Conservation and Management of Wetlands: Requisite Strategies

T. V. Ramachandra [1, 2, 3]

[1]Energy & Wetlands Research Group, Centre for Ecological Sciences,
&
[2]Centre for Sustainable Technologies,
[3]Centre for *infrastructure*, Sustainable Transportation and Urban Planning (C*i*STUP)
Indian Institute of Science
Bangalore – 560 012, INDIA

Tel: 91-80- 22933099/22933503 (extn 107)
Fax: 91-80-23601428/23600085/23600683[CES-TVR]
E-mail: cestvr@ces.iisc.ernet.in
energy@ces.iisc.ernet.in
http://ces.iisc.ernet.in/energy

Abstract

Wetlands constitute a vital component in our ecosystem. They aid in synthesising of nutrients and function as kidneys of the landscape. The rapid urbanisation trend consequent to unplanned developmental activities with burgeoning population has posed serious challenges in the regional planning and management involving plethora of issues like wetland conservation, infrastructure development, traffic congestion, basic amenities, etc. Issues such as water and food security, and clean environment have gained importance in recent times. Urban sprawl refers to the dispersed development along highways or surrounding a city and in rural countryside with implications such as loss of agricultural land, open space and ecologically sensitive habitats. Sprawl is thus a pattern and pace of land use in which the rate of land consumed for urban purposes exceeds the rate of population growth resulting in an inefficient and consumptive use of land and its associated resources. In this context, the holistic approaches in urban planning, and visualization of urban growth and its impact on natural resources has gained importance. The study unravels the pattern of growth in Greater Bangalore with driving factors and its implication on the natural resources (water, vegetation, energy), ecology and also on local climate, necessitating appropriate strategies for the sustainable management. Urbanisation has telling influences on the natural resources evident from the sharp decline in number of water bodies and also from depleting groundwater table. The talk would discuss the strategies to be adopted for the conservation and sustainable management of wetlands.

Bangalore is experiencing unprecedented urbanisation and sprawl in recent times due to concentrated developmental activities with impetus on industrialisation for the economic development of the region. This concentrated growth has resulted in the increase in population and consequent pressure on infrastructure, natural resources and ultimately giving rise to a plethora of serious challenges such as climate change, enhanced green-house gases emissions, lack of appropriate infrastructure, traffic congestion, and lack of basic amenities (electricity, water, and sanitation) in many localities, etc. This study shows that there has been a growth of 632% in urban areas of Greater Bangalore across 38 years (1973 to 2010). Urban heat island phenomenon is evident from large number of localities with higher local temperatures. The study unravels the pattern of growth in Greater Bangalore and its implication on local climate (an increase of ~2 to 2.5 ºC during the last decade) and also on the natural resources (76% decline in vegetation cover and 79% decline in water bodies), necessitating appropriate strategies for the sustainable management. The study reveals that frequent flooding (since 2000, even during normal rainfall) in Bangalore is a consequence of the increase in impervious area with the high-density urban development in the catchment and loss of wetlands and vegetation. This is coupled with lack of drainage upgrade works with the changes in enhanced run-offs, the encroachment and filling in the floodplain on the waterways, obstruction by the sewer pipes and manholes and relevant structures, deposits of building materials and solid wastes with subsequent blockage of the system and also flow restrictions from under capacity road crossings (bridge and culverts). The lack of planning and enforcement has resulted in significant narrowing of the waterways and filling in of the floodplain by illegal developments.

Keywords: Wetlands, Conservation, Mitigation, Spatial analysis, Urban floods

Introduction

Wetlands constitute vital components of the regional hydrological cycle. They are highly productive, support exceptionally large biological diversity, and provide a wide range of ecosystem services such as food, fibre, waste assimilation, water purification, flood mitigation, erosion control, groundwater recharge, microclimate regulation, enhance the aesthetics of the landscape, and support many significant recreational, social and cultural activities, aside from being a part of our cultural heritage. It was acknowledged that most urban wetlands are seriously threatened by conversion to non-wetland purposes, encroachment of drainage through landfilling, pollution (discharge of domestic and industrial effluents, disposal of solid wastes), hydrological alterations (water withdrawal and inflow changes), and over-exploitation of their natural resources. This results in loss of biodiversity and disruption in goods and services provided by wetlands (Ramachandra, 2009a,b,c; Ramachandra et al., 2012). Last section of this communication addresses the strategies considering the current trends in aquatic ecosystem conservation, restoration, and management including the hydrological and the biophysical aspects, peoples' participation and the role of non-governmental, educational, and governmental organisations and future research needs for the restoration, conservation, and management.

Urbanisation is a form of metropolitan growth that is a response to often-bewildering sets of economic, social, and political forces and to the physical geography of an area. It is the increase in the population of cities in proportion to the region's rural population. The 20^{th} century is witnessing "the rapid urbanisation of the world's population", as the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005 and is projected to rise to 60% (4.9 billion) by 2030 (UN, 2005). Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Ramachandra et al., 2012b; Ramachandra and Kumar, 2008). The process of urbanisation contributed by infrastructure initiatives, consequent population growth and migration results in the growth of villages into towns, towns into cities and cities into metros. Urbanisation and urban sprawl have posed serious challenges to the decision makers in the city planning and management process involving plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation), etc. (Kulkarni and Ramachandra, 2006). Apart from this, major implications of urbanisation are:

- **Loss of wetlands and green spaces:** Urbanisation has telling influences on the natural resources such as decline in green spaces (vegetation) including wetlands and / or depleting groundwater table (Ramachandra and Kumar 2008).
- **Floods:** Common consequences of urban development are increased peak discharge and an increased frequency of floods as land that was converted from fields or woodlands to roads and parking lots loses its ability to absorb rainfall. Conversion of water bodies to residential layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-rise buildings, removal of vegetative cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000 (Ramachandra et al., 2012a).
- **Decline in groundwater table:** Studies reveal the removal of water bodies has led to the decline in water table. Water table has declined to 300 m from 28 m over a period of 20 years after the reclamation of lake with its catchment for commercial activities. In addition, groundwater table in intensely urbanized area such as Whitefield, etc. has now dropped to 400 to 500m (Ramachandra et al., 2012a).
- **Heat island:** Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration (Ramachandra and Kumar, 2009).
- **Increased carbon footprint**: Due to the adoption of inappropriate building architecture, the consumption of electricity has increased in certain corporation wards drastically. The building design conducive to tropical climate would have reduced the dependence on electricity. Higher energy

consumption, enhanced pollution levels due to the increase of private vehicles, traffic bottlenecks have contributed to carbon emissions significantly (Ramachandra and Shwetmala, 2012). Apart from these, mismanagement of solid and liquid wastes has aggravated the situation.

Study Area

Greater Bangalore (77°37'19.54'' E and 12°59'09.76'' N), is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. With an area of 741 sq. km., Bangalore's city administrative jurisdiction was widened in 2006 by merging the existing area of Bangalore city spatial limits with 8 neighbouring Urban Local Bodies (ULBs), and 111 Villages of Bangalore Urban District (Ramachandra and Kumar, 2008; Sudhira *et al.*, 2003, 2007). Thus, Bangalore has grown spatially more than ten times since 1949 (69 square kilometres) and is a part of both the Bangalore urban and rural districts (figure 1.1). The mean annual total rainfall is about 880 mm with about 60 rainy days a year over the last ten years. The summer temperature ranges from 18° C – 38° C, while the winter temperature ranges from 12° C – 25° C. Thus, Bangalore enjoys a salubrious climate all-round the year. Bangalore is located at an altitude of 920 meters above mean sea level, delineating three watersheds, viz. Hebbal, Koramangala-Challaghatta and Vrishabhavathi watersheds (Figure 1.2). The undulating terrain in the region has facilitated creation of a large number of tanks providing for the traditional uses of irrigation, drinking, fishing, and washing. Bangalore had the distinction of having hundreds of water bodies through the centuries. Even in early second half of 20th century, in 1961, the number of lakes and tanks in the city stood at 262 (and spatial extent of Bangalore was 112 sq. km). However, number of lakes and tanks in 1985 was 81 (and spatial extent of Bangalore was 161 sq. km). This forms important drainage courses for the interconnected lake system (Figure 1.2), which carries storm water beyond the city limits. Bangalore, being a part of peninsular India, had the tradition of harvesting water through surface water bodies to meet the domestic water requirements in a decentralised way. After independence, the source of water for domestic and industrial purpose in Bangalore is mainly from the Cauvery River and ground water. Untreated sewage is let into the storm water drains, which progressively converge at the water bodies. Now, Bangalore is the fifth largest metropolis in India currently with a population of about 8.72 million as per the latest population census (figure 2). Population has increased from 410,987 (1941) to 4,130,288 (1991), 5,655,844 (2001) and 8,719,939 (2011). Spatial extent of the city has increased from 69 (1941) to 161 (1981), 226 (2001) and 745 (2011) sq.km. Due to the changes in the spatial extent of the city, the population density varies from 5956 (1941) to 18147 (1981), 25653 (1991), 25025 (2001) and 11704 (2011) persons per sq.km (Ramachandra et al., 2012b).

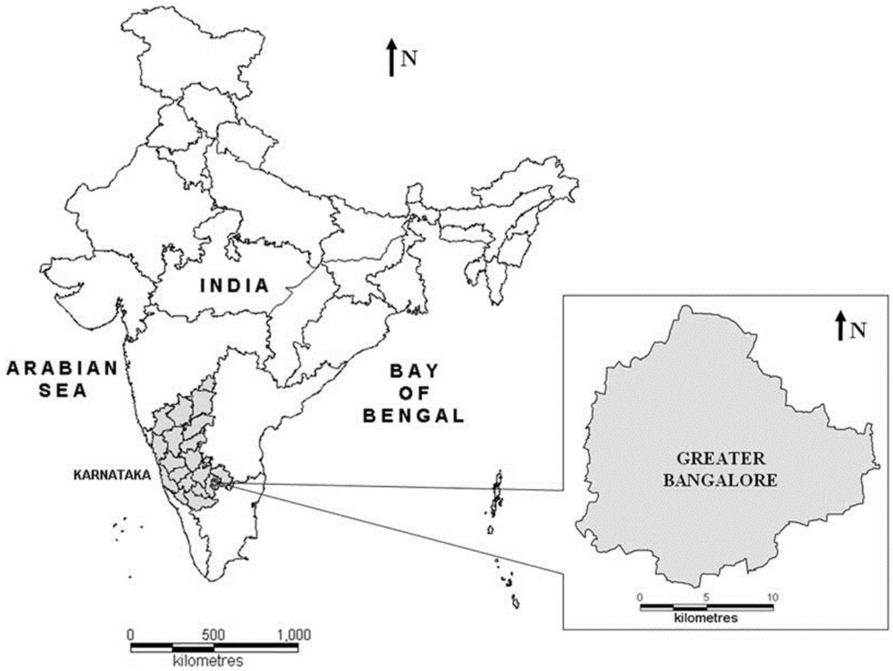


Figure 1.1: Study area – Greater Bangalore

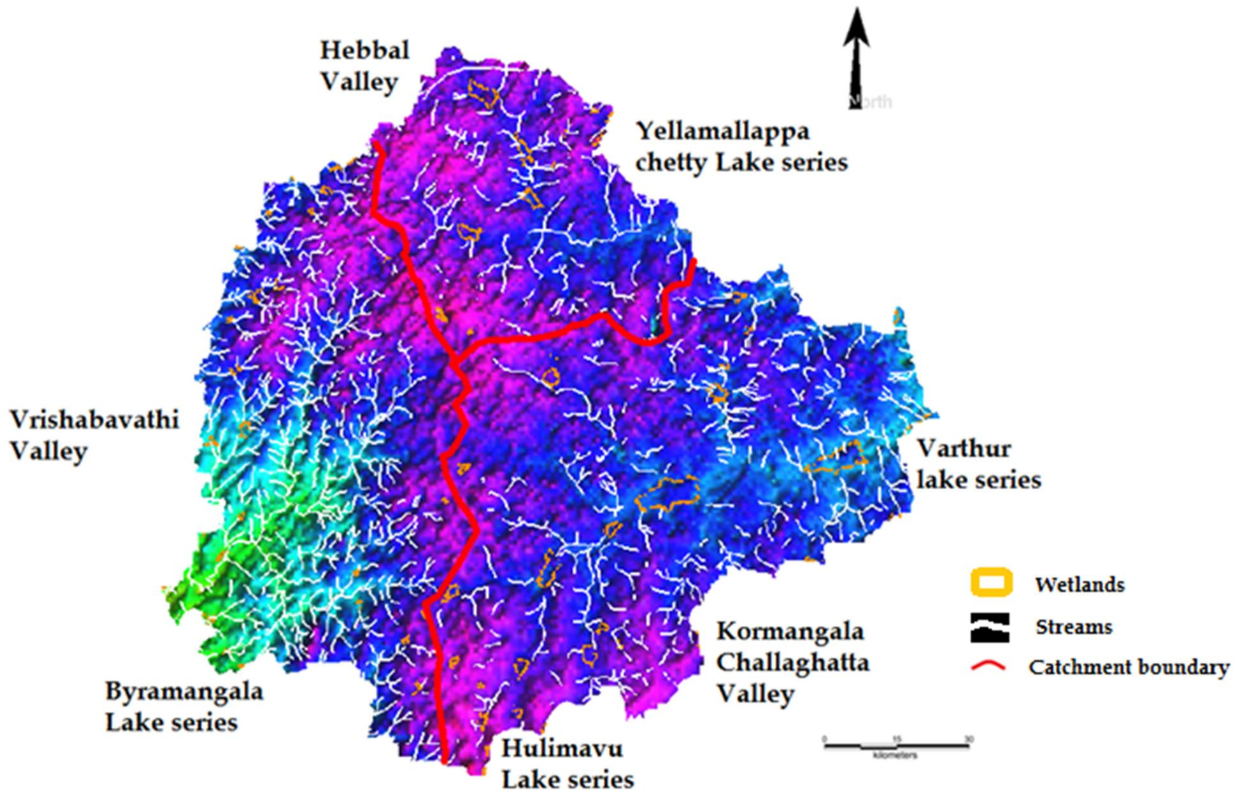


Figure 1.2: Watersheds (drainage with water bodies) of Greater Bangalore

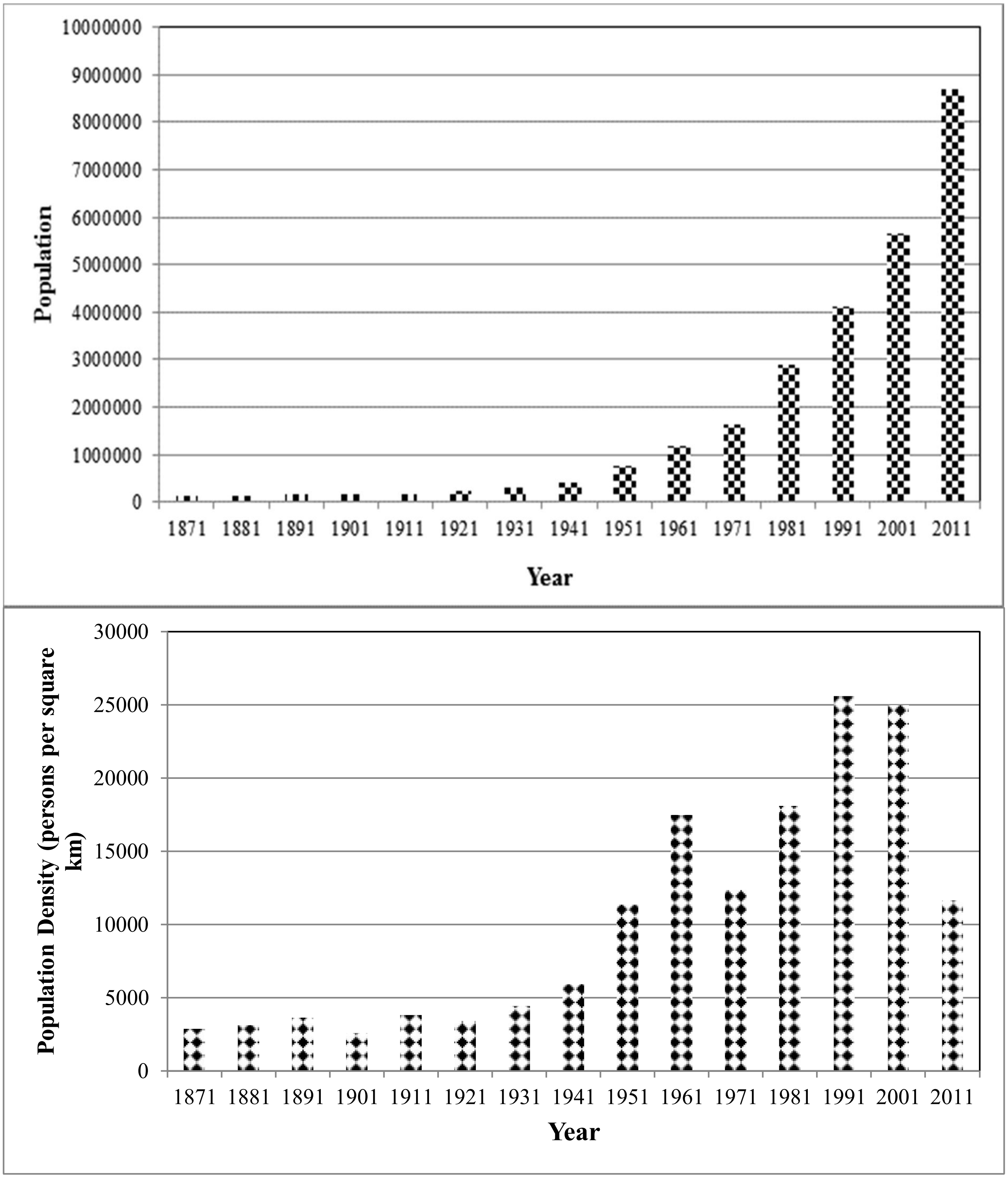


Figure 2: Population growth and population density

Materials and Methods

Data: Survey of India (SOI) toposheets of 1:50000 and 1:250000 scales were used to generate base layers. Field data was collected with a handheld GPS. The time series remote sensing data acquired from Landsat Series Multispectral sensor (57.5m) and Thematic mapper (28.5m) sensors for the period 1973 to 2010 and Landsat ETM+ (2000 and 2009) were downloaded from public domain (http://glcf.umiacs.umd.edu/data). Google Earth data (http://earth.google.com) served in pre and post classification process and validation of the results. Latest data for 2010 (IRS – Indian remote Sensing) was procured from the National remote Sensing Centre (http://www.nrsc.gov.in), Hyderabad. The methods adopted in the analysis involved:

- **Pre-processing of data:** The remote sensing data were geo-referenced, rectified, and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) was done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. Geo-referencing of acquired remote sensing data to latitude-longitude coordinate system with Evrst 56 datum: Landsat bands, IRS LISS-III MSS bands, MODIS bands 1 and 2 (spatial resolution 250 m) and bands 3 to 7 (spatial resolution 500 m) were geo-corrected with the known ground control points (GCP's) and projected to Polyconic with Evrst 1956 as the datum, followed by masking and cropping of the study area. The Landsat satellite 1973 images have a spatial resolution of 57.5 m x 57.5 m (nominal resolution) were resampled to 28.5m comparable to the 1989 - 2010 data that are 28.5 m x 28.5 m (nominal resolution). Landsat ETM+ bands of 2010 were corrected for the SLC-off by using image enhancement techniques, followed by nearest-neighbour interpolation. As the accuracy of the classified output of LANDSAT ETM+ was relatively low, the analysis for 2010 was repeated with IRS (LISS III) data procured from NRSC coinciding with the dates of field data collection.
- **Land use analysis:** The analyses of land use were carried out using supervised pattern classifier - Gaussian maximum likelihood classifier (GMLC) for Landsat and IRS data, and Bayesian Classifier (MODIS data). The method involves: i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth (latest as well as archived data), v) 60% of the training data has been used for

classification, while the balance is used for validation or accuracy assessment.

- Recent remote sensing data (2010) was classified using the collected training samples. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies. For earlier time data, training polygon along with attribute details were compiled from the historical published topographic maps, vegetation maps, revenue maps, etc.

- Normalised Difference Vegetation index (NDVI) was computed to understand the changes in the vegetation cover during the study period. NDVI is the most common measurement used for measuring vegetation cover. It ranges from values -1 to +1. Very low values of NDVI (-0.1 and below) correspond to soil or barren areas of rock, sand, or urban built-up. Zero indicates the water cover (Ramachandra and Kumar, 2009). Moderate values represent low-density vegetation (0.1 to 0.3), while high values indicate thick canopy vegetation (0.6 to 0.8).

- **Density Gradient Analysis:** Urbanisation pattern has not been uniform in all directions. To understand the pattern of growth *vis a vis* agents, the region has been divided into 4 zones based on directions - Northwest (NW), Northeast (NE), Southwest (SW), and Southeast (SE) respectively based on the Central pixel (Central Business district). Further, each zone was divided into concentric circle of incrementing radius of 1 km radius from the centre of the city that would help in visualizing and understanding the agents responsible for changes at local level. These regions are comparable to the administrative wards ranging from 67 to 1935 hectares. The growth of the urban areas in respective zones was monitored through the computation of urban density for different periods.

Results and Discussion

Land use analysis for the period 1973 to 2010 has been done using Gaussian maximum likelihood classifier and the temporal land use details are given in table 2. Figure 3.1 provides the land use in the region during the study period. Overall accuracy of the classification was 72% (1973), 75% (1992), 71% (1999), 80% (2002), 73% (2006), and 86% (2010) respectively. Land use analysis was done using the open source programs (i.gensig, i.class, and i.maxlik) of Geographic Resources Analysis Support System (http://wgbis.ces.iisc.ernet.in/ grass). From the classified raster maps, urban class was extracted and converted to vector representation for computation of precise area in hectares. There has been a 632% increase in built up area from 1973 to 2009 leading to a sharp decline of 79% area in water bodies in Greater Bangalore mostly attributing to intense urbanisation process. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973 to

1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) and 126.19% (2006 to 2010). Figure 4 shows Greater Bangalore with 207 water bodies (in 1973), which declined to 93 (in 2010). The rapid development of urban sprawl has many potentially detrimental effects including the loss of valuable agricultural and eco-sensitive (e.g. wetlands, forests) lands, enhanced energy consumption and greenhouse gas emissions from increasing private vehicle use (Ramachandra and Shwetmala, 2009). Vegetation has decreased by 32% (during 1973 to 1992), 38% (1992 to 2002) and 63% (2002 to 2010.

Disappearance of water bodies or sharp decline in the number of water bodies in Bangalore is mainly due to intense urbanisation and urban sprawl. Many lakes (54%) were encroached for illegal buildings. Field survey of all lakes (in 2007) shows that nearly 66% of lakes are sewage fed, 14% surrounded by slums and 72% showed loss of catchment area. In addition, lake catchments were used as dumping yards for either municipal solid waste or building debris (Ramachandra, 2009a). The surrounding of these lakes have illegal constructions of buildings and most of the times, slum dwellers occupy the adjoining areas. At many sites, water is used for washing and household activities and even fishing was observed at one of these sites. Multi-storied buildings have come up on some lake beds that have totally intervene the natural catchment flow leading to sharp decline and deteriorating quality of water bodies. This is correlated with the increase in built up area from the concentrated growth model focusing on Bangalore, adopted by the state machinery, affecting severely open spaces and in particular water bodies. Some of the lakes have been restored by the city corporation and the concerned authorities in recent times.

Study area was divided into concentric incrementing circles of 1 km radius (with respect to centroid or central business district) in each zone as shown in Figure 3.2. This illustrates radial pattern of urbanization for the period 1973 to 2010. In 1973, the growth was concentrated closer to the central business district and was minimal. In 1992, Bangalore grew intensely in the NW and SW zones. This growth can be attributed to the policy of industrialization consequent to the globalization during early 90's. Consequent to this, the industrial layouts came up in these areas specially in the NW and SW intensified the urban growth and as a result land was also acquired for housing and urban sprawl was noticed in others parts of the Bangalore. These phenomena intensified during post 2000 as the SE and NE Bangalore saw intense growth for development of IT and BT sectors. Subsequent to this, relaxation of FAR (Floor area ratio) in mid-2005, lead to the spurt in residential sectors, paved way for large scale conversion of land leading to intense urbanization in these localities. This also led to the compact growth at central core areas of Bangalore and sprawl at outskirts that are deprived of basic amenities. The gradient analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanization is intensifying from the city centre and has reached the periphery of the Greater Bangalore.

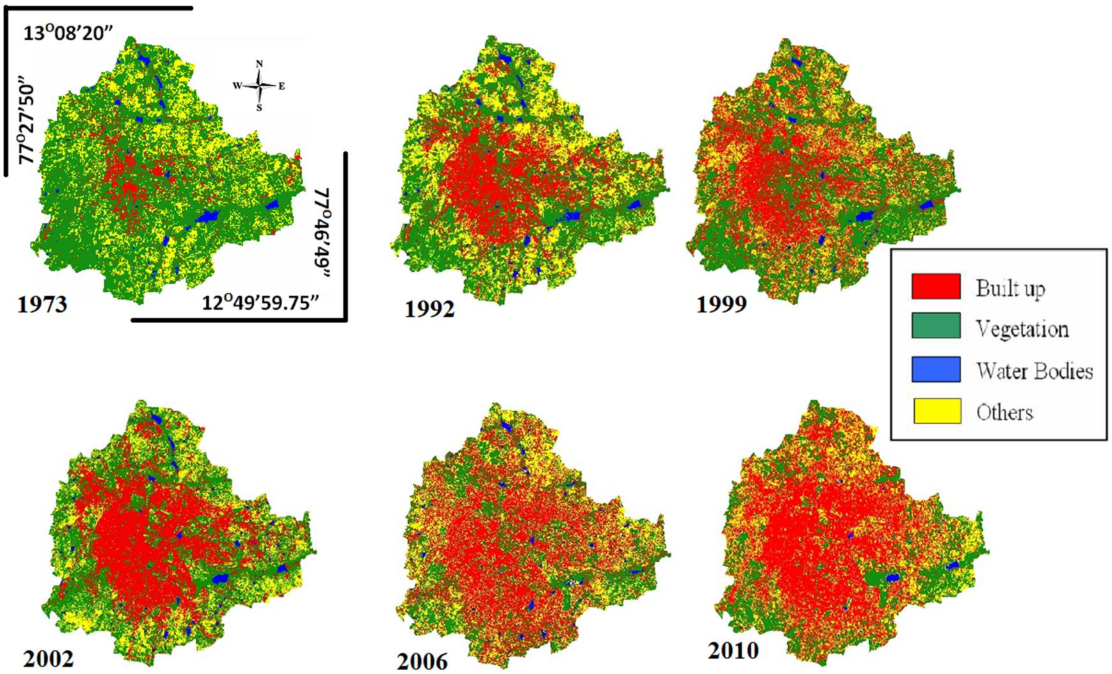


Figure 3.1: Greater Bangalore in 1973, 1992, 1999, 2002, 2006, and 2010

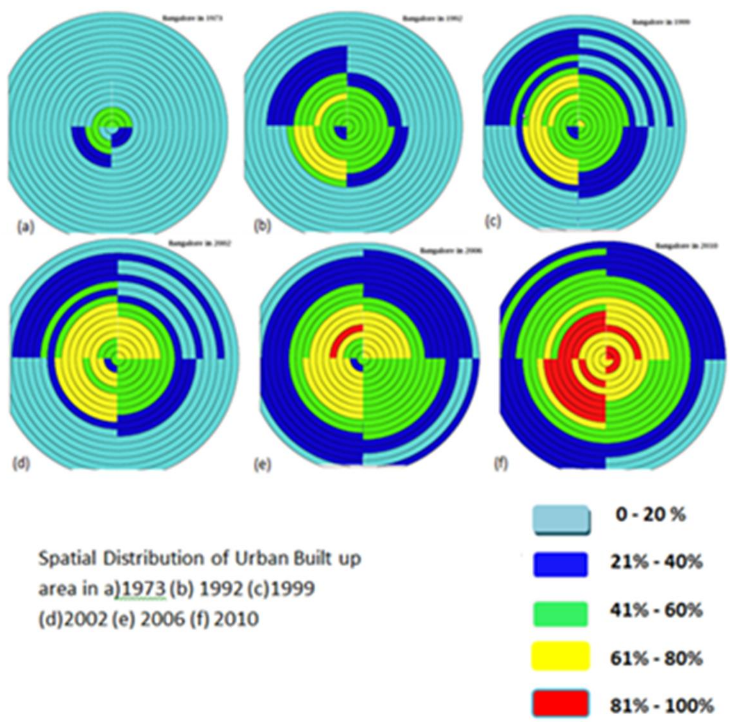
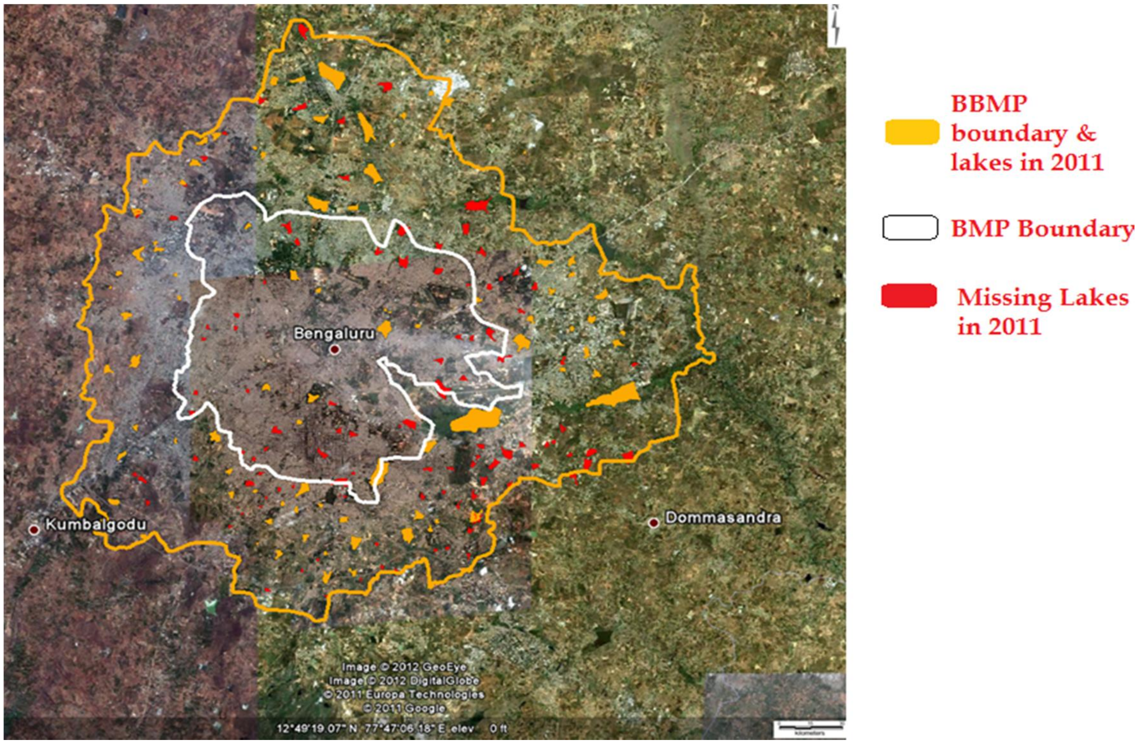


Figure 3.2: Gradient analysis of Greater Bangalore- Built-up density circle wise & zone wise from 1973 to 2010



Note -BMP: Bangalore Mahanagara Palike, BBMP: Bruhat Bangalore (Greater Bangalore) Mahanagara Palike

Figure 4: Greater Bangalore: 207 water bodies (1973), 93 water bodies (2010)
Erstwhile Bangalore city: 58 water bodies (1973), 10 water bodies (2010)

Table 2: Greater Bangalore LC statistics

Class →	Urban		Vegetation		Water		Others	
Year ↓	Ha	%	Ha	%	Ha	%	Ha	%
1973	5448	7.97	46639	68.27	2324	3.40	13903	20.35
1992	18650	27.30	31579	46.22	1790	2.60	16303	23.86
1999	24163	35.37	31272	45.77	1542	2.26	11346	16.61
2002	25782	37.75	26453	38.72	1263	1.84	14825	21.69
2006	29535	43.23	19696	28.83	1073	1.57	18017	26.37
2010	37266	54.42	16031	23.41	617	0.90	14565	21.27

Conservation and Management of Wetlands:

The loss of ecologically sensitive wetlands is due to the uncoordinated pattern of urban growth happening in Greater Bangalore. This could be attributed to a lack of good governance and decentralized administration evident from lack of coordination among many Para-state agencies, which has led to unsustainable use of the land and other resources. Failure to deal with water as a finite resource is leading to the unnecessary destruction of lakes and marshes that provide us with water. This failure in turn is threatening all options for the survival and security of plants, animals, humans, etc. There is an urgent need for:

- Restoring and conserving the actual source of water - the water cycle and the natural ecosystems that support it - are the basis for sustainable water management
- Reducing the environmental degradation that is preventing us from reaching goals of good public health, food security, and better livelihoods world-wide
- Improving the human quality of life that can be achieved in ways while maintaining and enhancing environmental quality
- Reducing greenhouse gases to avoid the dangerous effects of climate change is an integral part of protecting freshwater resources and ecosystems.

A comprehensive approach to water resource management is needed to address the myriad water quality problems that exist today from non-point and point sources as well as from catchment degradation. Watershed-based planning and resource management is a strategy for more effective protection and restoration of aquatic ecosystems and for protection of human health. The watershed approach emphasizes all aspects of water quality, including chemical water quality (e.g., toxins and conventional pollutants), physical water quality (e.g., temperature, flow, and circulation), habitat quality (e.g., stream channel morphology, substrate composition, riparian zone characteristics, catchment land cover), and biological health and biodiversity (e.g., species abundance, diversity, and range).

The suggestions for conserving and managing wetlands to mitigate frequent floods were as per the recommendations of Lake 2010: Wetlands, Biodiversity and Climate Change (22-24 December 2010) organized at the Satish Dhawan Auditorium, Indian Institute of Science, and Brainstorming session for evolving the strategies for the conservation and management of lakes (26th Sept 2009) at the Centre for Infrastructure, Sustainable Transport and Urban Planning [CiSTUP], Indian Institute of Science. Lake 2010 forum discussed the recommendations of Lake Symposiums (Lake 2008, Lake 2006, Lake 2004, Lake 2002, LimGIS 2001, Lake 2000, 1998 symposium) and Brainstorming Session (Ramachandra, 2009 a, b) apart from discussing the draft notification of the Regulatory Framework for Wetlands Conservation of The Ministry of Environment and Forests, Government of India. Policy interventions required in order to conserve fragile ecosystems – wetlands are:

1. **Carrying capacity studies for all macro cities:** to adopt holistic approaches in regional planning considering all

components (ecology, economic, social aspects) in rapidly urbanizing macro cities such as Greater Bangalore, etc.

2. **Demarcation of the boundary of water bodies:** The existing regulations pertaining to boundary demarcations within different states need to be reviewed according to updated norms and based on geomorphology and other scientific aspects pertaining to individual water bodies. Maximum Water Level mark should form the boundary line of the water body. The buffer zone should be treated as inviolable in the long-term interests of the water body and its biodiversity. This requires
   - Declare and maintain floodplains and valley zones of lakes as no activity regions
   - Remove all encroachments – free flood plains, valley zones, storm water drains, etc. of encroachments of any kind.
   - Ban conversion of lake, lakebed for any other purposes.
   - Urban wetlands, mostly lakes, have to be regulated from any type of encroachments.
   - Regulate the activity which interferes with the normal run-off and related ecological processes – in the buffer zone (200 m from lake boundary / flood plains is to be considered as buffer zone)

3. **Mapping of water-bodies:** The mapping of water bodies should also include smaller wetlands, springs etc. The neglect of these hydrological systems could cause considerable impoverishment of water flow in the river systems as well as turn out to be threats to rare kinds of biodiversity.

4. **Holistic and Integrated Approaches – Conservation and Management:** Integration of the activities with the common jurisdiction boundaries of Government Para-state Agencies for effective implementation of activities related to management, restoration, sustainable utilization, and conservation. This necessitates common jurisdictional boundary for all Para-state agencies. To minimise the confusion of ownership – assign the ownership of all natural resources (lakes, forests, etc.) to a single agency – **Lake Protection and Management Authority** (or Karnataka Forest Department). This agency shall be responsible for protection, development, and sustainable management of water bodies). There is a need to maintain catchment integrity to ensure lakes are perennial and maintain at least 33% land cover should be under natural Vegetation.

5. **Documentation of biodiversity:** The biodiversity of every water body should form part of the School, College, People's Biodiversity Registers (SBR, CBR, and PBR). The local Biodiversity Management Committees (BMC) should be given necessary financial support and scientific assistance in documentation of diversity. The presence of endemic, rare, endangered, or threatened species and economically important ones should be highlighted. A locally implementable

conservation plan has to be prepared for such species.

6. **Mitigation of Floods**: This entails maintenance of open spaces (vegetation, water bodies). Mitigation necessitates restoration of wetlands, removal of blockages in the drainage network, removal of encroachments (storm water drains, wetlands), prevention of indiscriminate disposal of solid waste (including building debris) in storm water drains, lake beds, catchment of wetlands and restoration of the connectivity of lakes.

7. **Preparation of management plans for individual water bodies:** Most large water bodies have unique individual characteristics. Therefore, it is necessary to prepare separate management plans for individual water bodies.

8. **Implementation of sanitation facilities:** It was noted with concern that the water bodies in most of India are badly polluted with sewage, coliform bacteria, and various other pathogens.

9. **Restoration of lakes:** The goals for restoration of aquatic ecosystems need to be realistic, and should be based on the concept of expected conditions for individual eco-regions. Further development of project selection and evaluation technology based on eco-region definitions and description should be encouraged and supported by the national and state government agencies.

10. **Protection of riparian and buffer zone vegetation:** Any clearances of riparian vegetation (alongside lakes) and buffer zone vegetation (around lakes) have to be prohibited.

11. **Restoration of linkages between water bodies:** The process of urbanization and neglect caused disruption of linkages between water bodies such as ancient lake systems of many cities. Wherever such disruptions have taken place, alternative arrangements should be provided to establish the lost linkages.

12. **Rainwater harvesting:** Intensive and comprehensive implementation of rainwater harvesting techniques can reduce taxation of water bodies and minimize electricity requirements. The country needs in principle a holistic rainwater harvesting policy aimed at directing water literally from "roof-tops to lakes" after catering to the domestic needs.

13. **Environment Education**: Lake Associations and citizen monitoring groups have proved helpful in educating the public. Effort should be made to ensure that such groups have accurate information about the causes of lake degradation and various restoration methods.

14. **Adopt Inter-disciplinary Approach**: Aquatic ecosystem conservation and management requires collaborated research involving natural, social, and inter-disciplinary study aimed at understanding various components, such

as monitoring of water quality, socio-economic dependency, biodiversity and other activities, as an indispensable tool for formulating long-term conservation strategies. This requires multidisciplinary-trained professionals who can spread the understanding of ecosystem's importance at local schools, colleges, and research institutions by initiating educational programmes aimed at raising the levels of public awareness of aquatic ecosystems' restoration, goals, and methods. Actively participating schools and colleges near the water bodies may value the opportunity to provide hands-on environmental education, which could entail setting up of laboratory facilities at the site. Regular monitoring of water bodies (with permanent laboratory facilities) would provide vital inputs for conservation and management.

Conclusion

Urbanisation and the consequent loss of lakes has led to decrease in catchment yield, water storage capacity, wetland area, number of migratory birds, flora and fauna diversity and ground water table. As land is converted, it loses its ability to absorb rainfall. The growth poles are towards N, NE, S and SE of the city indicating the intense urbanization process due to growth agents like setting up of IT corridors, industrial units, etc. Newly built-up areas in these regions consisted of maximum number of small-scale industries, IT companies, multi-storied building, and private houses that came up in the last one decade. The growth in northern direction can be attributed to the new International Airport, encouraging other commercial and residential hubs. The southern part of the city is experiencing new residential and commercial layouts and the north-western part of the city outgrowth corresponds to the Peenya industrial belt along with the Bangalore-Pune National Highway 4. Temporal land use analysis reveal that there has been a 632% increase in built up area from 1973 to 2009 leading to a sharp decline of 79% area in water bodies in Greater Bangalore mostly attributing to intense urbanisation process. The increase in urban built up area ranges from 342.83% (during 1973 to 1992), 129.56% (during 1992 to 1999), 106.7% (1999 to 2002), 114.51% (2002 to 2006) to 126.19% (2006 to 2010). Number of wetlands has declined from 207 (1973) to 93 (2010). The gradient analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanization is intensifying from the city centre and has reached the periphery of the Greater Bangalore.

Frequent flooding in the city is a consequence of the drastic increase in impervious area (of 632% in 4 decades) with the high-density urban developments. This is coupled with lack of drainage upgrade works with the changes in enhanced run-offs, the encroachment and filling in the floodplain on the waterways, obstruction by the sewer pipes and manholes and relevant structures, deposits of building materials and solid wastes with subsequent blockage of the system and also flow restrictions from under capacity road crossings (bridge and culverts). Increased peak discharge and higher frequency of floods are frequent at pockets with the intense urbanization, loss of lakes' interconnectivity, encroachment of storm water drains. The uncoordinated pattern of urban growth could be attributed to a lack of good governance and decentralized administration, which was evident from the lack of coordination among many Para-state agencies, which has led to unsustainable use of the land and other resources. The mitigation of frequent floods and the associated loss of human life and properties entail the restoration of interconnectivity among wetlands, restoration of wetlands (removal of encroachments), conservation, and sustainable management of wetlands

Acknowledgement

We thank the Ministry of Environment and Forests, Government of India, Indian Institute of Science and the NRDMS Division, the Ministry of Science and Technology, DST, Government of India for the sustained financial and infrastructure support to energy and wetlands research.

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