

Chapter 19

Assessment of Urban Dynamics Using Geospatial Techniques



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Abstract Bengaluru, the capital of Karnataka state and IT capital of India, is well known globally for its affable weather and greenery. During the last few decades, Bengaluru has witnessed phenomenal growth due to various factors, including rapid urbanization, unprecedented population expansion, and Spatio-temporal changes in vegetation cover and lakes. Reliable quantitative information about urban dynamics, especially in terms of vegetation cover and the lake system, is extremely crucial for preserving the quality of life in cities, suburbs, and periphery of metropolitan areas. A detailed geospatial study was carried out using satellite to understand the decadal changes in the vegetated regions and other land use/land cover classes in Bruhat Bengaluru Mahanagara Palike (BBMP) area to understand the decadal

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changes in the vegetated regions and ancillary datasets. An overall decrease of 4% area under vegetation cover was observed during 2006 and 2019. However, areas under other classes, mainly buildings, transport networks, and other urban categories, increased from 43.9 to 55.3%. A change map highlighting both positive and negative vegetation change areas and the vegetated areas with nominal changes was prepared for 198 BBMP wards. Karnataka Lake Conservation and Development Authority (KLCDA) requested a systematic spatial–temporal change detection study of drainages and lakes falling within the BDA limits. Under the project, lakes which required to be conserved, preserved, rejuvenated to prevent further deterioration the lakes, were identified using satellite and ancillary data. The study revealed that within the Bengaluru Development Authority (BDA) limits, about 500 lakes existed as per the cadastral map inventory, which decreased to 408 as per the inventory of 2017 satellite image. A prioritization of lakes analysis was carried out using the EMPRI's field support which indicated that 8.0% of lakes required revival and 46.0% of lakes required immediate action. The detailed database of lakes generated under the project is of immense importance to chalk out conservation and lake revival plans for a few lakes aimed at restoring the lake system of Bengaluru. This chapter highlights the findings of the studies undertaken for assessment of urban dynamics of Bengaluru city using geospatial techniques.

Keywords Bengaluru · Urbanization · Vegetation · Lakes · BBMP · BDA · Geospatial

19.1 Introduction

Bengaluru city (earlier known as Bangalore) has witnessed phenomenal population growth, especially during the last few decades. Several factors have contributed to urban sprawl of Bengaluru, primarily its pleasant climate with good infrastructure, presence of large technical manpower and skilled labor, comprehensive scientific and industrial base, and Information Technology (IT) in recent times, being the prime driving force, responsible for further city growth. Bengaluru, also known as 'Garden-city of India', encompassing a large area under tree cover, mainly as large number of small and large parks, over 400 lakes and thick vegetation patches in few forested regions along with good vegetation cover in cantonments and many PSUs, Government and research institutions.

Bengaluru city also experienced a lot of industrial growth during the past few decades with the setting up of factories like Hindustan Machine Tools (HMT), Hindustan Aeronautical Limited (HAL), Indian Telephone Industry (ITI), Bharat Electronics Limited (BEL), etc. Additionally, in recent times, Bengaluru has become major software hub with many software technology parks located in various locations of the city. Economic growth has had a significant impact on ecosystems and biodiversity. The city was once known for its tree-lined wide avenues, historic parks, and expansive water bodies. The influx of growth has led to the encroachment and

pollution of water bodies, the felling of thousands of trees, and large-scale conversion of open areas into commercial, industrial, and residential settlements. According to Census, Bengaluru had a population of 12.07 lakhs in 1941, which increased to 29.22 lakhs in 1981 and 84.26 lakhs in 2011. The current city population is about 128.2 lakhs (BBMP 2019). Some of the ill-effects of this phenomenal growth of population due to natural causes and migration, as well as urban expansion led to deterioration of biodiversity, water scarcity and epidemics, consequent impacts on human health and well-being, decrease in vegetation cover, development of slums, unplanned growth, pressure on the infrastructure for sewerage, water supply, garbage disposal, traffic jams, urban flooding, air, and water pollution, etc. within the city.

Globally, urbanization and urban sprawl are causing rapid changes in the ecosystem (Wratten et al. 2013). Behera et al. (1985) studied Bengaluru city growth from 1912 to 1985 utilizing SOI topo maps, as well as Landsat-MSS (1973) satellite image of 80 m spatial resolution and Landsat-TM satellite image of 30 m spatial resolution (1985). Land use land cover included major classes like built-up, agriculture, plantation/parks, scrub, waterbody, rock outcrop, and non-green area, highlighting that the growth of the built-up area was at the cost of surface water bodies and agricultural land. The urban sprawl and developmental activities happening at a very fast pace in Bengaluru City have taken a toll on both the urban vegetation and urban lake system. World Health Organization has recommended a minimum green space of 9.5 m²/person, considering the goods and services (oxygen, moderation of microclimate etc.) of an urban environment (Ramachandra et al. 2014). Urban vegetation represents more significant heterogeneity in the form of green spaces, including parks, avenue trees, home gardens, office complexes, plantations, and urban forests. For maintaining a better quality of life in urban regions, tree patches and green lung spaces have been extremely essential as they provide numerous benefits; hence detailed information about urban green cover in the suburbs and the fringes of metropolitan areas is a prerequisite (Dimitrov et al. 2018). Lakes/tanks are an essential part of the urban ecosystem for the conservation of water, recharging groundwater, and maintaining the biodiversity of the region. Due to the rapid urbanization of Bengaluru, many lakes have been slowly altered to layouts, buildings, parks, playgrounds, stadiums, bus stands, industrial sheds etc. and the rest of the surviving lakes have turned into cesspools as a result of indiscriminate discharge of industrial sewages and unrestricted discarding of solid wastes. Further, deterioration of the lakes may lead to water scarcity and reduce groundwater recharge, which would adversely affect the wetlands ecosystem of the city.

In view of the developmental activities in Bengaluru city, such as road-widening, metro-line construction, expansion of built-up areas as new lay-outs and high-rise buildings, increasing population, various integral components of urban dynamics and Spatio-temporal changes needs to be understood. Geospatial techniques provide excellent tools for carrying out these studies due to the multi-temporal and synoptic coverage of satellite imagery and amenability for digital image processing. Thus, an in-house research initiative on assessment of vegetation cover change was carried out (RRSC-South 2019), and the lake inventory was carried out as a user project, titled 'Spatio-Temporal Analysis of Lakes of Bengaluru' (S-TALAB) in collaboration with

KLCDA, Bengaluru (RRSC-South 2018). The present chapter discusses the results of these two studies.

19.2 Study Area

Bengaluru, the capital city of Karnataka state, India, is among the rapidly growing cities of the world and is located in the southern part of the Deccan Plateau. Bruhat Bengaluru Mahanagara Palike (BBMP) limits of Bengaluru is the study area for assessment of temporal changes in vegetation cover, land use, and land cover (Fig. 19.1a). BBMP jurisdiction covers the majority area of the Bengaluru urban district and lies between $77^{\circ}25'$ to $77^{\circ}48'$ E longitude and $12^{\circ}50'$ to $13^{\circ}10'$ N latitude.

Due to its elevation, Bengaluru enjoys a pleasant and equable climate throughout the year. The average minimum temperature range during winter is $10\text{--}15^{\circ}\text{C}$, and the maximum summer temperature range is between 30 and 38°C . Bengaluru receives about 970 mm of rain annually, the wettest months being August, September, and October.

Bengaluru City is drained by two minor rivers Vrishabhavathi River, a tributary of Arkavathi, which flows for a small stretch on the west side, and the other one is Dakshina Pinakini or South Pennar, which flows in the eastern region of the city. Hebbal, Koramangala-Challaghatta, and Vrishabhavathi are the three major valley systems. The city is situated at an elevation of 920 m above Mean Sea Level with undulating topography of hills and valleys. Bengaluru is unique, where the lakes form into a group of reservoirs in each of the three valley systems. It is seen that, the ridge top in each valley gives birth to small streams. Due to the natural flow, the streams merge to form a major stream system. Thus, one finds that all the lakes of Bengaluru are located in the valleys interconnected with a group of series of chains of lakes,

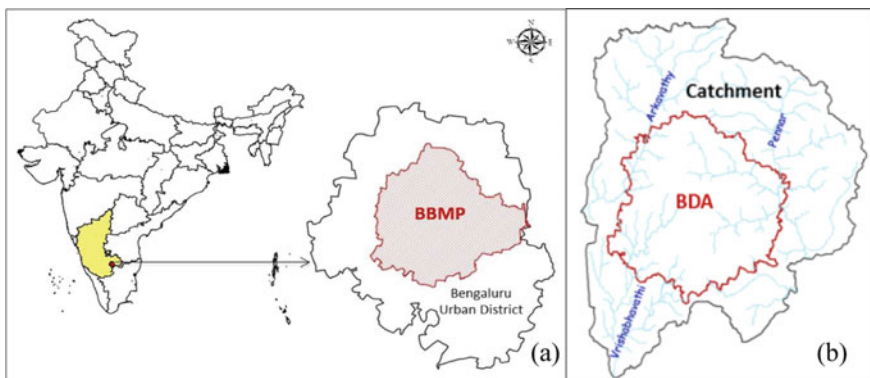


Fig. 19.1 Location of the study areas **a** BBMP region for vegetation cover assessment and **b** BDA region with a catchment area of surrounding watersheds

giving a Cascading effect to the drainage system. For the S-TALAB project, catchment area falling mostly in Bengaluru Urban and Rural districts falling in Cauvery and Dakshinna Pinakini basins has 7 major watersheds. However, the results of the analysis are limited to BDA boundary within the catchment area (Fig. 19.1b).

19.3 Satellite and Ancillary Data Used

For vegetation cover assessment, satellite data of 2006 (IRS-1D PAN + Resourcesat-1 LISS-III merged data), 2019 (Resourcesat-2 LISS-IV, MX) and ancillary datasets were used. Ancillary datasets from different sources, which were utilized directly or as a reference, during the study, include Cartosat-1-based Digital Elevation Model (10 m) for ortho-rectification, legacy data on vector layers on parks, playgrounds, lakes, roads, rail, administrative, and ward boundaries, etc. sourced from BBMP, BBMP ward-wise statistics, Reference Topomaps, Reserved Forest boundary, geo-tagged field photographs and relevant image processing and GIS Software packages, available with the center.

The inventory of lakes within BDA was carried out by using both optical and Synthetic Aperture Radar (SAR) data. Multi-resolution cloud-free optical data viz., merged product of Cartosat-1 + Resourcesat LISSIV (2017) along with Corona Black and White data of 1965 was the primary data for delineating the lake boundary. As when required, Sentinel-2 optical data was also processed and used, whereas the Sentinel-1 satellite SAR data pertaining to monsoon months corresponding to the non-availability of cloud-free optical data the water spread area. Information collected by EMPRI on various characteristics of the lakes viz., its name, lake code, location details, administrative details etc. has also been incorporated. The existing thematic layers which were created under various national/regional projects were collected and updated using HRS (High-resolution Satellite) data. Collateral information was collected from various related organizations and suitably utilized.

19.4 Methodology

19.4.1 *Vegetation Cover Assessment in Bengaluru City*

Primarily focussing on the status of vegetation cover, these changes were assessed for the years 2006 and 2019 within the BBMP area. Additionally, all other major Land Use/Land Cover classes have also been classified. Both satellite datasets pertaining to years 2006 and 2019 were digitally classified. Information on 730 Ground Truth locations, along with geo-tagged field photographs, was collected, covering diverse areas of vegetation components with density classes, non-vegetated urban regions

and areas under other major classes. The classified outputs were refined using AOI-based corrections using high-resolution satellite data. Linear features (road, rail) were overlaid after creating appropriate buffers, while the polygon-based features (parks and playgrounds) were overlaid as vegetation and open land suitably. The overall classification scheme was divided into 3 major categories, namely, (a) Vegetation areas comprising of dense vegetation, moderately dense vegetation, and sparse vegetation, (b) Lake areas consisting of water, vegetation in lake, weeds in lake and dry lake/tank area, (c) Others include the non-vegetated part of the study area, viz. built-up, major transport network (road, rail) and other classes (open-land, plot/sites, open area in parks, playgrounds, fallow land, wastelands, etc.).

Area statistics corresponding to different vegetation and other land use land cover classes were generated for both periods (2006 and 2019). These statistics were further analyzed to compute relative deviations and area percentage changes using year 2006 as reference. Ward-wise statistics were also computed for 198 wards of BBMP. Additionally, statistics for 34 prominent areas showing good tree cover were also computed separately and analyzed.

19.4.2 Spatial and Temporal Change Analysis for Lakes of Bengaluru City

Multi-date high-resolution satellite datasets were analyzed along with collateral data like cadastral maps, DEM, toposheets etc., for carrying out spatial and temporal change analysis of lakes for the purpose of generating an inventory as well as monitoring the lakes. Thematic layers were developed for the entire study area (4000 km²). However, the Spatio-temporal analysis has been carried out for the lakes within BDA limits. The lake jurisdictional boundary as per the survey numbers, was created for lakes greater than 3.0 acres using cadastral maps. The location information of lakes provided by EMPRI served as a reference for lake identification.

19.5 Results and Discussion

The findings and observations of the present study are presented in two sections below, namely (i) Assessment of vegetation and other land use land cover categories (ii) Assessment of spatial and temporal changes in lakes.

19.5.1 Assessment of Vegetation and Other Land Use Land Cover Categories

19.5.1.1 Vegetation Cover Change Analysis

Ortho-rectified IRS-1D PAN merged with Resourcesat-1 LISS-III satellite data was used for classification for the year 2006. It was noticed from the classified output that the vegetation cover was relatively lesser in most of the core urban areas in comparison to the peripheral area. It was also observed that the core city region had a densely built-up area, whereas the peripheral region infrastructure was still developing.

Resourcesat-2 LISS-IV (MX) ortho-rectified satellite dataset was used for classification for 2019. Vegetation cover in Bengaluru was estimated to be 18,572.2 ha (26.1%) in 2019, while in 2006 it was 21,414.9 ha (30.1%), suggesting overall decrease of 4% in vegetation. Similarly, the area under built-up, major transport network, and other urban categories increased from 43.9–55.3% during 2006 and 2019 within BBMP region. Built-up areas were spreading in radial pattern toward the periphery. Numerous high-rise buildings have contributed to vertical growth along with horizontal growth due to new layouts, mostly in the peripheral region of the city.

Increase and densification of vegetation were observed in most government/Public institutions/campuses, Defense lands, and parks. Vegetation cover in some of the forests region viz. Thurahalli, Ibbaluru, Bannerghatta has become denser. Increase of vegetation cover was observed in stabilized residential layouts also. Reduction in vegetation was observed mainly in developing/newly developed lay-outs, areas close to infrastructure development (like ring roads, road-widening, metro rail, etc.) In general, decrease in vegetation cover was noticed in the core city area and peripheral wards. Figure 19.2 gives the status of the vegetation as of 2019 overlaid on ward boundaries and satellite data. Table 19.1 depicts the status of total vegetation cover in 2006 and 2019 with reference to a geographical area. At one hand reduction in vegetation has occurred due to construction activities, while at the other (Figs. 19.4 and 19.6), densification and increase in vegetation cover is conspicuously witnessed (Figs. 19.3 and 19.5). Therefore, the overall impact due to negative changes in vegetation cover at specific locations is minimized due to the positive changes and density improvement in vegetation cover at various other locations, within the city.

19.5.1.2 Vegetation Change Analysis at Ward Level Within Bengaluru

There are about 198 wards within the BBMP region whose geographical areas vary from a minimum of 32 ha to a maximum of 2847 ha (Fig. 19.7). Based on their area, these wards have been divided into five categories for carrying out a detailed analysis of vegetation status during two time periods. It is seen that wards greater

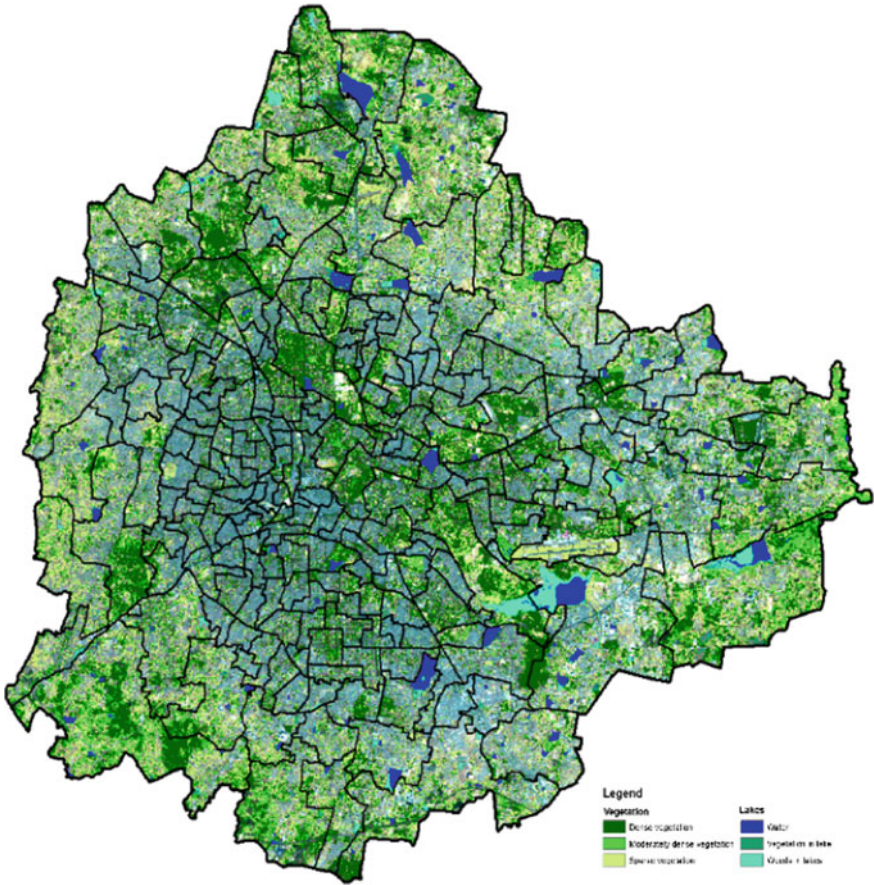


Fig. 19.2 Status of vegetation and lakes of Bengaluru in 2019. (Overlaid on 2019 LISS-IV FCC, with BBMP wards boundaries)

Table 19.1 Vegetation change area estimates across 2006 and 2019

Year	Area under vegetation (Tree cover) in ha	% Contribution wrt total BBMP geographical area
2006	21,414.9	30.1
2019	18,572.2	26.1
	Overall change	- 4.0

than 500 ha or 1000 ha are mostly located in peripheral regions, while the smaller wards are mainly located in the core city area.

Out of the total 198 wards of BBMP, 82 wards exhibited a positive trend with vegetation increase, 54 wards showed a negative trend with a decrease in vegetation

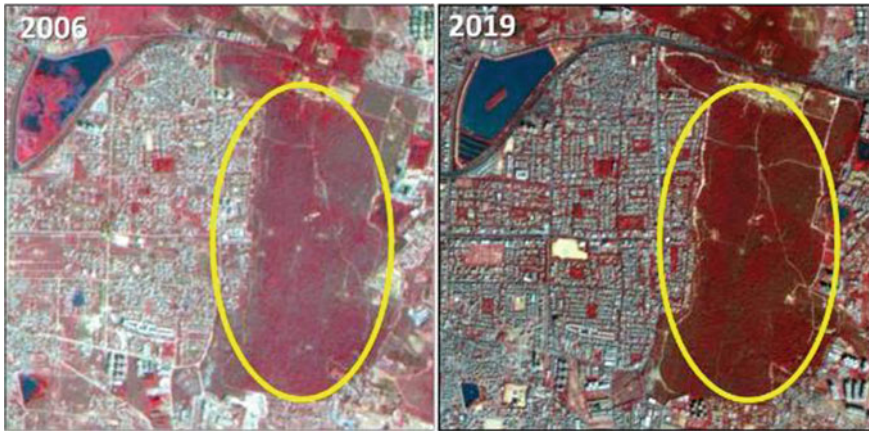


Fig. 19.3 Positive changes—Densification of vegetation in Ibbaluru forest; Agara lake rejuvenation is also seen

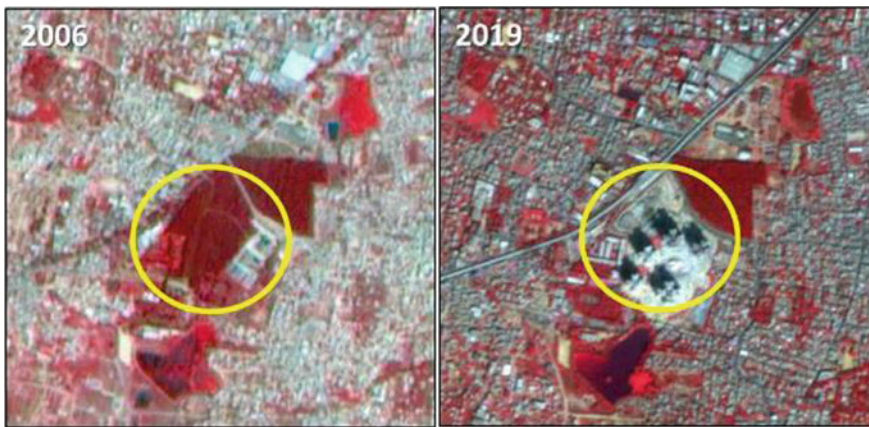


Fig. 19.4 Negative changes—Dense plantation patch converted to construct high-rise buildings in Konanakunte

cover, and 62 wards showed minimal changes in terms of vegetation cover with respect toward area (within 2%).

Urbanization is on the rise inwards located in peripheral region viz. ward numbers 1, 2, 3, and 11 in Yelahanka (toward north), due to location of International Airport and Aerospace zone; ward numbers 53, 54, 55, 81, 83, 84 and 85 in Mahadevapura (eastern side) due to presence of Information Technology Park Limited (ITPL) and other software technology parks and ward numbers 159 and 198 in RR Nagara (south-west toward Mysore road) due to upcoming residential lay-outs and construction of houses. Within wards in the core city, many old buildings have been dismantled to

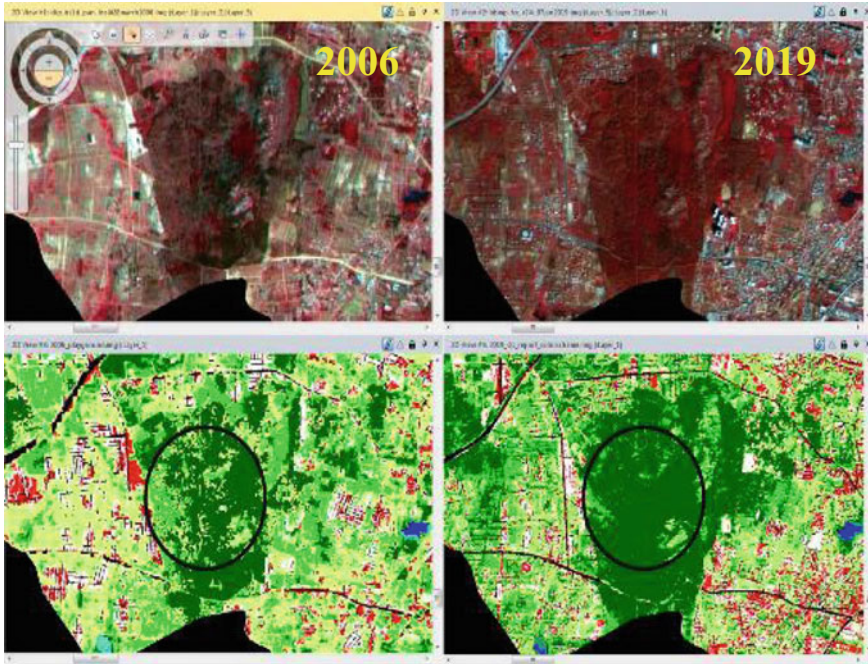


Fig. 19.5 Positive changes in Thurahalli Forest (mainly densification)

build new multi-storey apartments, contributing to vertical growth. Detailed ward-wise vegetation change analysis for these wards reveals trends to significant positive and negative changes in their vegetation cover during 2006 and 2019.

Within the core city, Shivajinagar, Chikpete, and Padarayanapura wards have just about 2% area under vegetation, as these areas are highly congested, with unplanned built-up regions and roads. On the contrary, Jalahalli with defense and public sector establishments has about half the area with vegetation cover. Hagdur, Varthur, and Kuvempu Nagar wards in the periphery have less built-up and more area under vegetation, possibly due to building activities, yet to pick up. Based on assessment of percent vegetation area with reference toward area, it was noticed that Jalahalli, Varthuru, Armane Nagara, Kuvempu Nagar, Hagadur, and Sampangiram Nagar wards have greater than 50% ward area under vegetation cover. A study of the actual vegetated area in 2006 indicates that vegetation cover was as high as about 1200–1400 ha in Varthuru and Hemmigeppura wards, whereas in core city wards and commercially dominant wards, it was less than 2 ha viz., Chickpete, Kempapura Agrahara, Padarayanapura, Shivajinagar, Kushal Nagar wards etc. A similar trend was observed in 2019 in core city wards. A significant decrease in vegetation cover was noticed in Varthuru (1447–957 ha), and a slight decrease in Hemmigeppura (1247–1218 ha) was observed.

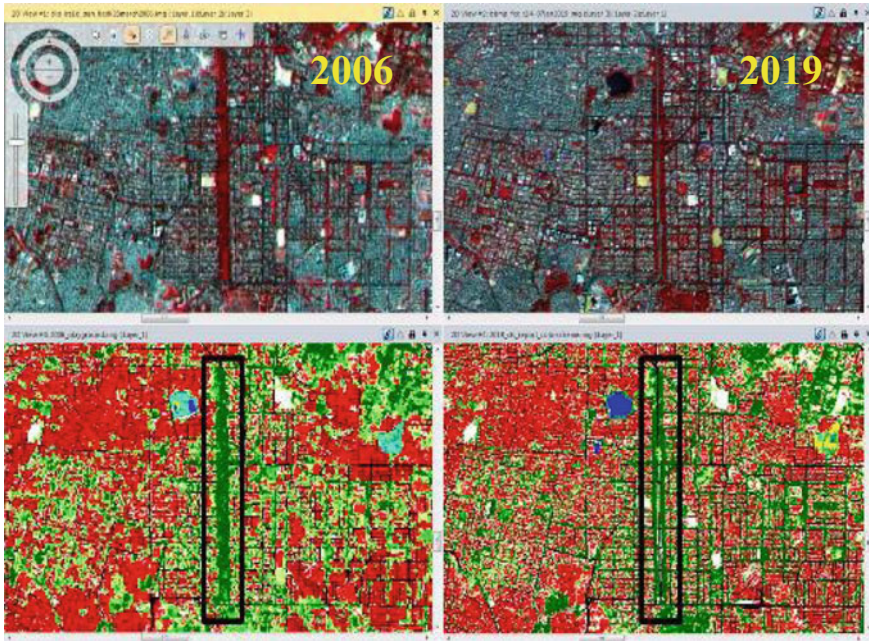


Fig. 19.6 Negative changes in R V Road and surroundings (construction of metro line)

Several wards indicated significant positive changes, while others indicated negative changes, and few others also showed a mixed category of changes within different ward regions. For example, positive changes such as densification of vegetation were very evident in the eastern part of HSR Layout ward (ward no. 174, with 705 ha total area), which contains part of Ibbaluru forest. Additionally, Agara lake rejuvenation is another positive change in the northern part of this ward resulting in the increase of water spread by about 10 ha and clearing of weeds from 25 ha area within the lake (Fig. 19.8).

19.5.1.3 Change Assessment Within Densely Vegetated Areas of City

Several important areas of Bengaluru with dense tree cover have also been analyzed separately to assess the changes in vegetation cover (dense to moderately dense) within these locations for two time periods, viz., 2006 and 2019 (Fig. 19.10). These 34 locations include various vegetation niche areas in parks (Cubbon park and Lalbagh); public sector areas (such as HAL, BEL, ITI, HMT); defense areas (such as CMP, Madras Regiment, BSF); research/academic institutes (such as Bengaluru University, GKVK, IISc, IIM); and forest areas (such as Thurahalli, Ibbaluru, Doresanipalaya forests). The boundaries of these prominently vegetated areas have been interpreted from satellite imagery based on the compound wall and roads and do not necessarily

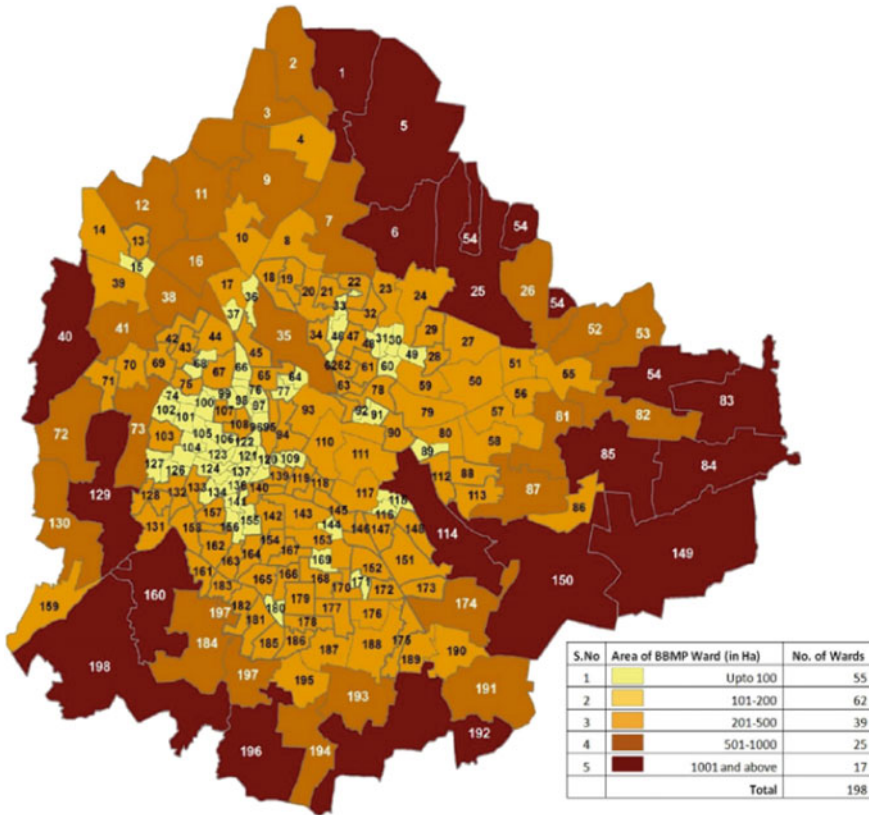


Fig. 19.7 Geographic area-wise distribution of wards

represent the actual administrative boundaries. In many locations, the surrounding areas were also included for assessing the changes in vegetation cover. Locations of these areas are depicted in Fig. 19.9, and the statistical results are presented in Table 19.2. The numerals depicted in Fig. 19.10 and the serial numbers in Table 19.2 are to be referred to together.

It was observed that there was an overall increase of 261.1 ha in the vegetation Cover indicating an increase of 5.4% in dense and moderately dense vegetation cover within these locations. In forest areas alone, there is an increase of 177.3 ha vegetation (Thurahalli and Ibbaluru forest areas mainly). Most public sectors, academic/research institutes, and defense areas have increased their vegetation cover, thereby contributing to an overall positive change in vegetation status. Percentage-wise positive change greater than 50% with respect to 2006 is seen in DRDO and surroundings, HAL-Part 3 and Kadugodi-Part 1, further densification of dense and moderately dense vegetation was noticed.

However, a reduction of about 108 ha of vegetation cover in the GKVK campus contributed to a negative change of 29.4%. It could mainly be attributed to the

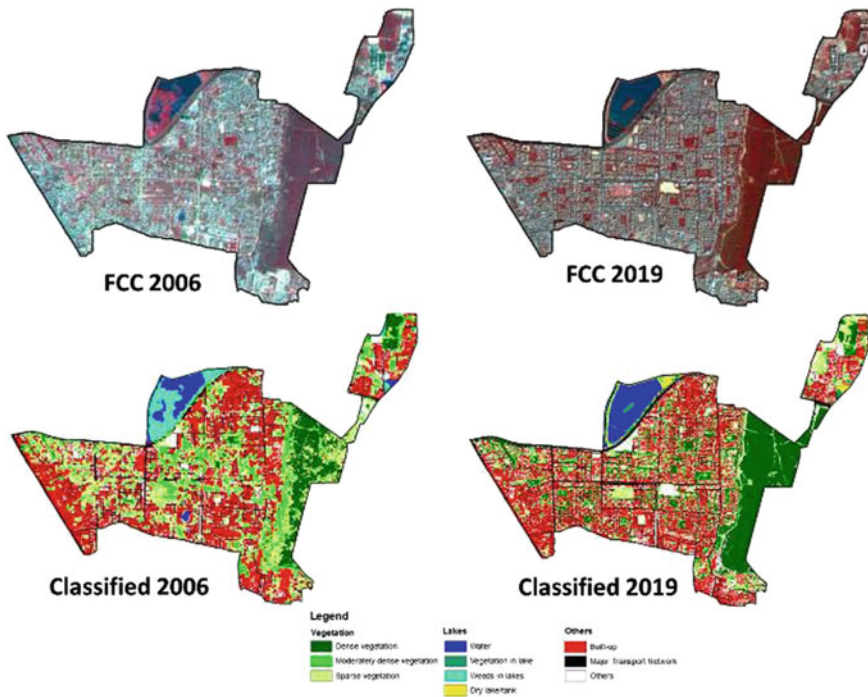


Fig. 19.8 Comparison of vegetation cover and water-spread in HSR Layout (Ward no. 174)

conversion of densely vegetated areas into agricultural research plots, resulting in decreased vegetation. About 12–13% decrease in vegetation cover was also observed in Nallurhalli, Pattandur Lake, and surrounding areas in the eastern part of city, where construction activities have taken place. Also, in both Cubbon and Lalbagh parks, a marginal decrease in vegetation cover was observed due to minor construction activities within the parking area. Therefore, change analysis of prominently vegetated areas of the city gave a good idea about the status of urban vegetation in the city, with an overall increase of 261.1 ha in vegetation cover within these areas.

19.5.2 Spatio-Temporal Assessment of Long-Term Changes: Natural Drainage Systems and Lakes

Using 1965 Corona satellite data and recent 2017, a geospatial database of lakes and drainages was created for a study area falling within BDA bounds. The surface water spread area of lakes was mapped using temporal SAR data. Long-term changes of lakes and drainage pattern in terms of water spread area, inventory, modification of drainages, prioritization of lakes were attempted.

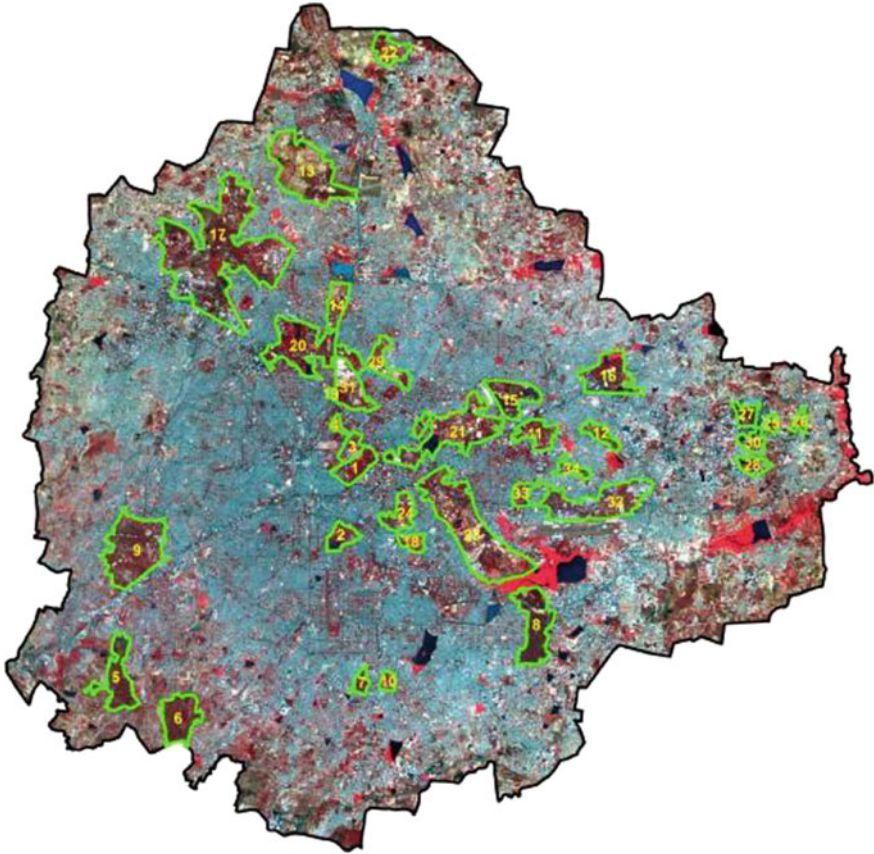


Fig. 19.9 Densely vegetated areas of Bengaluru city (Numerals in the figure represent the serial numbers of locations, refer to Table)

19.5.2.1 Delineation of Watersheds in the Catchment Area

A geospatial database was created for a catchment area of 4000 km² surrounding Bengaluru. The catchment area was further divided into 481 micro-watersheds with a geographical area ranging from 2500 to 15,000 ha (approximately). These micro-watersheds were further grouped into 86 urban, 105 semi-urban, along with 290 rural watersheds depending on the percentage of urban areas within them. The micro-watersheds are depicted in Fig. 19.10.

19.5.2.2 Inventory of Lakes and Its Spectral Properties

The urban lakes showed spectral and tonal variations when examined on LISS-IV data. Based on the field knowledge, the status of the lakes could be identified as

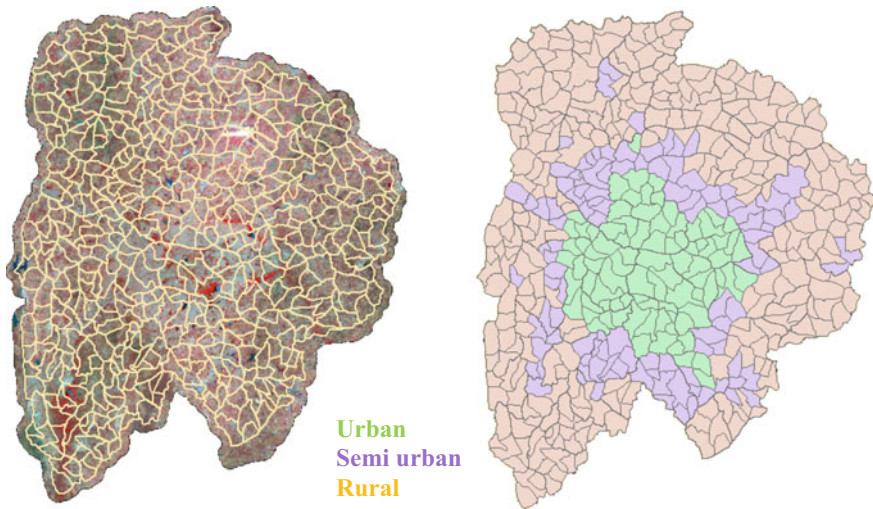


Fig. 19.10 Depicting the Micro watersheds based on its location—urban, semi-urban and rural

whether it is deep, shallow, turbid, polluted or filled with weeds or dry lake bed. The digital number of different lakes was plotted in Fig. 19.11. The figure depicts lesser DN values for clear water when compared across the three bands of LISS-IV data. However, the DN value was higher for turbid water. Similarities were observed between the spectral signature of aquatic weed and vegetation (bright red to pinkish in color) and dry lakes and open land/fallow lands. These spectral characteristics of water and surrounding land use patterns are used to demarcate the lake extent as manifested on HRS data for creating geospatial database on lakes.

The inventory of lakes has been done using both Corona 1965 satellite data and LISS IV satellite data of 2017. It is quite difficult to delineate the actual jurisdictional boundary of the lakes using satellite data alone. The ancillary data viz., cadastral maps, toposheets, drainage system DEM etc. have also been used to interpret lakes and their extent.

The village cadastral maps were used to inventory lakes within the BDA region and attribute information such as lake-ID, name of the lake, geo-location, area, administrative hierarchy (village, hobli, and taluka), and survey numbers were added for the creation of baseline database. Georeferenced cadastral maps covering the BDA region available at Survey and Land Records department were used in the study for the creation of a comprehensive database on lakes. Cadastral maps for 16 villages in the core urban areas were not available; hence the lakes falling in the core urban area were digitized from 1965 satellite data. Collateral data from EMPRI, SSLR ground survey data, toposheets were also used for improving the quality of the database. Figure 19.12 gives the spatial distribution of lakes as in 1965 and 2017.

Table 19.2 Details of change analysis for densely vegetated areas of Bengaluru

S. No.	Location of prominently vegetated area important areas	Vegetation area (ha)		Change Area (ha)	% Change (wrt 2006)
		2006	2019		
1	Cubbon Park	106.7	102.4	- 4.3	- 4.0
2	Lalbagh	62.5	59.7	- 2.8	- 4.5
3	Vidhan Soudha and Surroundings	40.6	59.7	- 3.3	- 8.1
4	Golf Course	24.0	22.5	- 1.5	- 6.3
5	Thurahalli Forest Part 1	174.7	219.9	45.2	25.9
6	Thurahalli Forest Part-2	173.2	225.1	51.9	30
7	Doresanipalaya Forest	42.7	44.5	1.8	4.2
8	Ibbaluru Forest	190.4	268.6	18.2	41.1
9	Bengaluru University and Surroundings	352.2	398.5	46.3	13.1
10	Indian Institute of Management	30.2	32.3	2.1	7.0
11	Defence Research and Development Organisation (DRDO), CV Raman Nagar	93.5	102.2	8.7	9.3
12	DRDO and Surroundings	32.6	53.7	21.1	64.7
13	Gandhi Krishi Vignana Kendra (GKVK) Campus and Surroundings	369.1	260.6	- 108.5	- 29.4
14	University of Agricultural Science (UAS) Campus at Hebbal and Surroundings	70.5	61.0	- 9.5	- 13.5
15	National Government Electrical Factory (NGEF)	124.7	144.5	19.8	15.9
16	Indian Telephone Industry (ITI)	149.1	165.9	16.8	11.3
17	Bharat Electronics limited (BEL), and Hindustan Machine Tools (HMT) Surroundings	1006.2	962.0	- 44.2	- 4.4
18	National Dairy Research Institute (NDRI)	18.9	20.1	1.2	6.3
19	National Tuberculosis Institute	7.3	7.5	0.2	2.7
20	Defence Area and Indian Institute of Science (IISC)	313.4	312.0	-1.4	- 0.4
21	Madras Regiment Area, Halasuru	255.0	300.8	45.8	18.0

(continued)

Table 19.2 (continued)

S. No.	Location of prominently vegetated area important areas	Vegetation area (ha)		Change Area (ha)	% Change (wrt 2006)
		2006	2019		
22	Airforce, Yelahanka	51.1	72.2	21.1	41.3
23	Defence Area Near old airport	406.3	441.7	35.4	8.7
24	Corps of Military Police (CMP)	72.9	78.6	5.7	7.8
25	Kadugodi Part 1	13.3	23.1	9.8	73.7
26	Kadugodi Part 2	29.7	29.5	- 0.2	- 0.7
27	Kadugodi Part 3	57.7	61.5	3.8	6.6
28	Nallurhalli and Surroundings	41.7	36.4	- 5.3	- 12.7
29	TV Tower and Surroundings	121.6	136.2	14.6	12.0
30	Pattandur Lake and Surroundings	44.9	38.8	- 6.1	- 13.6
31	Palace Grounds and surroundings	81.3	96.9	15.6	19.2
32	Hindustan Aeronautics Limited (HAL)—Part 1	228.4	215.4	- 13	- 5.7
33	HAL—Part 2	41.7	42.2	0.5	1.2
34	HAL—Part 3	27.8	43.0	15.2	54.7
Total		4855.7	5116.7	261.1	5.4

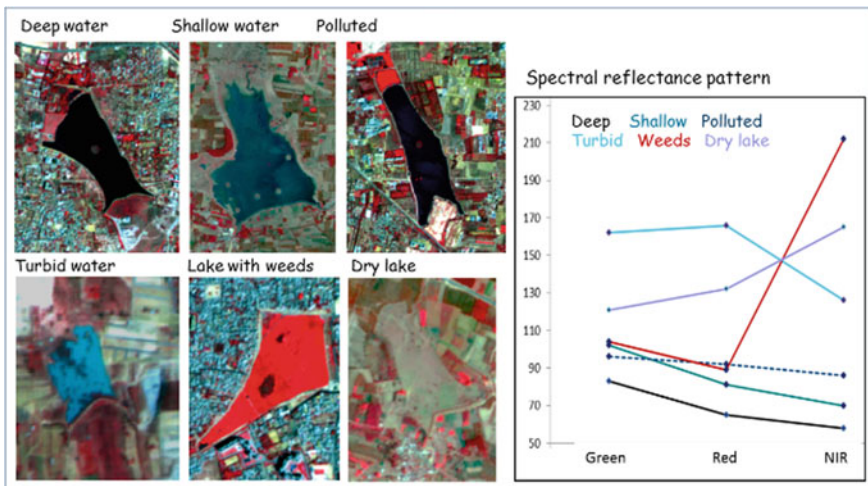


Fig. 19.11 Spectral Pattern of Urban lakes

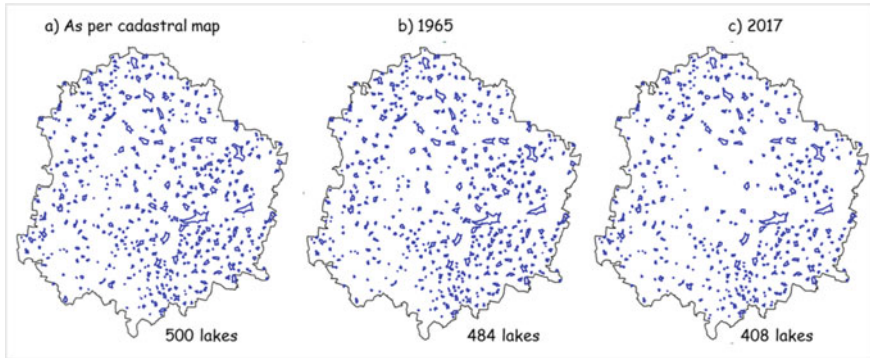


Fig. 19.12 Distribution of Lakes **a** as in 1965 and **b** as in 2017

19.5.2.3 Spatial and Temporal Changes in Lakes

Spatio-temporal changes have been carried out for the lakes falling within BDA limits to understand the changes within the urban area. The details of the lakes with their temporal changes are given in Table 19.3 and spatially represented in Fig. 19.13. A cursory analysis reveals that out of 500 lakes as per cadastral maps within the BDA limits, lakes were present during 1965. This number was further reduced to 408 lakes as per satellite data analysis of 2017. This is an indication of change in land use over the past 50 years. From the statistics, it is evident that about 86 lakes were converted from waterbody to different land uses. A positive indication is that 10 lakes have been newly formed after 1965.

Uncontrolled urbanization and haphazard growth of the city is the main cause for the degradation of lakes within the BDA limits and changes observed within the lakes. Some of the observations about the land use of lakes are given below and represented in Fig. 19.14

- Lake footprint has reduced, which is reflected from the reduction in the geographical area of the lake.
- Partial infestation of lakes with aquatic weeds

Table 19.3 Details of number of lakes within BDA limits

S. No.	Details	No. of lakes
1	Cadastral maps (1850s): lakes delineated	500
2	Corona Space Image: lakes delineated	484
3	L4 + Cartosat-1 image: lakes delineated	407
4	Non-existing lakes prior to 1965	16
5	Converted lakes between 1965 and 2017	86
6	New Lakes constructed after 1965	10

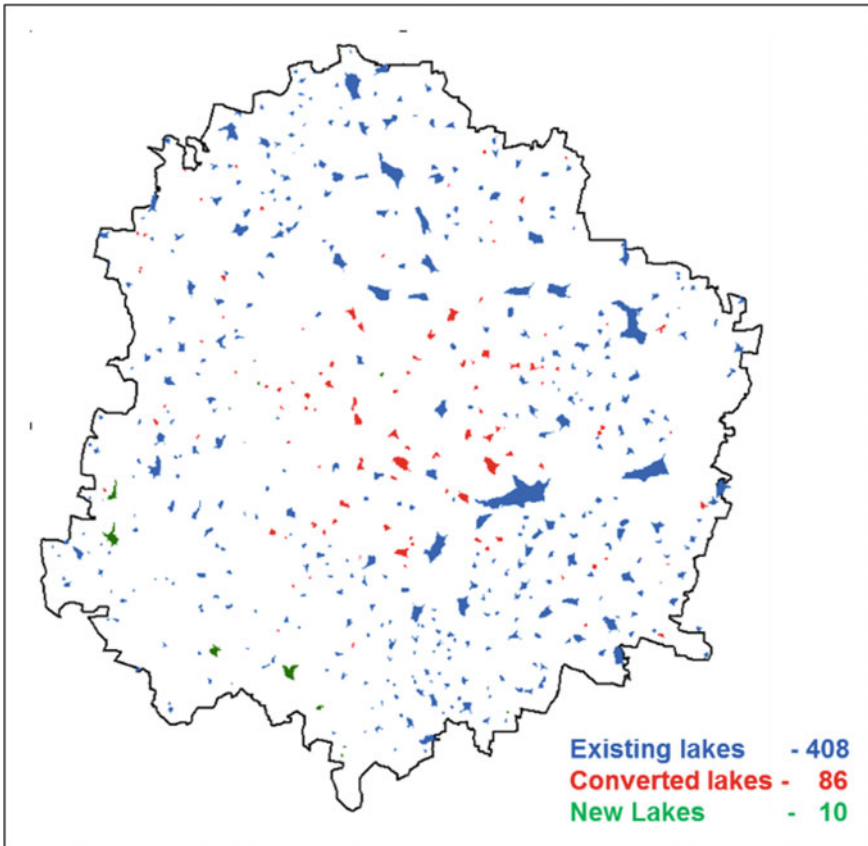


Fig. 19.13 Spatio-temporal changes of lakes within BDA limits

- Land use changes observed where some lakes have been partially transformed to built-up areas or parks or vegetated patches, etc.
- New lakes have been constructed within the Bannerghatta Reserved Forest area

19.5.2.4 Surface Water Spread Area of Lakes Within BDA

Bangalore received an annual rainfall of about 1600 mm (approx.) in 2017, while the average annual rainfall over the last few areas was 859 mm. However, it was observed that maximum rain was observed in 2017 during the monsoon months. The maximum water spread area of the lakes was observed from mid-August to October 2017. Sentinel SAR data in VV and VH polarization corresponding to peak rainfall periods from August to November 2017 was used for delineating the water spread area. The results have been validated using optical data of November 2017.

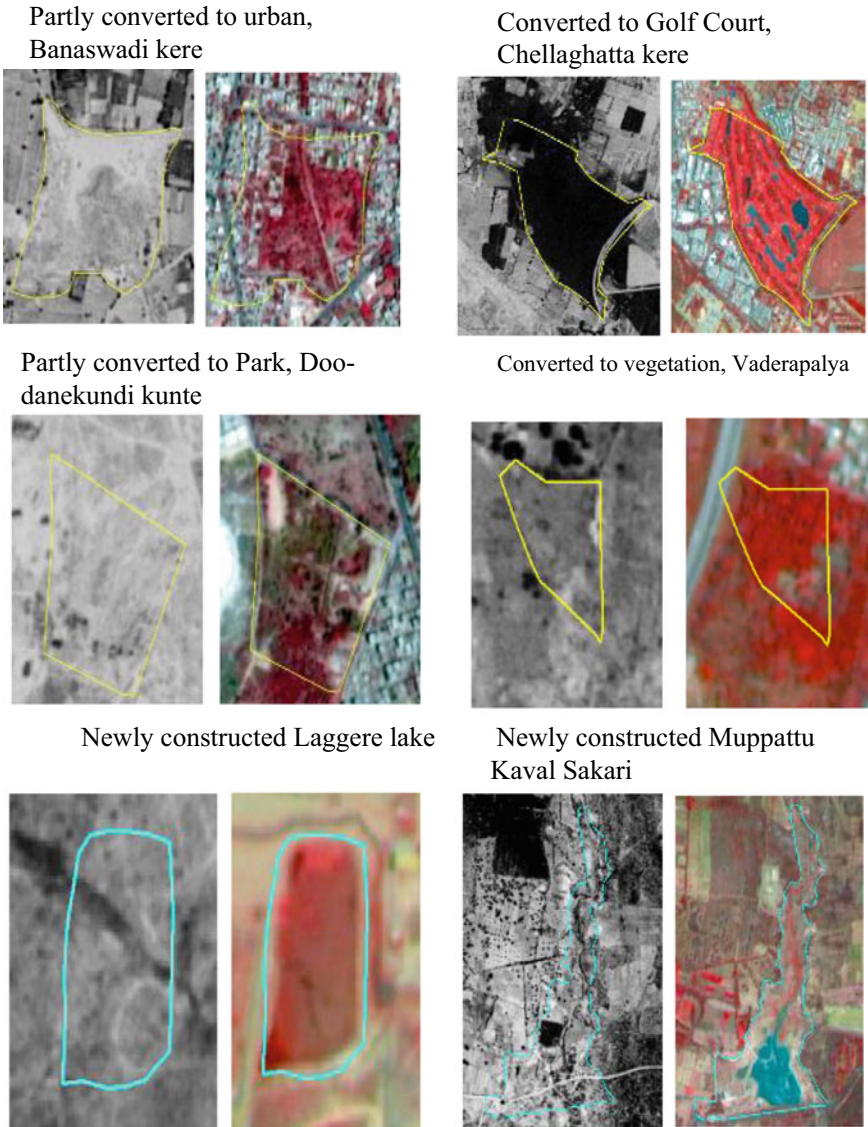


Fig. 19.14 Typical spatio-temporal changes: 1965–2017

From the Sentinel SAR data using thresholding algorithm based on valley emphasis method, water spread area within each lake was extracted using the backscatter values (Fig. 19.15). Weeds and surface vegetation exhibited higher backscatter when compared with water. This trait was used to interpret the spread of water within each lake. The lakes were grouped into five groups based on the percentage of the geographical area covered with the spread of water (Fig. 19.16).

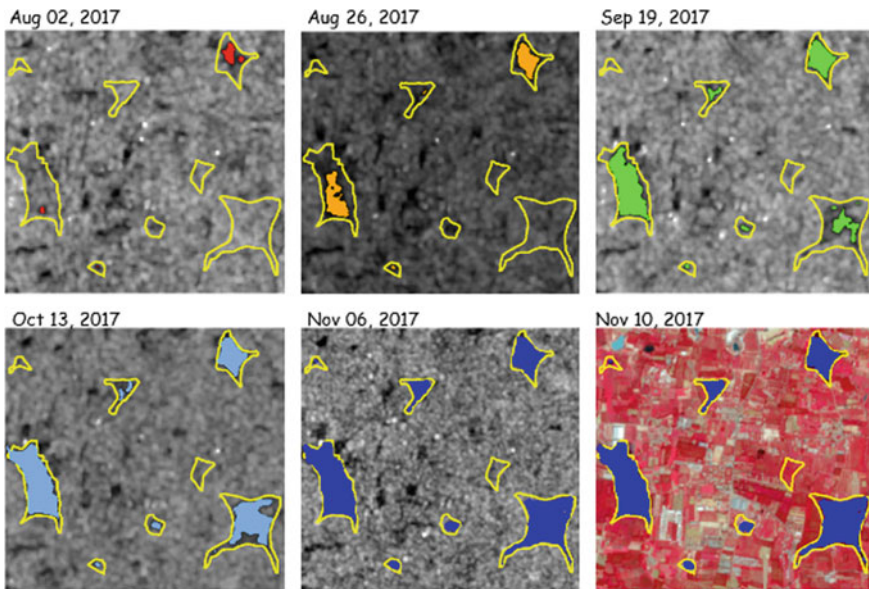


Fig. 19.15 Water spread area extracted for different periods from SAR and optical data

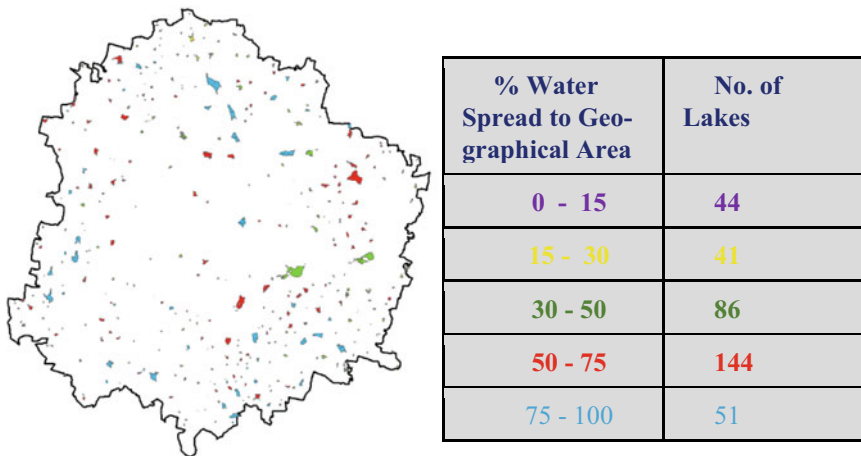


Fig. 19.16 SAR Image and Proportion of water spread area to Geographical area of lakes

Even during a very wet monsoon season, nearly 85 lakes were dry or completely covered with weeds/vegetation, and a total of 171 lakes have only about 50% of their geographical area underwater. This reflects the status of the filling up of lakes even during the monsoon.

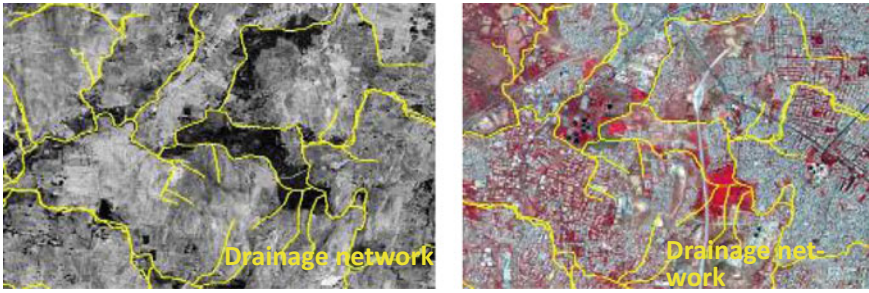


Fig. 19.17 Typical drainage network in urban area as interpreted from satellite data

19.5.2.5 Drainage Network

Visual interpretation methods were adopted for interpreting and generation of drainage network from satellite data on a 1:10,000 scale using collateral data also (Fig. 19.17). The drainage network was delineated as lines from the Corona Space Image of 1965, which was generated and updated using 2017 satellite data.

As drainages were fully or partially covered with weeds/vegetation or lined with trees on both sides or, in some cases, fully covered with concrete, delineating drainage from satellite data was very difficult as it was not clearly interpretable on satellite data. Sometimes, roads were confused as drainages while interpreting drainages due to its similar spectral nature. The drainages, especially first-order streams and drains, which were not clearly seen on the satellite data, have been analyzed from toposheets and DEM. Spatially depiction of the changes in the drainage pattern is given in Fig. 19.18. Due to rapid urban development and construction of many industrial establishments, large apartments, layouts, etc., drains' length has significantly changed from 1965 to 2017. The total drainage length from the interpreted drainage layer showed a loss of 325.4 km of drainage network in Bengaluru city as observed from 1965 to 2017.

19.5.2.6 Characterization and Prioritization of Lakes

Characterization and prioritization of lakes were carried out by EMPRI by a systematic collection of field information of 78 parameters and adopting the Battelle method suitably modified for Indian condition, and lakes have been prioritized based on the importance of action required. From their study it emerged nearly 210 lakes need urgent revival and care for its existence.

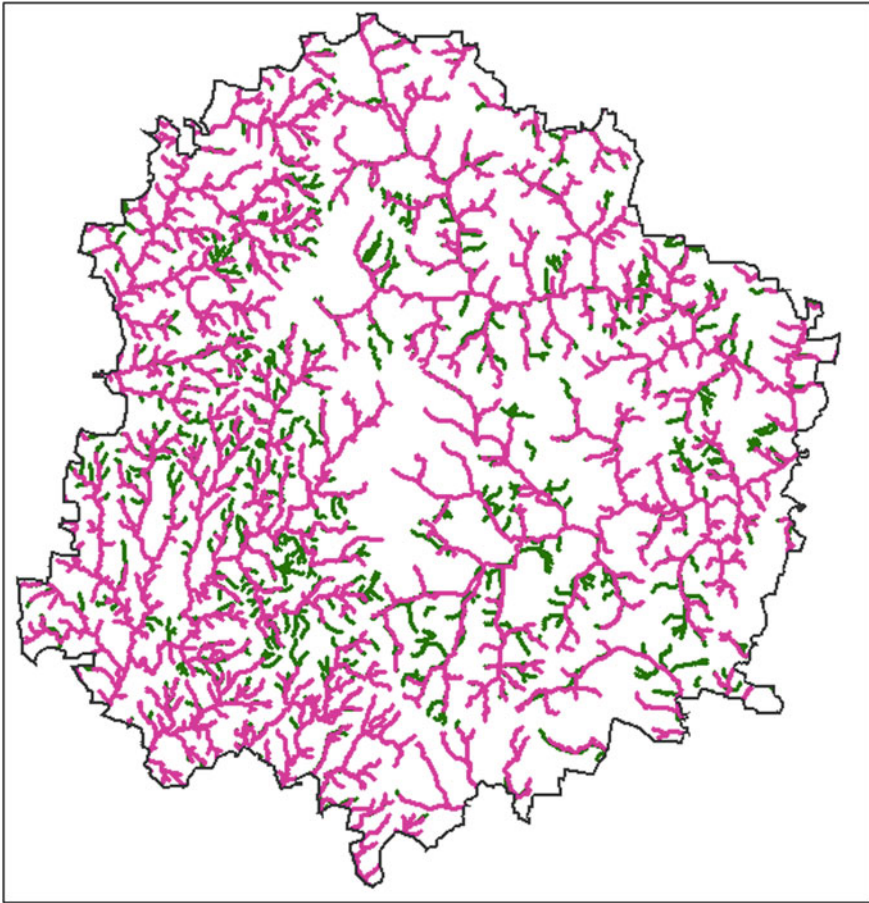


Fig. 19.18 Changes in drainage network between 1965 and 2017

19.6 Conclusion and Recommendations

This chapter presents a summary of two major studies involving assessment of various components of urban dynamics of Bengaluru city viz., vegetation, land use/land cover, and lakes, using geospatial techniques. Based on the total area of BBMP, spread across 711.59 km² (consisting of 198 wards), the total change in the vegetation status of Bengaluru city was estimated to be a reduction of about 4% between the years 2006 and 2019 i.e., decrease of vegetation cover in Bengaluru from 30.1% (21,414.9 ha) in 2006 to 26.1% (18,572.2 ha) in 2019. For this estimation, densely vegetated areas and moderately vegetated categories were considered, as they represent the main component of vegetation (consisting of tree cover). Area, representing vegetation of seasonal nature especially the grasses, herbaceous vegetation on vacant sites/plots, fallow land, scrubland etc. grouped under sparse vegetation class was not considered

for change analysis. A detailed vegetation change map was prepared (between 2006 and 2019). Ward-wise detailed analysis of vegetation indicated that out of 198 wards within BBMP area, the vegetated area increased in 82 wards, vegetated area decreased in 54 wards while 62 wards showed nominal changes in vegetated areas or almost similar status. Additionally, an exclusive vegetation change analysis for importantly vegetated 34 areas of Bengaluru city (such as Lalbagh, Cubbon Park, etc.) indicate an increase in vegetation cover by 261.1 ha (accounting to 5.4% increase), suggesting a total positive trend in vegetation cover in terms of area and density under these locations.

Most BBMP wards have numerous green parks, apart from historically present and recently planted avenue plantations. Defense campuses established since the pre-independence era and non-built up spaces in many government institutions/campuses within the city also have a very large presence of intact vegetation cover, undisturbed by the uninhibited pace of urbanization. The greenery in such locations is functioning as real lung spaces for the local populace. Urbanization is observed to be spreading toward the peripheral region in a radial pattern. The negative changes observed in multiple locations have not impacted the overall density of vegetation in a negative manner. To improve the vegetation cover of Bengaluru city, the recommendations/suggestions based on the present study are: (i) protecting the existing vegetation (ii) further densification of vegetated areas (iii) replacement of dead, dying, and diseased trees (iv) compensatory planting at other areas or in the neighborhood for road-widening/metro lines (v) Selection of appropriate plant species (vi) Transplantation of trees (vii) Seeding using seed balls (viii) Vertical/Terrace gardens (ix) Enhancing the existing vegetation by plantation drives (x) Kitchen Gardens/Indoor vegetation (xi) Growing more trees around Lakes/Playgrounds/Open spaces (xii) Densification of Parks and (xiii) Rain Water Harvesting.

The unplanned urban expansion and creation of urban infrastructure have incurred a loss of natural drainage network and the conversion of lakes in Bengaluru. The results of the spatial-temporal analysis of lakes within BDA limits are emphasized.

- Lakes with size > 3.0 acres: The interpretation of cadastral maps, Corona 1965 image, and Cartosat1 + LISS 4 image of 2017 have yielded that from 500 lakes as per cadastral maps have been converted and reduced to 484 during 1965 and further reduced to 408 during 2017. Thus about 86 lakes have been converted from lakes into different land use after 1965. On the positive side, about 10 new lakes were also constructed especially in the Bannerghatta park area of the city.
- Drainage pattern: The total loss 325.24 km drainage length has been observed due to urbanization within BDA Area. Total length of the natural drainage network was estimated as 1647.5 km (in 1965) and 1295.1 km (in 2017).
- Surface water spread area: SAR data analysis has shown that 212 lakes out of the existing 408 lakes depicted more than 50% area under surface water-spread (2017 monsoon season). 113 lakes depicting area under 25% water-spread, though with good monsoon season during 2017, require immediate attention for protection and conservation. The remaining lakes were dry and completely occupied by weeds

in spite of the heavy rains showing a possible loss of drainage connectivity and flow of water into these lakes.

Lake inventory and its present status and loss of drainage network are valuable inputs to prepare an integrated action plan for the conservation of the lakes. Some of the immediate actions required are conservation of lakes which have been covered with aquatic weeds; improve the drainage connectivity between lake series and also clear the drainages which are covered with vegetation, garbage etc. and ensure smooth flow of water, desilting of lakes, setting up of STPs and treating the drainage water before letting it into the lakes, preventing the various forms of solid, liquid and other bio-medical wastes being dumped into the lakes. Apart from this, integrated development of lakes requires further studies on the impact of urbanization, status of pollution, computing run-off estimation, and flood inundation.

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