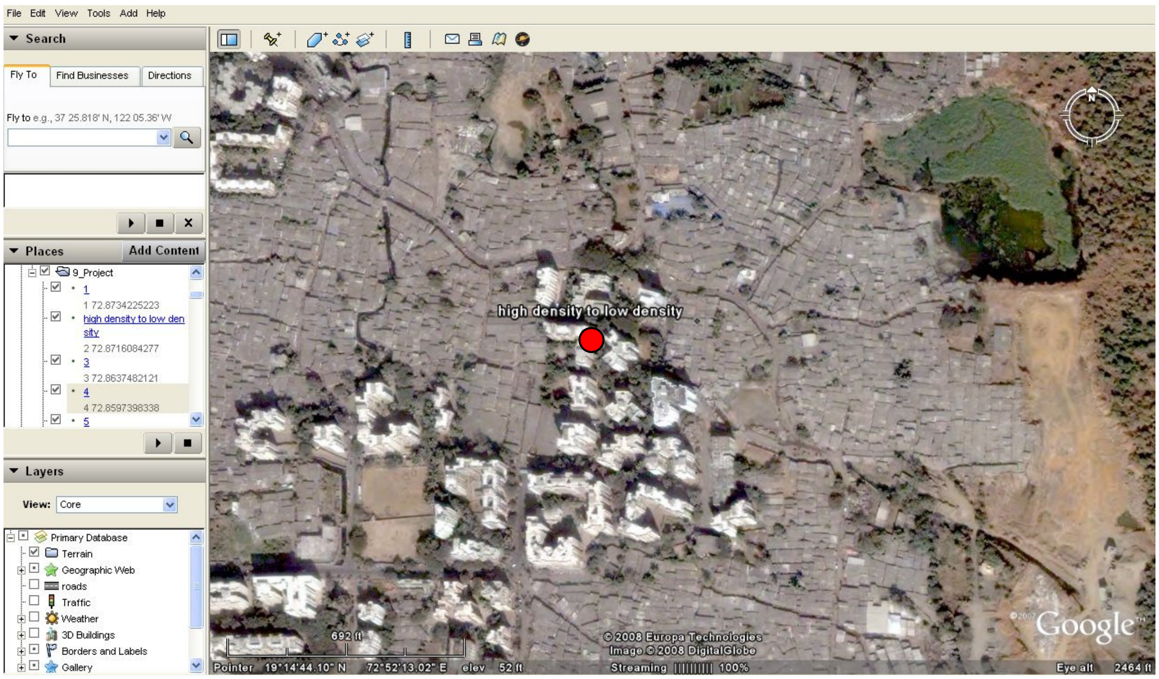

Figure 4.15. Area converted from high density built-up land to low density built-up land from 1992 to 2001

Almost 23 square miles have been converted from low density built-up areas and high density built-up areas to forest. This does not mean that buildings were torn down to plant trees. Rather it means that trees were planted on the sides of roads or along buildings as a result of the reforestation drives that took place throughout the city, and the satellite image classified the tree foliage covering the built-up area as in the class of forest, as it blocked the view of buildings. This can be seen from the fact that there is a decrease in the overall low density built-up land from 1992 to 2001 (from 144.38 sq miles to 132.08 sq miles). A satellite image from the town Churchgate, is an example of trees planted around buildings, and is shown in Figure 4.16.

Figure 4.16. Google Map image of trees planted along roads

Figure 4.17 show an example of area from the town of Nariman Point that was converted from low density built-up area to forest. This figure shows new trees planted along the buildings and the tree foliage covering a part of the built-up area.

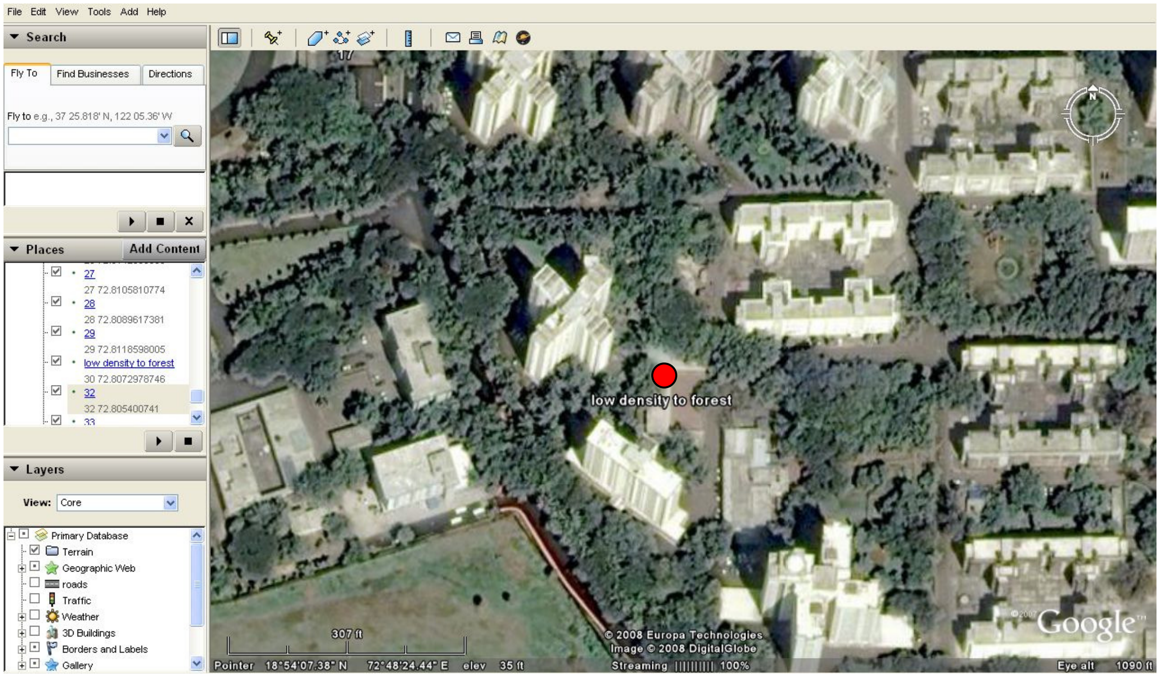

Figure 4.17: Area converted from low density built-up land to forest from 1992 to 2001.

Below are four figures that display the changes in different classes from 1992 to 2001. Figure 4.18 displays the overall change in all classes from 1992 to 2001. Figure 4.19 depicts the change from all classes to low density built-up and high density built up area. Figure 4.20 displays specifically the change from low density built-up to high density built up area. Figure 4.21 depicts the overall change in the forested land of the area.

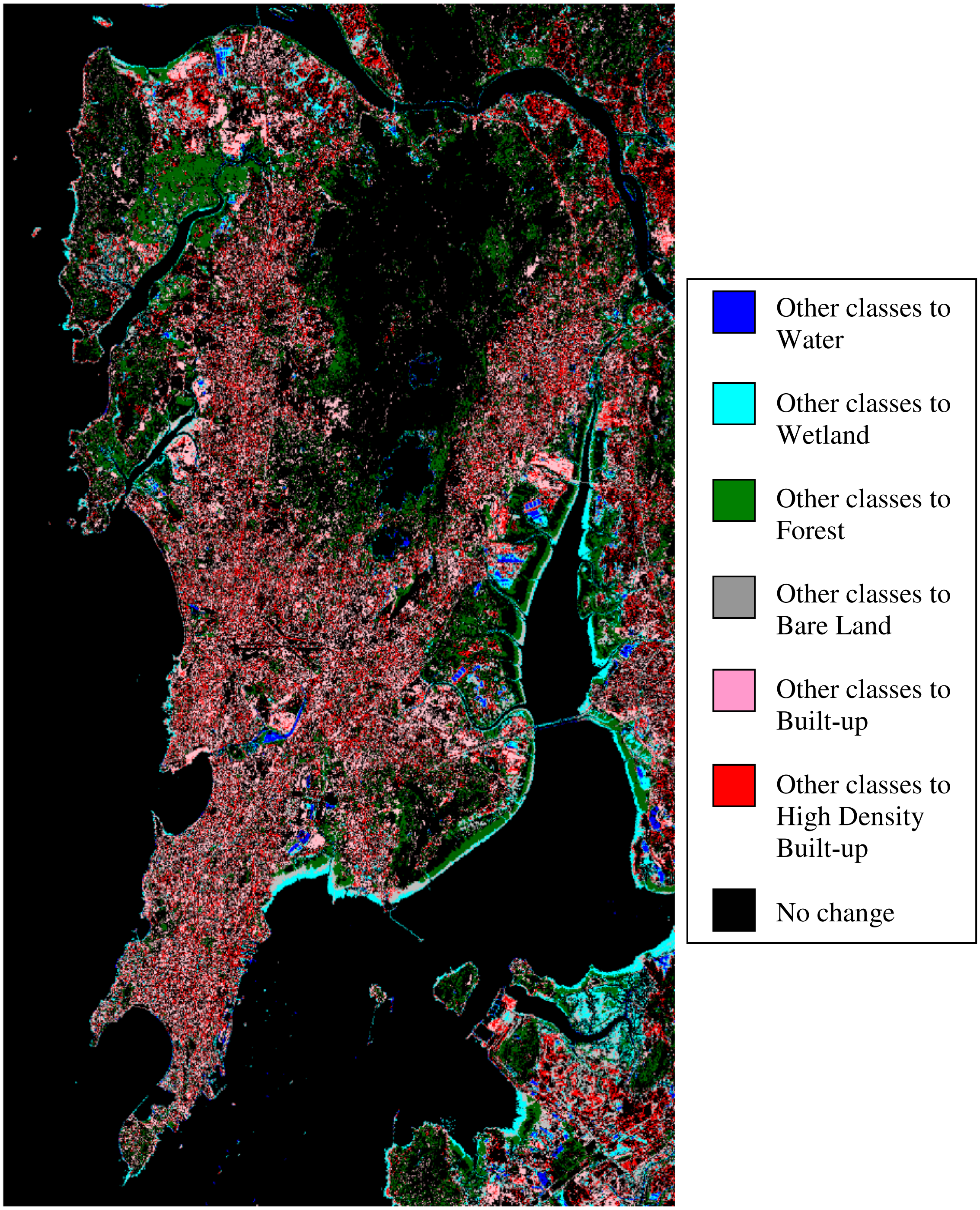

Figure 4.18. Overall change in all classes, 1992 to 2001

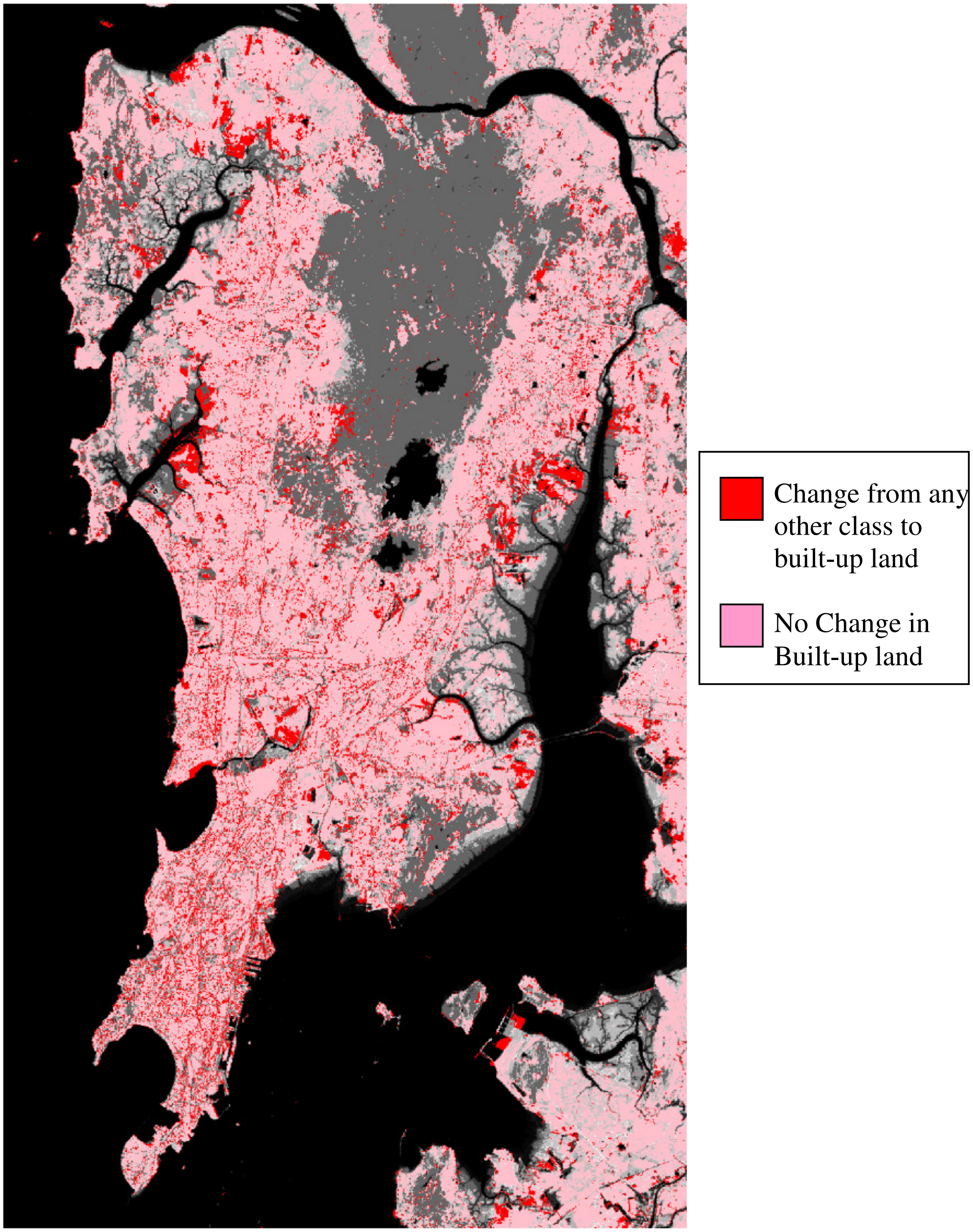

Figure 4.19. Change in Built-up area, 1992 to 2001

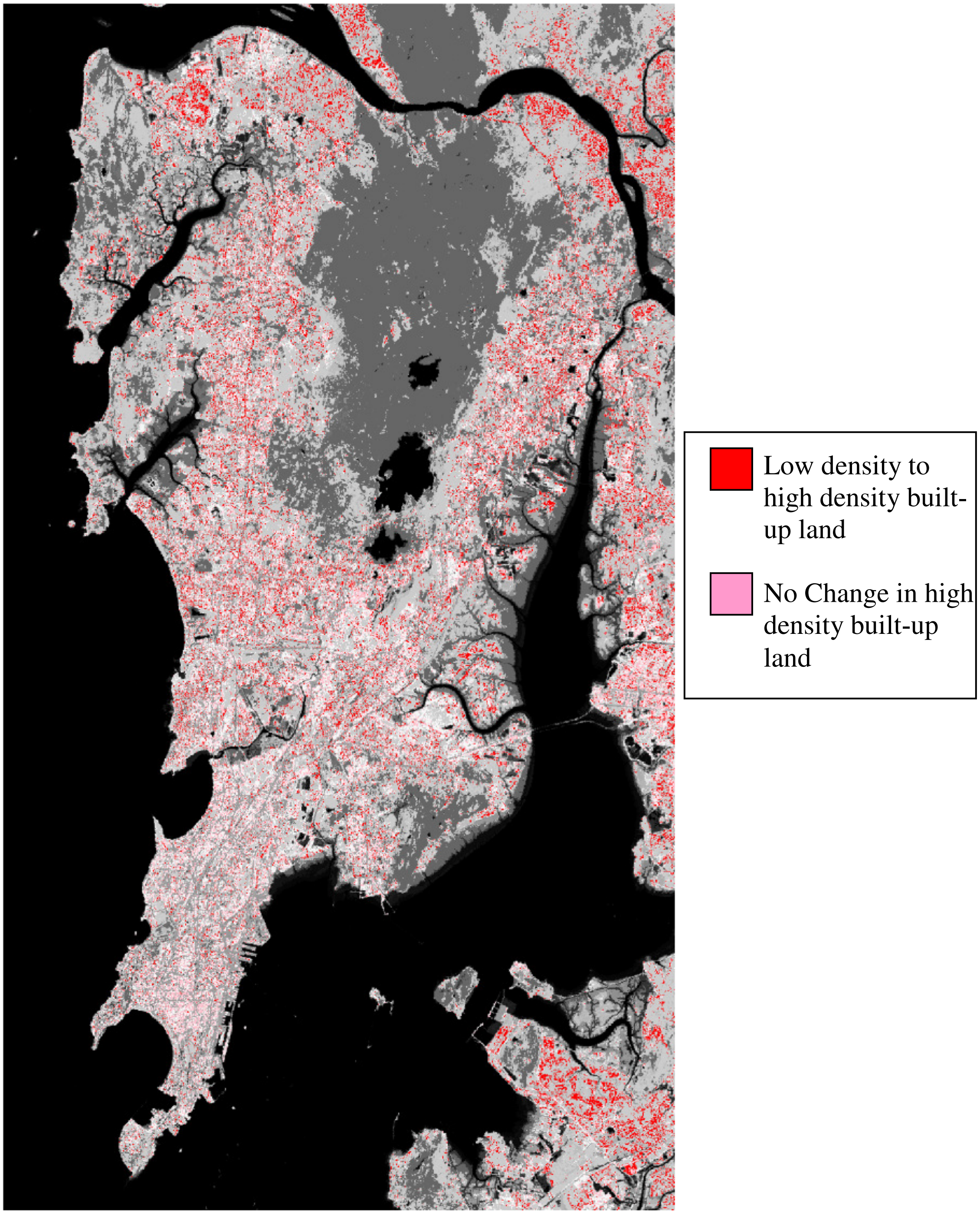

Figure 4.20. Change from low density to high density, 1992 to 2001

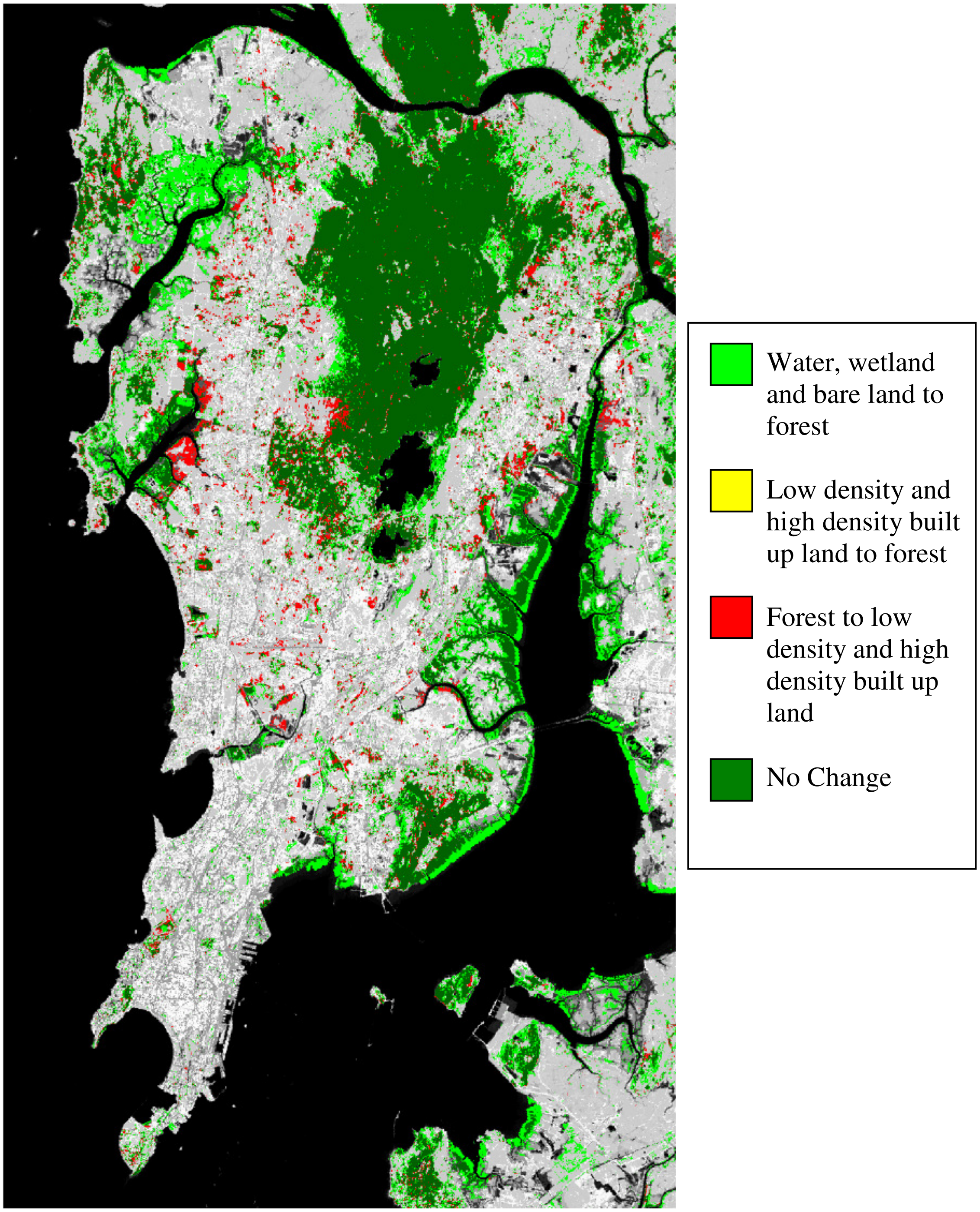

Figure 4.21. Change in forest area, 1992 to 2001

4.3.3. Overall Analysis of Land-use and Land-cover Change from 1973 to 2001

Table 4.5 below shows a LULC transition matrix collectively from 1973 to 2001. This shows change from one class to all other classes for all individual classes.

Table 4.5. Land-use land-cover transition matrix from 1973 to 2001 (square miles)

To 2001 / From 1973	Water	Wetland	Forest	Bare land	Low density	High density
Water	**180.39**	1.75	1.63	1.71	2.50	1.15
Wetland	11.58	**6.28**	10.30	8.16	13.76	7.03
Forest	0.98	2.15	**64.25**	4.36	40.72	9.29
Bare land	1.14	2.30	10.18	**2.33**	5.79	1.61
Low density	1.36	2.40	10.95	7.51	**55.57**	18.37
High density	2.70	2.13	3.06	5.09	13.68	**8.70**

From Table 4.2 it can be seen that here has been a considerable decrease in the wetland from 1973 to 2001 (from 57.16 sq miles to 17.02 sq miles). From Table 4.5, it can be seen that 20.79 sq miles of wetland has been converted to low density and high density built up land from 1973 to 2001. Figure 4.22 shows an example of area from the town of Kandivali that has changed from wetland to built-up from 1973 to 2001. The wetlands are land filled to build buildings.

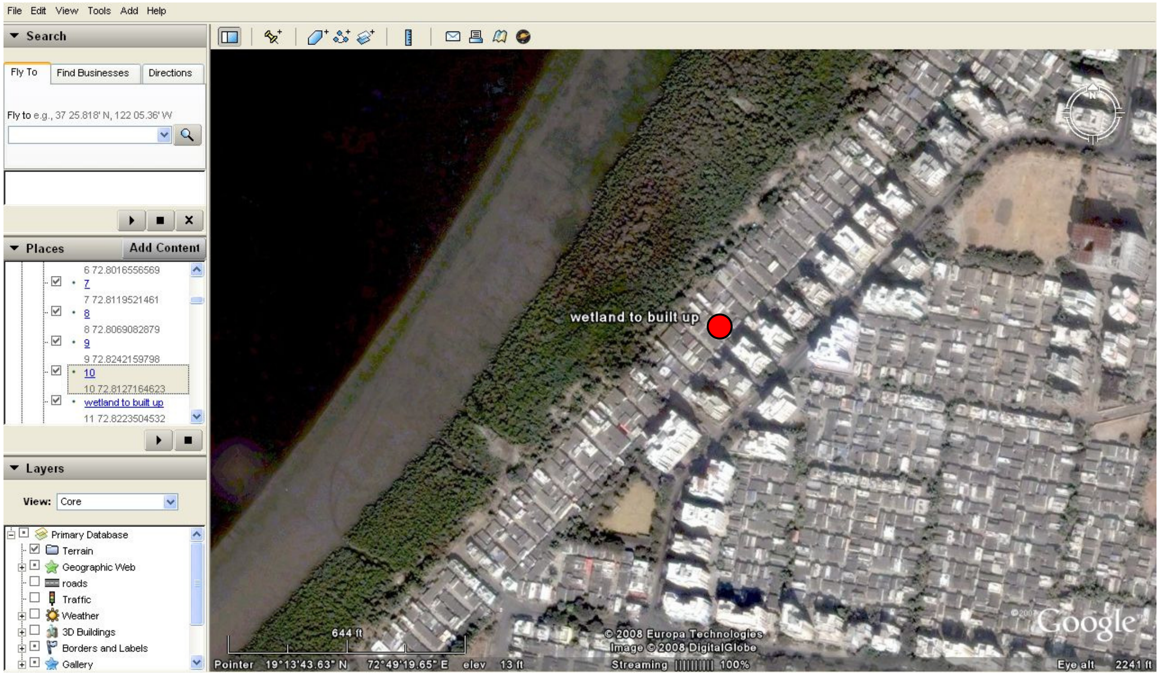

Figure 4.22. Area converted from wetland to built-up area from 1973 to 2001

A total of 40.72 sq miles have been converted from forest to low density built-up area and 9.29 sq miles have been converted from forest to high density built up land. Figure 4.23 displays an example of area that has been converted from forest to built-up land from 1973 to 2001. The snapshot was taken from the town of Maroshipada.

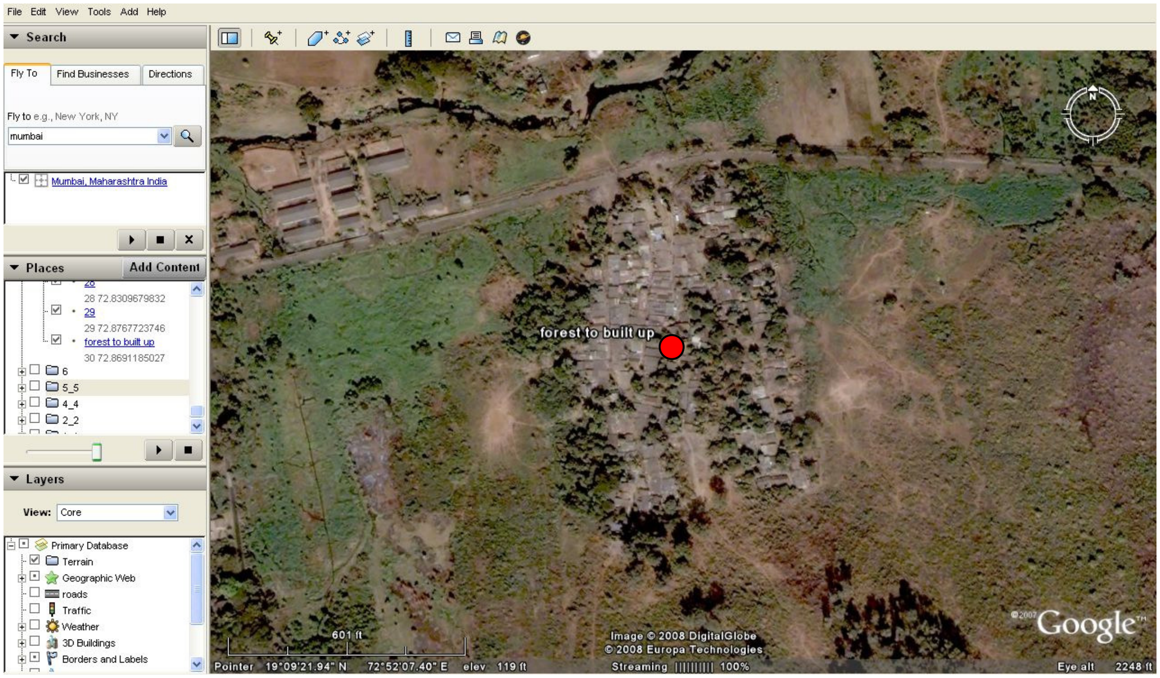

Figure 4.23. Area converted from forest to built-up land from 1973 to 2001

There has been a substantial change of 10.18 sq miles from bare land to forest. 10.94 sq miles have been also changed from low density built-up land to forest. An overall 18.37 sq miles have been converted from low density built-up area to high density built-up area and 13.68 sq miles have changed from high density built-up area to low density built-up area.

Figure 4.24 depicts the overall change in all classes from 1973 to 2001. Figure 4.25 displays the change from all classes to low density built-up and high density built up land. Figure 4.26 depicts specifically the change from low density built-up area to high density built up area. Figure 4.27 displays the overall change in the forested land of the area.

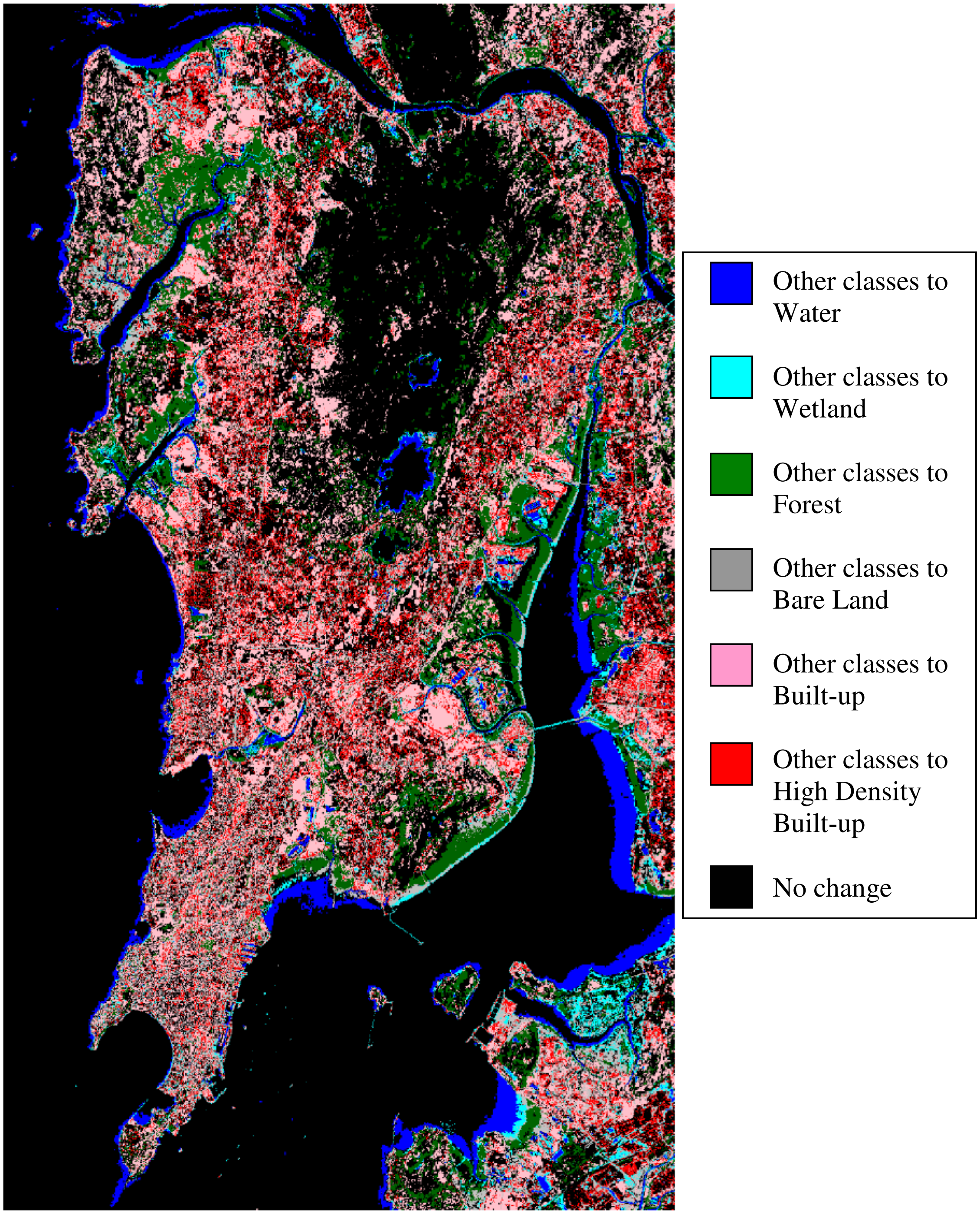

Figure 4.24. Overall change in all classes, 1973 to 2001

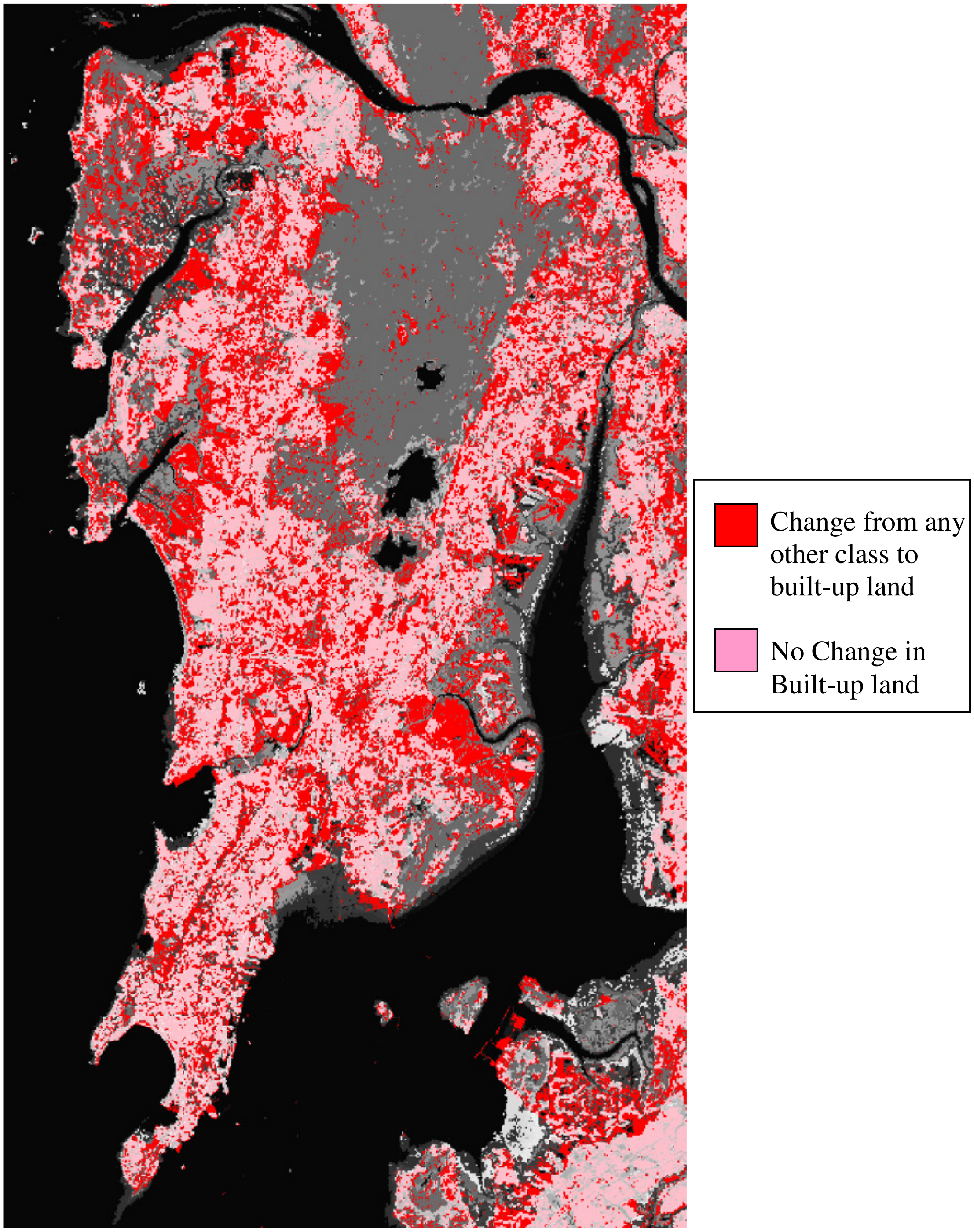

Figure 4.25. Change in Built-up area, 1973 to 2001

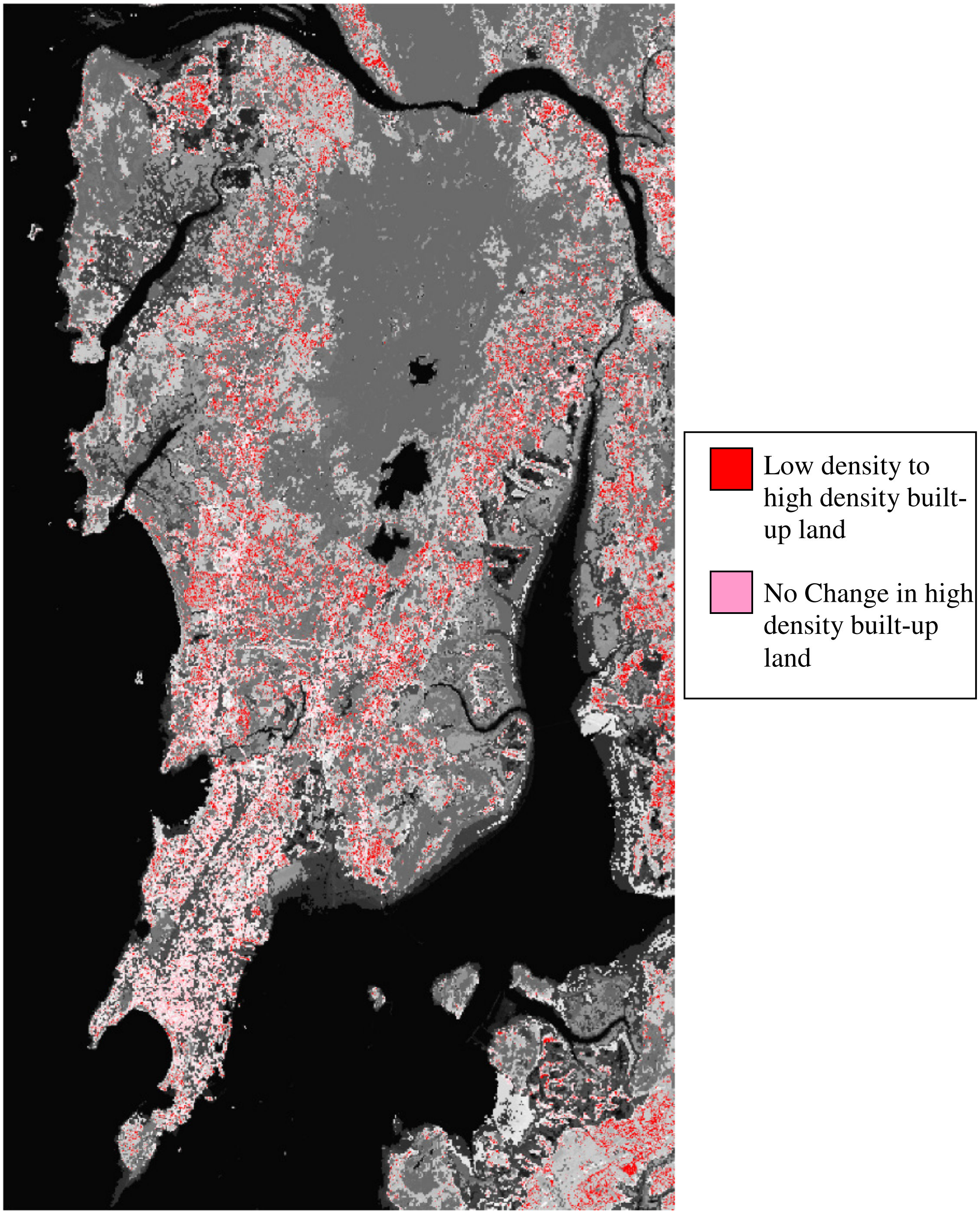

Figure 4.26. Change from low density to high density, 1973 to 2001

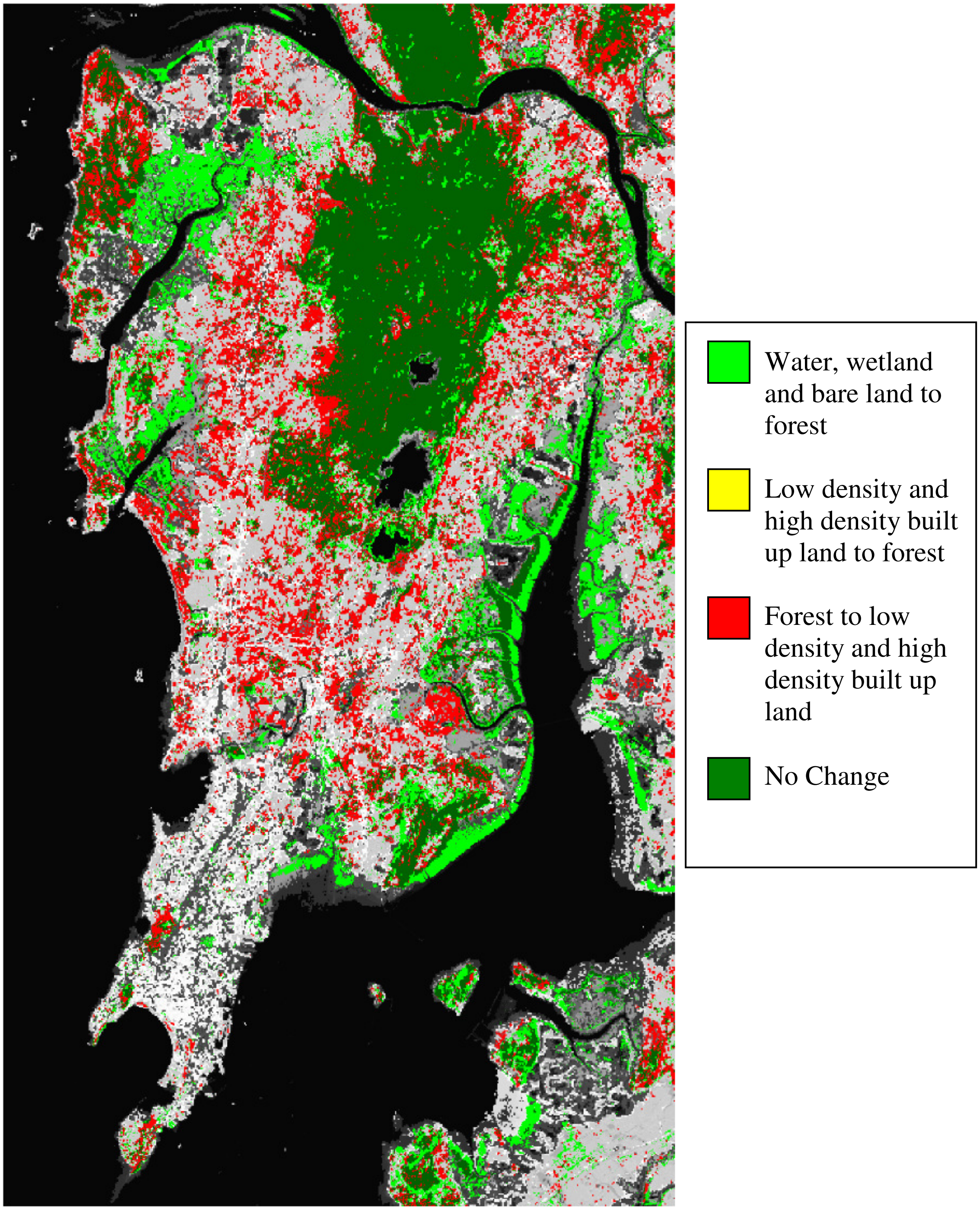

Figure 4.27. Change in forest area, 1973 to 2001

CHAPTER 5

SUMMARY AND CONCLUSION

5.1. Conclusion from the Analysis

The aim of this study was to determine the change in land-use and land-cover (LULC) in Mumbai from 1973 to 2001.

The creation of maps from 1973, 1992 and 2001 LULC for Mumbai were derived using the unsupervised classification technique. An Anderson's Level II LULC classification scheme was used comprising six classes namely water, wetland, forest, bare land, low density built-up land and high density built-up land. Final classification accuracy was determined to be satisfactory or 'good' by means of employing standardized accuracy assessment measures, the overall accuracy and the kappa statistic. Overall accuracies of 85%, 87% and 90% as well as kappa statistic of 0.8046, 0.8243 and 0.8668 were obtained for the years 1973, 1992 and 2001 respectively. These were achieved by ground truthing using Google Earth.

Land-use land-cover transition matrices were created to show the change in different classes from 1973 to 1992, 1992 to 2001 and collectively from 1973 to 2001. This study determined that an increase occurred in the area of forest cover from 1992 to 2001 (79.31 sq miles to 100.39 sq miles). This might be due to the environmental awareness that is taking place in Mumbai which began approximately in the early 1990's. Various movements like 'Clean Mumbai Green Mumbai' and 'Grow More Tress' campaign have taken place in the city. Figure 5.1 and 5.2 show signboards on the sides of roads emphasizing on keeping the city clean and green.

Figure 5.1. Keep our town clean and green

Figure 5.2. Clean city green city

The greening of Mumbai is an ongoing venture. Various schools follow plantation drives after a major event in the school like sport’s day etc. Different people have started contributing in small groups to increase plantation drives. The Rotary club contributes every year in various plantation drives that take place in the city. The Inner Wheel Club of Mumbai carries out plantation drives every year and has been doing it for the past many years. Other Non-Government Organizations (NGO’s) like ‘Haryali’ have been working hard to help protect and upgrade the environmental conditions of the city. These are just a few examples of small organizations doing their part for the betterment of the environment. Trees are also planted along both the median and sides of roads by the government. Figures 5.3 shows an example of these trees planted along the roadway.

Figure 5.3. Trees planted on the sides and median of road

From the LULC transition matrices it can also be ascertained that there is a tremendous amount of increase in the total built-up land in the city. Low density built-up land has increased from 96.5 sq miles in 1973 to around 132 sq miles in 2001. High density built-up land has also increased from about 35.4 sq miles in 1973 to about 46 sq miles in 2001. Almost 16 sq miles have been converted from bare land to built up-land. All of the above are indicators of increasing in the population and rapid urbanization and industrialization in Mumbai.

Mild effects of Slum Redevelopment can also be seen as there is a change from high density built-up area to low density built-up areas from 1992 to 2001 (23.40 sq miles).

One of the effects of the tremendous population growth and urbanization taking place in the city is that more than one-fourth of the land in the metropolitan Mumbai will be converted to built-up land by 2011 (Acharya, A.K. 2004). Another effect is the physical expansion of the built-up area beyond the city limits. Growth in metropolitan area beyond the city boundary brings many undesirable changes in the LULC patterns within the city, as well as its surrounding areas. (Acharya, A.K. 2004).

5.2. Limitations

There are a few limitations in this study. The first limitation is the ground truthing that was done with the help of Google Earth. Ground truthing was done first to the 2001 image and then subsequently to 1992 and then 1973. The Google Earth Image is from sometime in 2003. So it can be safe to say that the most accurate ground truthing was done for the 2001 image.

The second limitation of the study is the issue of class uncertainties in image classification. Low density and high density areas could be sometimes miss-classified. From the accuracy assessment conducted, it was seen that bare land is the class most generally classified wrongly into the high density built-up class due to the closeness of various factors like tone, color and texture in both classes.

By considering the shortcomings, perhaps this study could serve as a basis for further research and analysis of LULC in Mumbai in the future with possibly an image from a much recent year. Potential GPS points collected on the field might provide additional data to assess in the ground truthing. As satellite technology continues to advance, satellites with increased resolution characteristics will be utilized in future studies. Presently, commercialized satellites such as the Ikonos Satellite system offer satellite imagery with 1 meter panchromatic and 4 meter multispectral, spatial resolution. In addition, hyperspectral sensors characterized by very large spectral ranges will also improve future mapping projects. However, the high cost and tremendous data storage requirements currently limit the use of such data for larger scale mapping projects. Nonetheless, future utilization of such satellite imagery will allow for finer levels of detail for more accurate classifications and analysis of more subtle changes in the LULC.

5.3. Summary

The use of Landsat MMS, Landsat TM and Landsat ETM+ data to detect LULC changes in Mumbai has generally been a success. The image interpretation coupled with GIS has demonstrated its ability to provide comprehensive information on the direction, rate, and location of LULC changes as a result of industrialization and urbanization and large amounts of immigration from other parts of the country. LULC transition matrices have proved useful in monitoring the dramatic changes that have taken place in Mumbai. The LULC change maps have also been a helpful tool to analyze visually, the spatial change and distribution of different classes of land-use and land-cover across the metropolis. Overall changes in the landscape show an increased trend for urban development with forested, bare land and coastal wetlands suffering the consequences. It also shows that the reforestation movements taking place throughout the city have indeed helped in increasing the forest cover of Mumbai. Thus, the results show that integration of remote sensing and GIS is effective in monitoring and analyzing LULC patterns.

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