Assessment of long-term changes in lakes and natural drainage patterns of Bengaluru city using historical satellite images

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ABSTRACT

Bengaluru City once known for its beautiful lakes has lost its glory due to indiscriminate urbanization and many lakes have been gradually converted to different land use and rest of the surviving lakes are reduced to cesspools due to direct discharge of industrial effluents, sewage, dumping of solid wastes. Hence, it is very much essential to conserve, manage and maintain lakes as a part of the urban ecosystem and restore to its pristine status. The present study jointly undertaken by Regional Remote Sensing Centre – South, NRSC/ISRO and Karnataka Lake Conservation and Development Authority (now Karnataka Tank Conservation and Development Authority) for creating systematic geospatial database for analysing the spatio-temporal dynamics of lakes and drainage patterns. Major focus of the study was to characterize the entire catchment area of the city using satellite and collateral data for prioritization of watersheds / lakes to identify the hot spots and generate inputs for developmental plans for conservation, preservation and rejuvenation of lakes and to prevent further deterioration. Considering the rapid expansion of Bengaluru city, the present study has been carried out at two levels a) Core urban area – in BDA limits consisting of 1301 sq. km and b) Extended study area – in combined catchment area of Arkavathi and South Pinakini rivers covering 4000 sq.km. The work components included preparation of satellite database, delineation of watershed & morphometric analysis, inventory of drainage & lakes, mapping of surface water spread area and customization of Lake Information System. The watershed boundaries were delineated hierarchically from basin to micro-watershed level along with codification. The present study mainly focused on systematic generation of geodatabase for physical characterization of lakes and drainages. Corona Space Imagery of 1965 was used as reference data, while, LISS-IV and Cartosat-1 data of 2017 was used for change analysis. All-weather capable Synthetic Aperture Radar (SAR) data from Sentinel-1 satellite was used for mapping of surface water spread area of lakes. Ancillary data like Digital Elevation Model, SOI topographical maps (1972), cadastral maps (1903-1926) and detailed field survey data were used in interpretation for improving the quality of database. Ground truth was collected for 120 selected lakes using Mobile app to augment satellite data analysis. Digital image processing, GIS and data analytic techniques were used for integration of different thematic and ancillary data for analysing the spatio-temporal dynamics of lakes and drainage patterns. The extensive database created under the project helps to work out detailed conservation and revival plans for selected lakes & drainages (streams) towards bringing back live lake system of Bengaluru.

1. INTRODUCTION

Bengaluru is popularly known as “City of Lakes”. The lakes / tanks are critical for survival of the city as it does not have any perennial river. In order to conserve water, lakes have been built during the period of Western Gangas, the Cholas and the Hoysalas. Traditionally these lakes are interlinked through chain of natural drainage systems and largely the agrarian communities clustered around these lakes. As per the Karnataka Lake Conservation and Development Authority Act, 2014, “Lake” means an inland water-body irrespective of whether it contains water or not, mentioned in revenue records as Sarkari Kere, Kharab Kere, Kunte, Katte or by any other name. It includes the peripheral catchment areas (Raja Kaluve) main feeder inlet and other inlets, bunds, weirs, sluices, draft channels, outlets and the main channels of drainages. Lakes are essential of any region for conservation of water, recharging ground water and channelize water flow to prevent water logging and flooding. The naturally undulating terrain of Bengaluru with its hills and valleys is perfectly suited for the development of lake systems. The general flow of water is from North to South-East as well as North to South-West along the natural gradient. During last 3-4 decades, lakes and tanks in the urban and peri-urban areas of Bengaluru city have undergone remarkable changes due to rapid urbanization, encroachments, pollution which resulted in significant damages to Lake Ecosystem. EMPRI (Environmental Management & Policy Research Institute) has carried out an extensive study for inventory of water bodies in Bengaluru Metropolitan area (BMA) along with bio-chemical analysis for 14 major water quality parameters. The study revealed that 101 lakes are disused due to rapid urbanization, 331 water bodies have the possibilities of encroachment, 89 lakes are dried, 261 lakes are polluted as per the water quality analysis and 303 water bodies have solid waste dump (EMPRI, 2017). The use of multispectral data for inventory of surface water bodies has been demonstrated using satellite data (Sharma et al., 1989). Mapping of water bodies at national level is being carried out periodically at NRSC using multi-resolution satellite data and hosted on BHUVAN geoportal.

2. OBJECTIVES

The present joint study between RRSC-South/ NRSC and KLCDA, GoK was undertaken for creating a systematic geospatial database on lakes and drainage pattern in Bengaluru using historical satellite data of 1965 and 2017 using historical satellite and ancillary data for monitoring spatio-temporal dynamics of lakes and drainage patterns which serves as important inputs for conservation of natural resources through integrated management plans. In order to understand the process of lake degradation and arrive at lake management practices, there is a need to carry out a scientific study of the spatiotemporal dynamics of lakes / tanks in urban areas and identify the hotspots for arriving at conservation strategies. Thorough understanding of the spatial patterns of catchment area, drainage pattern and continuity, feeder channels and land use /land cover, lake series and extent of urbanization is essential for preparing a prospective management plan. The main focus of the study is to understand the impact of rapid urbanization of Bengaluru city on lakes and surface hydrology.

3. STUDY AREA

Bengaluru and surroundings are part of two major river basins, the Cauvery and the Dakshina Pinakini. Western part of the City is in Vrishabhavathi River basin which is a tributary of Arkavathi River (tributary of Cauvery River). Eastern part is in Dakshina Pinakini basin. The city has three main valley systems: Hebbal, Koramangala – Challaghatta and Vrishabhavati. The city is located at an altitude of 920m above MSL due to which the natural flow of water is away from the city and into the valleys. In order to map the lakes and study the status & condition of lakes in the city, it is essential to study the changes in the river catchment area and drainage network. Considering the rapid expansion of Bengaluru city and to arrive at long term conservation plan to preserve the surface hydrological system, the study has been carried out at two levels a) Core urban area – in BDA limits consisting of 1301 sq. km and b) Extended study area with the combined catchment area of Arkavathi and South Pinakini covering 4000 sq.km.

4. SATELLITE AND ANCILLARY DATA

Multi-resolution Cloud-free optical data (Cartosat-1, Resourcesat, Sentinel-2, Corona) from 1965 to 2017 was used in the study for inventory of lakes and drainage pattern, while, Synthetic Aperture Radar (SAR) data from Sentinel-1 satellite of 2017 monsoon period was used for delineating water spread area of lakes. Survey of India Topomaps was used as reference data.The geo-location of 492 lakes along with attribute information (Lake Name, unique code, village, hobli, taluka and extent) provided by EMPRI was also utilized for accurate location of lakes. The legacy thematic layers (transport layer, LULC (Landuse/Landcover) maps, watershed boundary), created under various national / regional projects were used as reference data which was subsequently updated using HRS(High-resolution Satellite) data. Ancillary data such as Survey of India toposheets at 1:50,000 Scale (RRSC), Administrative layers (BDA-Bengaluru Development Authority & BBMP- Bruhat Bengaluru Mahanagara Palike boundary), Transportation layer (rail and road), Watershed map (India-WRIS project), Field photos and Locations of lakes as provided by EMPRI, LULC maps (RRSC), Drainage network map (KSRSAC & India-WRIS) and Georeferenced Online Cadastral maps (SSLR- Survey Settlement And Land Records) were used in this study.

5. METHODOLOGY

Temporal high-resolution satellite data was analyzed in the project along with ancillary data like toposheets, cadastral maps, DEM etc for spatio-temporal analysis of lakes. The inventory and periodic monitoring of lakes has been carried out using historical satellite and ancillary data. The methodology was adopted for entire catchment area of about 4000 sq km and the base layers were created. Initially, all the lakes with extent of greater than 3.0 acres were mapped using cadastral maps for creating lake jurisdictional boundary as per the survey numbers. The geolocation of 492 lakes provided by EMPRI was also used as reference database for identification of lakes. The major work components are given in the flowchart below (Fig.1).

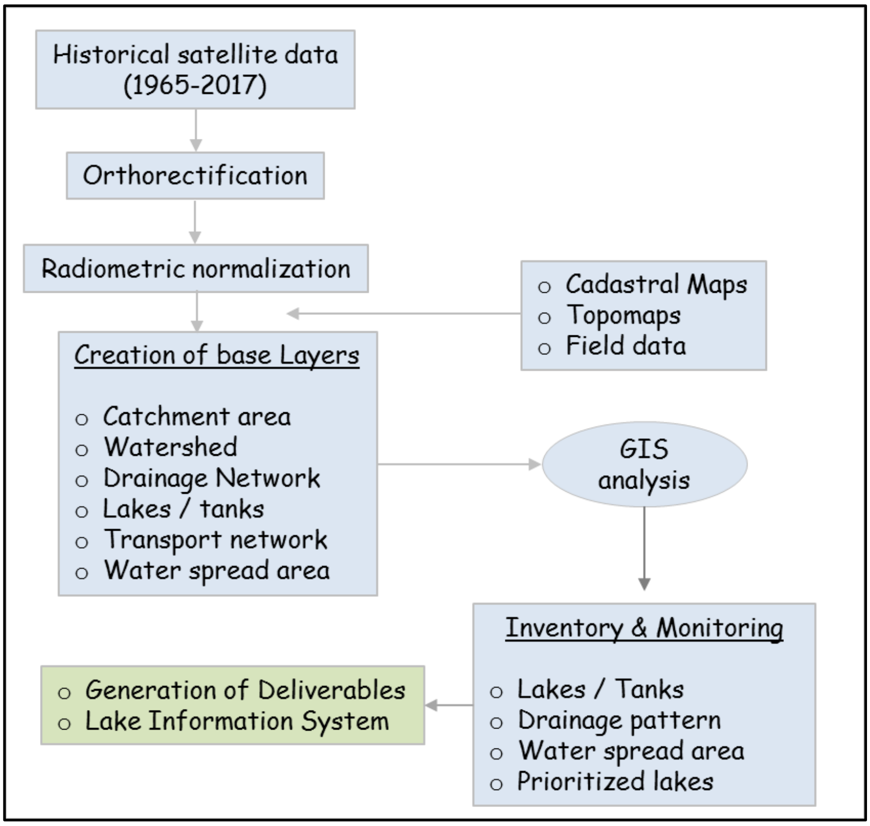


Figure 1. Flowchart showing Overall Methodology

5.1.1 Satellite data analysis

Multi-sensor and multi-resolution datasets covering 1965 to 2017 has been used for identification and mapping of lakes and drainage patterns for subsequent spatial analysis. The satellite datasets (Corona, Cartosat-1 and Resourcesat LISS-IV) in TIFF (Tagged Image File format) were Ortho-rectified with standard UTM projection and WGS 84 spheroid using photogrammetric block adjustment technique and Digital Elevation Model generated from Cartosat-1 Stereo pairs of 2008. Orthorectification of LISS-IV data was carried out using RPCs, well distributed GCPs & image tie points following block adjustment technique. Radiometric normalization of multispectral data was followed to minimize the effects of sensor calibration, solar elevation, atmospheric conditions and topography. The digital numbers were converted to radiance and the radiance was converted to Top-of-Atmosphere (TOA) reflectance or apparent reflectance. Radiometrically corrected Cartosat-1 mono and LISS-IV datasets were mosaicked after colour balancing. Data fusion of LISS IV data of 5.0 m resolution and Cartosat-1 data of 2.5m was carried out using Brovey method resulting in 2.5 m hybrid data characterized by the multispectral information content of LISS-IV and spatial information of Cartosat-1 data.

5.1.2 Field data collection

Field information on the lakes and its physical characteristics such as extent & type, survey no. contamination, usage etc. shared by KLCDA and EMPRI was used for preliminary interpretation. The field survey data consists of the following information: Lake name, village, Hobli & Taluka, Location of lakes and extent and Current status of lakes (Existing / non-existing). Field visits were carried out in 120 lakes by KLCDA and RRSC-South teams to physically verify the location and present status of the lakes and data was collected using “Namma Kere” mobile app. The geographic coordinates along with field photos were captured using mobile app and database on field information was created for subsequent analysis.

5.1.3 Inventory of Lakes

Standard image processing techniques using a combination of digital and visual interpretation methods have been used to analyze the spatiotemporal dynamics of urban lakes. Initially, the topographical maps at 1:50,000 scale has been used to generate thematic layers such as drainage, water bodies, transport network within study area and updated using on-screen visual interpretation of satellite data and DEM. Georeferenced cadastral maps available at SSLR online have been used for delineating the lake jurisdictional extent along with survey numbers. Corona space image of 1965 was used for interpreting lake boundary as manifested on the data and updated using 2014/2017 high resolution satellite data.

5.1.4 Spatio-temporal changes in lakes

Spatial analysis was carried out to analyze the change detection from 1965 to 2017. The extent of surface water has been used for identification and delineation of lake boundary due to typical spectral signature of water body characterized by high absorption at near infrared wavelengths and beyond, making water bodies appear as dark on remote sensing data. Further, the water body of urban lakes is contaminated by suspended sediments, industrial / sewage contaminants, pollutants, dissolved impurities etc. Besides this, the water is also infested with various types of aquatic weeds. The spectral signature of different urban lakes containing deep water, shallow water, turbid water, polluted water and weeds along with dry lakes as manifested on LISS-IV data were analyzed .

5.1.5 Drainage Network

Mapping and monitoring of natural drainage patterns along with lakes are very critical for understanding the impact of urbanization on surface hydrology. High resolution satellite data along with DEM was used for mapping natural drainages. Initially, the drainage network from the toposheets was digitized as polylines to generate a base data and subsequently updated using 1965 Corona data and ancillary data like toposheets, DEM, cadastral maps etc. The 1965 drainage network was overlaid on the 2017 satellite data for revision and finally two GIS layers were created for spatially depicting drainage network for 1965 and 2017 years and for change analysis. The streams have been ordered hierarchically starting from first order to higher orders depending on flow and connectivity. The heads of the streams were assigned first order and subsequent streams are considered as higher orders (Strahler, 1957, 1964).

5.1.6 Characterization and Prioritization of rural watersheds

A watershed is a hydrological unit from which the rain water flows into common point forming lakes, ponds and combines with other watersheds to form a network of rivers and streams that progressively drain into larger water areas. Watersheds may be classified into number of groups based on criteria like size, shape, drainage density, administrative and management. The existing watershed layer from the INDIA-WRIS has been extracted for the study area and revised based on 2017 satellite data. Delineation of watershed was carried out hierarchically from basin to micro-watershed level. Coding of watersheds has been done from the upstream to downstream direction. The hierarchical schema adopted in India-WRIS. Characterization and prioritization for the rural areas was carried out using conventional watershed approach using thematic layers(1:50,000) like slope, soil, land use / land cover, transport network, drainage & watershed, hydro-geomorphology and administrative boundary layers (Ramesh et al., 2001).

5.1.7 Water Spread Area of lakes

The lake water spread area is very important parameter for analyzing the current status and prioritization. Due to frequent cloud cover and overcast sky conditions during monsoon season, availability of optical data is limited and hence, data from microwave (SAR) satellites was used for mapping water spread area of lakes. The surface water of calm and open water bodies can be detected on a SAR image due to specular reflection with little backscatter, thus, water appearing as dark tone/ black colour on SAR image. Pre-processing of SAR data included radiometric calibration, speckle filtering using 5x5 Gamma MAP filter and orthorectification. Calibration of SAR data in terms of backscatter coefficient (Sigma Naught) was carried out for correction of radar backscatter due to variation in incidence angles. Finally, terrain geocoding was carried out to remove terrain induced distortions using DEM. Surface water spread extraction using SAR data was carried out using histogram-based approach following Valley Emphasis Method (Nguyen, 2016). The optimal threshold value for separating water bodies in the SAR image is calculated from the valley of two peaks in the bimodal histogram observed within lake boundary. Water spread area of lakes was extracted using the above approach and aggregated to generate total water spread area for each lake.

6. RESULTS AND DISCUSSION

Considering the rapid expansion of Bengaluru city in the last 2-3 decades, the project was implemented at two levels a) Catchment Area – extended study area covering ~4000 sq km and b) BDA Limits - Core study area covering ~1300 sq km - for systematic study of lakes and establishing a Standard Operating Procedure. Quality checking of the maps was carried out at two levels a) Internal QC by RRSC-S team and b) External QC by the team consisting of KLCDA, EMPRI and RRSC officials.

6.1 Delineation of Watersheds

The catchment area surrounding Bengaluru consists of two major basins, Pennar and Cauvery basin. It has two major sub-basins viz., Pennar Upper basin and Cauvery Middle Basin with seven major watersheds. The catchment area further divided into 56 sub-watersheds and the geographical area ranged from 43.0 to 108.0 sq. km. Out of 56 sub-watersheds, 9 are urban watersheds, 11 belong to semi-urban and rest are rural watersheds. Fig-2 depicts boundaries at basin, major and sub watershed levels covering the extended study area of about 4000 sq. km. The sub-watersheds are further subdivided into 481 micro-watersheds. The area of these micro-watersheds ranged from 2580 ha to 14860 ha. The micro-watersheds are grouped into urban (86), semi urban (105) and rural (290) watersheds based on the proportion of urban areas in each micro-watershed for subsequent analysis.

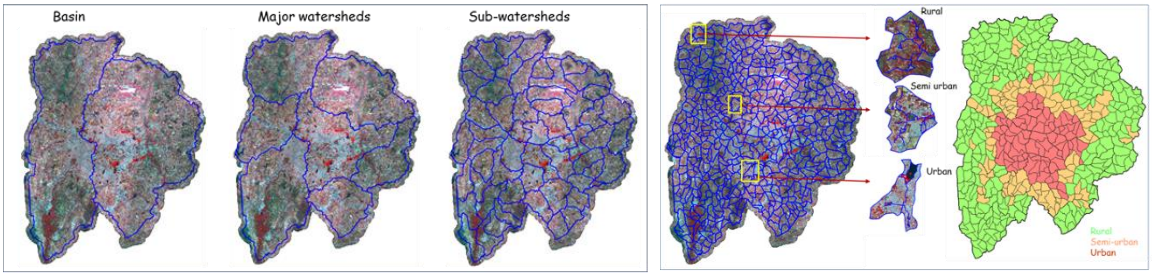


Figure 2. Watershed boundaries of the total catchment area

6.2 Inventory of lakes

Systematic inventory of lakes was carried out for the catchment area using Corona Space Image of 1965 and Cartosat-1+LISS-IV merged data of 2017 for analyzing the significant changes in time and space(Fig.3). As per the user request, lakes / tanks of more than 3.0 acres were considered in the project. Delineation of actual jurisdictional boundary of lakes is quite challenging due complex nature of urban lakes and spectral signature of water alone was not sufficient to demarcate lake boundary since most of the lakes are not fully covered with water. The spectral reflectance of clear water is quite low in all the three bands of LISS-IV data while reflectance was significantly higher for turbid water. The spectral signature aquatic weed was bright red to pinkish in color similar to the vegetation while spectral properties of dry lakes were similar to that of open land / fallow lands. The lake boundary for the catchment area represents the lake foot print / extent as seen from the satellite data and may not represent the actual lake boundary as defined in the cadastral maps with survey numbers. Thus, geographical area and extent of each lake may not exactly match with the jurisdictional boundary of lakes. Interpretation of some of lakes using satellite data alone was difficult due to large heterogeneity associated with urban lakes in terms of extent & depth of water, presence weeds, pollution, turbidity etc. However, use of collateral data such as topographical maps, drainage network and DEM played an important role for improved interpretation of lakes and resolving some of the challenges. The lakes are characterized by bund which helped in resolving the issue. Some of the lakes were completed infested with weeds or converted to plantations which caused problems in accurate delineation of the lake boundary. Many lakes are dry or partially filled with water during satellite data acquisition period

(February-March). The spectral signature of such lakes was similar to fallow / wasteland making interpretation challenging. Toposheets and cadastral maps helped in differentiating lakes from quarries with water. Some of the lakes were devoid of drainage connectivity during 2017. The total number of lakes, its extent and distribution along with geo-location was validated using the field data obtained from EMPRI. Finally, attribute data in terms of lake-id, name of village, hobli, taluk, extent, survey no and status was updated for each lake.

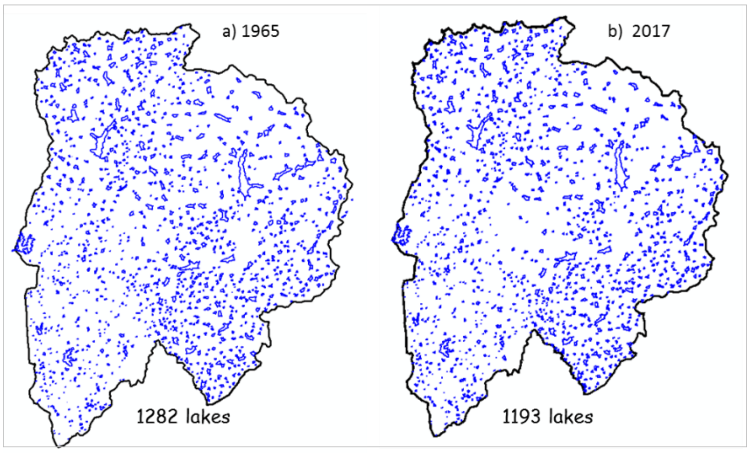


Figure 3. Spatial distribution of lakes a) as in 1965 and b) as in 2017

6.3 Spatio-temporal changes in lakes

About 1282 lakes were identified in Catchment area during 1965 using Corona Space Image and 1193 lakes during 2017 using LISS-IV + Cartosat-1 merged data (Table-1). The study revealed that about 116 lakes have been converted for different purposes indicating land use changes within the lake boundary. At the same time, about 27 lakes have been newly constructed after 1965 especially in the Bannerghatta forest area which is quite encouraging.

Table-1: Status of lakes during 1965 to 2017 in the Catchment area

S.N	Details	No of Lakes
1	No. of Lakes as on 1965 Corona Space Image	1282
2	No. of Lakes in 2017 L4+Cartosat-1 image	1191
3	New Lakes constructed after 1965	27
4	Lakes converted (non-existing as lakes in 2017)	116

The satellite data analysis revealed that about 484 lakes were present in BDA area during 1965 while 408 lakes during 2017 indicating significant land use changes in the lakes during last five decades.The list of lakes and temporal changes are provided in Table-2. The study revealed that about 86 lakes have been fully converted to different land use purpose after 1965 and 10 new lakes have been constructed after 1965. 16 lakes were converted even before 1965 indicating gradual loss of lakes in Bengaluru.

Table-2: Status of lakes as per cadastral map, 1965 to 2017 within BDA limits

S.N	Details	No of Lakes
1	No of lakes as per the Cadastral maps	500
2	No. of Lakes as on 1965 (as per Corona Space Image)	484
3	No. of Lakes in 2017 (as per L4+Cartosat-1 image)	407
4	No. of lakes converted before 1965 (Non-existing)	16
5	No. of lakes converted after 1965 (Non-existing)	86
6	New Lakes constructed after 1965	10

The temporal changes in lakes are spatially depicted in Fig-4. The degradation of lakes was quite significant in the core urban area due rapid urbanization and unplanned growth of Bengaluru city. However, conversion of lakes was also observed in the rural areas which is quite disturbing trend. Significant land use changes observed in the lakes are listed below.

- Change in size and shape of lakes resulting in significant reduction of lake foot print and geographical area
- Some of the lakes are fully or partially infested with aquatic weeds
- Change in land use within the lakes – some of lakes were fully or partially converted into built-up, parks, plantation, agriculture etc
- Construction of new lakes especially in the rural areas and Bannerghatta Reserved Forest area

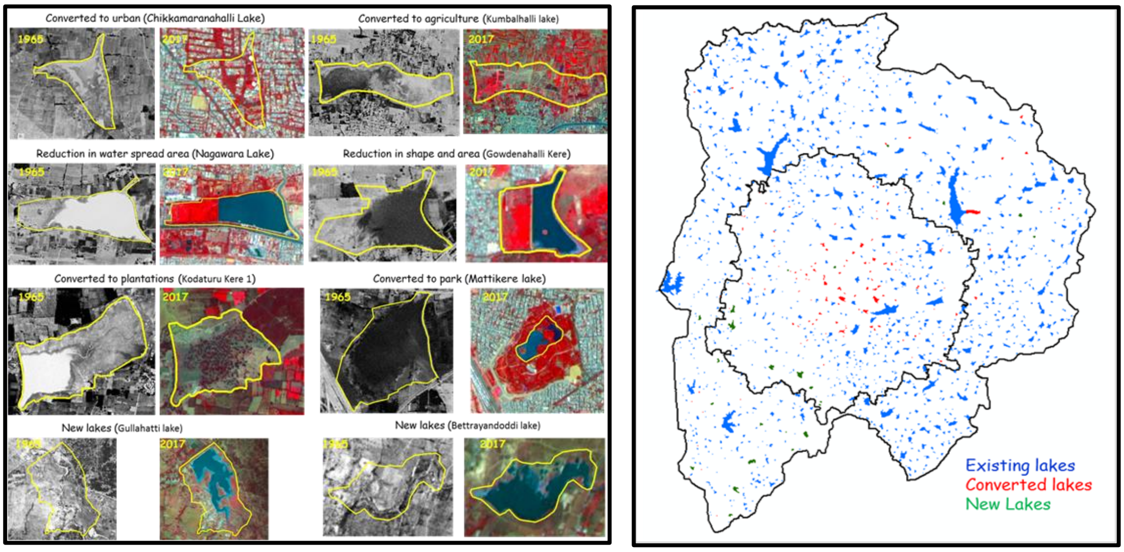


Figure 4. Spatio-temporal changes in lakes in the catchment area.

6.4 Drainage Network

The drainages are linear / curvy-linear features for carrying excess water and represent the valley regions. Sometimes they are lined with trees on both sides. The drainages take origin in relatively higher altitudes, hillocks or from ridge lines and they interconnect to lakes in the downstream. The drainage / stream course may be clearly seen in the semi-urban and rural areas while they may be lined in the urban areas and carry the sewage along the storm water. Visual interpretation of satellite data at 1:5000 scale along with ancillary data such as DEM, cadastral maps and toposheets were used for delineating the drainage pattern (Fig.5). Initially, drainage network was demarcated as polylines from Corona Space Image for creation of spatial database for 1965 with support from toposheets of 1:50,000 scale and updated using 2017 satellite data.

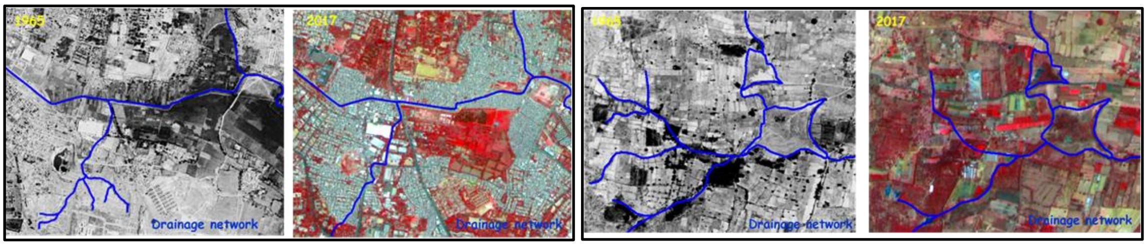


Figure 5. Typical drainage networks in urban and rural areas as interpreted from Satellite data

Some of challenges associated with satellite data interpretation for drainage network delineation are drainages are fully or partially covered with weeds / vegetation or lined with trees on both the sides,or, fully covered with concrete and thus, the drainages are not clearly discernible on satellite data. The existing transport network was used for better interpretation due to similar spectral signature of road and drainages observed in the urban areas due the lining of the storm water drainages.Toposheets and DEM were used where the first order streams and drains with smaller width were not clearly manifested on the satellite data.

6.5 Spatio-temporal changes in natural drainage network

Spatial patterns of drainage network and its connectivity to lakes are critical for the survival lakes. The drainage patterns as manifested on the satellite data of 1965 and 2017 covering the catchment area were mapped. The total length of natural drainage network in catchment area as interpreted from the HRS data were 4018.82 km and 3581.52 km during 1965 and 2017, respectively. Loss of drainage network from 1965 to 2017 was investigated in the catchment area using spatial analysis. The results indicated that the natural drainage length decreased by about 437.3 km from 1965 to 2017 in the catchment area(Fig.6) .The first order streams are most affected during the urbanization process followed by the second order streams. In general, third and higher order streams were not disturbed to large extent however; the some of the stream course have been remodelled to suite urban development.

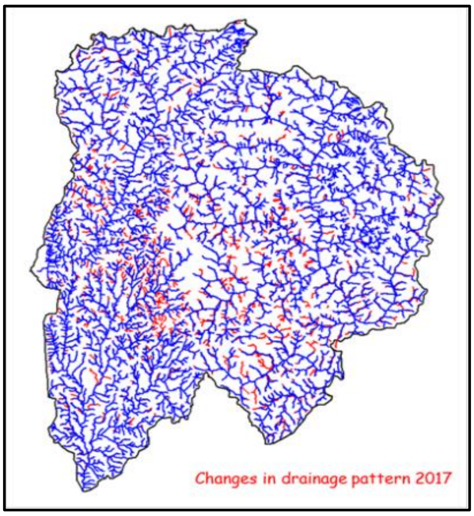


Figure 6. Loss of drainage network from 1965 to 2017

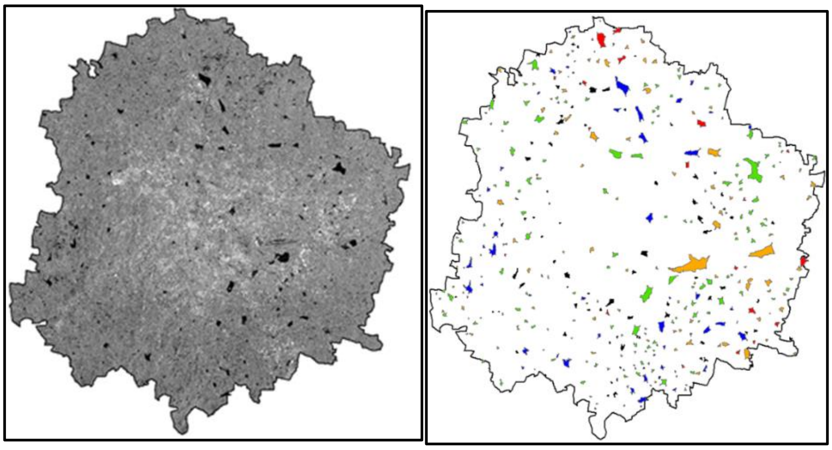
The total drainage length in BDA area was found to be 1647.5 and 1295.1 km for 1965 and 2017, respectively. The long-term changes in the drainage pattern was analyzed. The length of drains has significantly changed from 1965 to 2017 due to large scale urban development by the way of construction of large apartments, industrial establishments, layouts etc., within the BDA limits. The study revealed loss of about 325.4 km of drainage network in Bengaluru city from 1965 to 2017. Further study is essential for systematic analysis of natural drainage patterns and its inter-connectivity lakes / tanks for planning / remodelling of drainage network to prevent inundation during flash flood events as observed in the city during 2017 monsoon.

6.6 Prioritization of watersheds

The catchment consisted of 2 basins, 7 major watersheds, 56 subwatersheds and 481 micro-watersheds. The micro-watersheds are grouped into urban (86), semi urban (105) and rural (290) watersheds based on the proportion of urban areas. 290 watersheds falling in the rural areas of the study area were considered for prioritization using criteria-based approach (Ramesh et al., 2001). Based on the priority, the micro-watersheds were categorized into five classes: very high, high, medium, low and very low. The rural watersheds located along the main national trunk routes showed higher priority mainly due to developmental activities taking place in the region. Majority of the watersheds in the Pennar Basin showed medium to high priority due to disturbance in the natural resources of the region as a result of rapid urban growth leading to deterioration of watersheds. Majority of the watersheds falling in Cauvery Basin in the Western part of the catchment area showed relatively low priority due to lesser disturbance because of undulating terrain and minimal urban growth activities in the region. The study clearly indicated the requirement of various watershed treatments for improving the watershed conditions. Water conservation through check dams / percolation ponds/farm ponds, treatment of drainage lines, improvement in land use are some of the measures that could be adopted for improving the condition of watersheds in the region. Further, it was observed that the watersheds in peri-urban region were falling in the high priority category requiring immediate action to minimize deterioration and ranking could be decided based on the extent of urban areas within each watershed.

6.7 Surface Water Spread Area of Lakes

The Monsoon season of 2017 was wettest ever for Bengaluru city and recorded annual rainfall of about 1615.2 mm rainfall as compared to average annual rainfall of 859 mm. Due to incessant rains from mid-August to October 2017, the water spread area of the lakes was maximum. Five date Sentinel SAR data in VV and VH polarization corresponding to peak rainfall periods from August to November 2017 was used for delineating water spread area and the results were validated with optical data of November 2017. The backscatter value for water ranged from -26 to -20 dB in VH polarization while dry lakes showed higher backscatter of -15 to -12 dB. The water spread was extracted within each lake boundary using the Thresholding algorithm based on Valley Emphasis method. Water bodies covered with surface vegetation / weeds showed higher backscatter in comparison to open water which enabled delineation of water spread area. Based on proportion of water spread area to geographical area, the lakes were grouped into five categories Fig-7. The results indicated that 196 lakes have water spread area of at least 50 per cent or more to its geographical area. However, 79 lakes were dry or completely covered with weeds. The analysis revealed that some of the lakes are dry or partially filled with water inspite best monsoon season during 2017.



Water Spread to Geographical Area of Lakes (%)	Number of Lakes
0 – 10 %	79
10 – 25 %	34
25 – 50 %	99
50 – 75 %	145
75 – 100 %	51

Figure 7. SAR Image and Proportion of water spread area to Geographical area of lakes

6.8 Lake Information System Customized in QGIS

As per the user request, Lake Information System was implemented using an open source GIS package namely QGIS. Lake Information System was developed and implemented for storing and visualization of all geospatial layers including satellite image, GIS layers, field data and other ancillary information. QGIS is a widely used, popular, free and open-source cross-platform Geographic Information System (GIS) meeting user requirement. The software package allows the user to analyse and edit spatial information and supports numerous vector, raster, and database formats and functionalities. QGIS supports various formats such as shape files, coverages, geodatabase, dxf, MapInfo, PostGIS including Web Map Service. All the deliverables generated under the project was customized in QGIS environment to store visualize, analyze, edit and update the thematic layers.

7. CONCLUSIONS

In the present study, a geospatial database has been created for the study area comprising of catchment area and BDA limits for lakes and drainage pattern during 1965 and 2017 using historical satellite data in terms of inventory of lakes & drainage, spatio-temporal changes, water spread area and prioritization of rural watersheds. Temporal SAR data was used for mapping of surface water spread area of lakes. The study indicated gradual loss of natural drainage network and conversion of lakes due to continuous horizontal expansion of Bengaluru city and creation of urban infrastructure.

- Lakes (size >3.0 acres): As per the interpretation of satellite data, in catchment area, about 1282 lakes existed during 1965 which reduced to 1191 during 2017. 116 lakes were converted to various purposes during urban development phase of Bengaluru while 27 new lakes were constructed after 1965 especially in the Bannerghatta Reserved Forest.In BDA Area, About 500 lakes were existing as per the cadastral maps which reduced to 484 during 1965 and 407 during 2017. 86 lakes have been converted after 1965 while 10 new lakes were also constructed.
- Drainage Network: For Catchment area, the total length of natural drainage network during 1965 was 4018.82 km which decreased to 3581.52 km during 2017 showing reduction of 437.3 km. For BDA Area, the total length of natural drainage network was 1647.5 km and 1295.1 km during 1965 and 2017 respectively showing loss of 325.24 km.
- Prioritization: Criteria based watershed prioritization for 291 rural watersheds revealed that 69.8 per cent of watersheds belong to medium to very high priority while 30.2 per cent showed low priority. Majority of watersheds of Pennar basin showed higher priority requiring immediate action for restoration.
- Surface water spread area: 196 lakes showed more than 50 per cent surface water spread area during 2017 monsoon season. 113 lakes showed lakes showed less than 25 per cent water spread area inspite best monsoon season in 2017 requiring immediate attention while the rest are dry and completely occupied by weeds.

A reliable spatial data on lakes and drainage patterns serves as a valuable input to an integrated action plan in Conservation of lakes which are severely infested with aquatic weeds, Improve the urban drainage and ensure its connectivity to lake series, De-silting of lakes and ensuring connectivity of drains / streams to lakes, Treating the sewage and leaving the treated sewage to lakes , Watershed treatment for rural watersheds for conservation of natural resources and Setting up of STPs, prevention of dumping of solid, liquid and other bio-medical wastes to lakes. Additional investigations such as impact of urbanization, pollution, run off estimation and flood inundation are required for integrated development of lakes. Physical characterization of watersheds / lakes was carried out in the study and further investigation is required to collect lake chemical, biological, ecological and socio-economic parameters periodically to come out with integrated developmental plan for long term conservation of lakes. Periodic updation of database using satellite & ground-based observations and development of user-friendly Decision Support System is suggested for continuous monitoring of the lake systems by different stakeholders.

8. REFERENCES

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