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World Wetlands Day

February 2nd marks the 44th year since the signing of the Ramsar Convention on Wetlands and World Wetlands Day.

Wetlands Abroad: Australia, India, and the Mediterranean

Advancing Green Infrastructure and the Green Economy

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Background image: Saratoga Springs, New York. Photo credit: Jim Newton, 2002

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Wetlands: Kidneys of Bangalore's Landscape

Unprecedented urbanization in Bangalore, the capital and urban center of India's Karnataka state, has resulted in a significant loss of wetlands and in the numerous human-health and environmental services they provide. An increase in flooding and reduction of wastewater treatment are among the many challenges facing India's changing landscape.

By T.V. Ramachandra and Bharath H. Aithal

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, fiber, and waste assimilation, water purification, flood mitigation, erosion control, groundwater recharge, and microclimate regulation. They also 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 overexploitation of their natural resources. This results in loss of biodiversity and disruption in goods and services provided by wetlands (Ramachandra, 2009). The 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 nongovernmental, educational, and governmental organizations, and future research needs for the restoration, conservation, and management of wetlands.

Urbanization is a form of metropolitan growth that is a response to an often-bewildering set 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 20th century is witnessing "the rapid urbanization 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 (U.N., 2005). Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Ramachandra et al. 2012; Ramachandra & Kumar 2008). The process of urbanization contributed by infrastructure initiatives, consequent population growth, and migration results in the growth of villages into towns, towns into cities, and cities into metros.

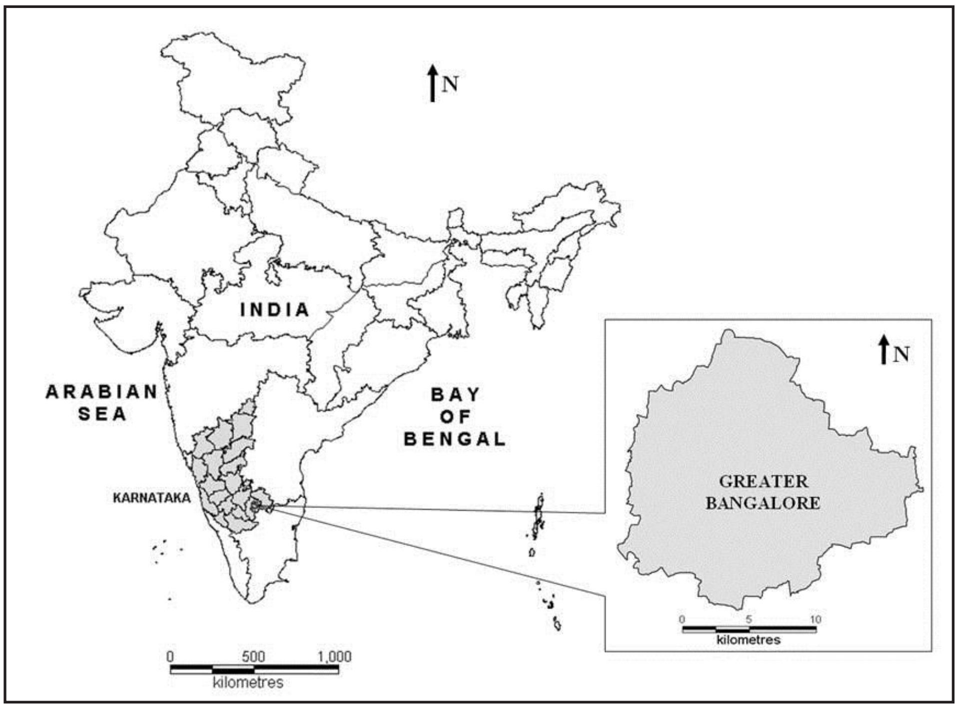

Figure 1: A map of the study area: Bangalore, Karnataka, India.

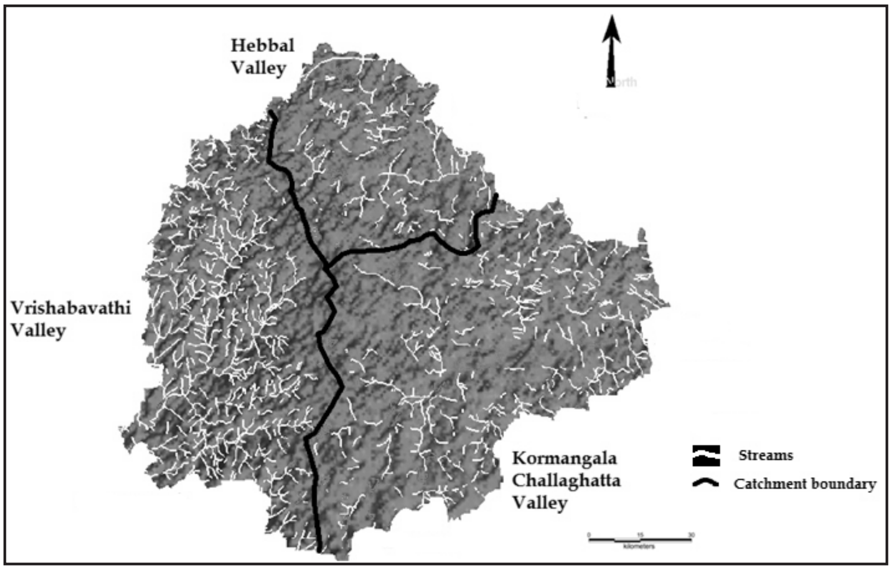

Figure 2: The watersheds, catchment boundaries, and streams of Bangalore.

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.

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, and traffic bottlenecks have contributed to carbon emissions significantly. Apart from these, mismanagement of solid and liquid wastes has aggravated the situation.

Urbanization and urban sprawl have posed serious challenges to the decisionmakers in the city planning and management process involving a plethora of issues like infrastructure development, traffic congestion, and basic amenities (electricity, water, and sanitation) (Kulkarni & Ramachandra 2006). Apart from this, major implications of urbanization are:

Loss of wetlands and green spaces: Urbanization has telling influences on the natural resources such as decline in green spaces (vegetation) including wetlands and/or depleting groundwater table. Quantification of trees in the region using remote sensing data with field census reveal 1.5 million trees and human population is 9.5 million, indicating one tree for seven persons in the city.

Floods: Conversion of wetlands 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, and reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post-2000.

Decline in groundwater table: Studies reveal the removal of wetlands has led to the decline in water table. The water table has declined to 300 meters (m) from 28 m over a period of 20 years after the reclamation of lakes with its catchment for commercial activities. In addition, groundwater table in intensely urbanized areas, such as Whitefield, has now dropped to 400-500 m.

Unplanned urbanization has drastically altered the drainage characteristics of natural catchments, or drainage areas, by increasing the volume and rate of surface runoff. Drainage systems are unable to cope with the increased volume of water, and are often blocked due to indiscriminate disposal of solid wastes. Encroachment of wetlands, floodplains, etc. obstructs flood-ways causing loss of natural flood storage.

Study Area

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 74 km^2, Bangalore's city administrative jurisdiction was widened in 2006 (Greater Bangalore) by merging the existing area of Bangalore city spatial limits with 8 neighboring Urban Local Bodies, and 111 Villages of Bangalore Urban District (Ramachandra & Kumar 2008; Ramachandra et al. 2012). Thus, Bangalore has grown spatially more than 10 times since 1949 (69 km^2) and is a part of both the Bangalore urban and rural districts (Figure 1). The mean annual total rainfall is approximately 880 mm, with about 60 rainy days per year over the last 10 years. The summer temperature ranges from 18°-38° C, while the winter temperature ranges from 12°-25° C. Bangalore is located at an altitude of 920 m above mean sea level, delineating three watersheds, viz. Hebbal, Koramangala-Challaghatta, and Vrishabhavathi Watersheds (Figure 2).

CLASS	Urban		Vegetation		Water		Other	
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

Table 1: Bangalore Land Change Statistics.

The undulating terrain in the region has facilitated the 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 the early second half of the 20th century, in 1961, the number of lakes and tanks in the city stood at 262 (and spatial extent of Bangalore was 112 kilometers squared (km^2). However, the number of lakes and tanks in 1985 was 81 (and spatial extent of Bangalore was 161 km^2). This forms important drainage courses for the interconnected lake system (Figure 2), which carries stormwater 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 decentralized way. After independence, the source of water for domestic and industrial purpose in Bangalore is mainly from the Cauvery River and groundwater. Untreated sewage is let into the stormwater 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. Spatial extent of the city has increased from 69 (1941) to 161 (1981), 226 (2001), and 745 (2011) km^2. Due to the changes in the spatial extent of the city, the population density varies from 5,956 (1941) to 18,147 (1981), 25,653 (1991), 25,025 (2001), and 11,704 (2011) persons per km^2.

Land use analyses were carried out using a supervised pattern classifier: Gaussian maximum likelihood classifier (GMLC) for Landsat and IRS data, and Bayesian Classifier (MODIS data). The method involved (Ramachandra et al. 2012): (1) generation of False Colour Composite (FCC) of remote sensing data (bands—green, red, and NIR). This helped in locating heterogeneous patches in the landscape; (2) 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; (3) loading these training polygons coordinates into pre-calibrated GPS; (4) 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); (5) supplementing this information with Google Earth (latest as well as archived data); (6) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land use analysis was carried out using the Geographic Resources Analysis Support System (GRASS) for the period 1973 to 2010 (see Table 1) and urban dynamics as illustrated in Figure 3. There has been a 632% increase in built-up area from 1973 to 2010, leading to a sharp decline of 79% area in water bodies in Bangalore mostly attributing to intense urbanization process. Analyses of the temporal data reveals an increase in urban built-up area of 342.83% (during 1973

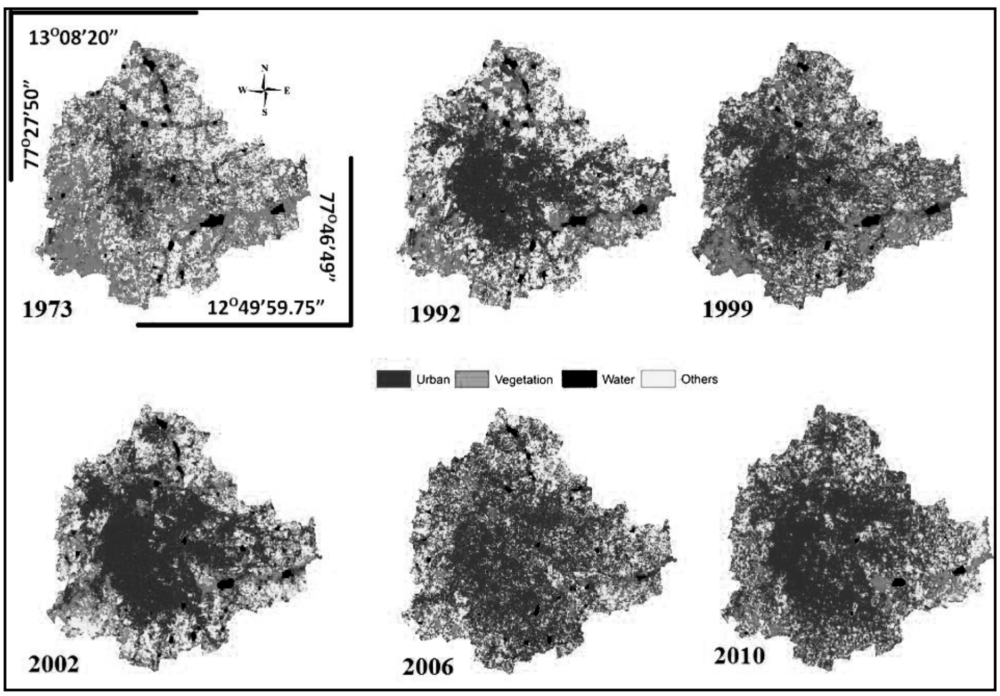

Figure 3: Bangalore land changes in 1973, 1992, 1999, 2002, 2006, and 2010.

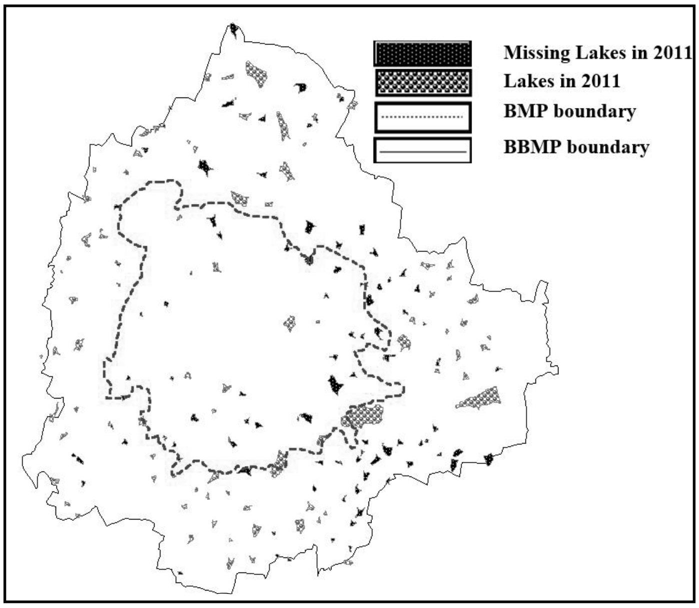

Figure 4: Bangalore with 207 water bodies (1973), 93 water bodies (2010). Erstwhile Bangalore city 58 water bodies (1973), 10 water bodies (2010).

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 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 & 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 urbanization 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 time, 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 lakebeds that have totally intervened 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

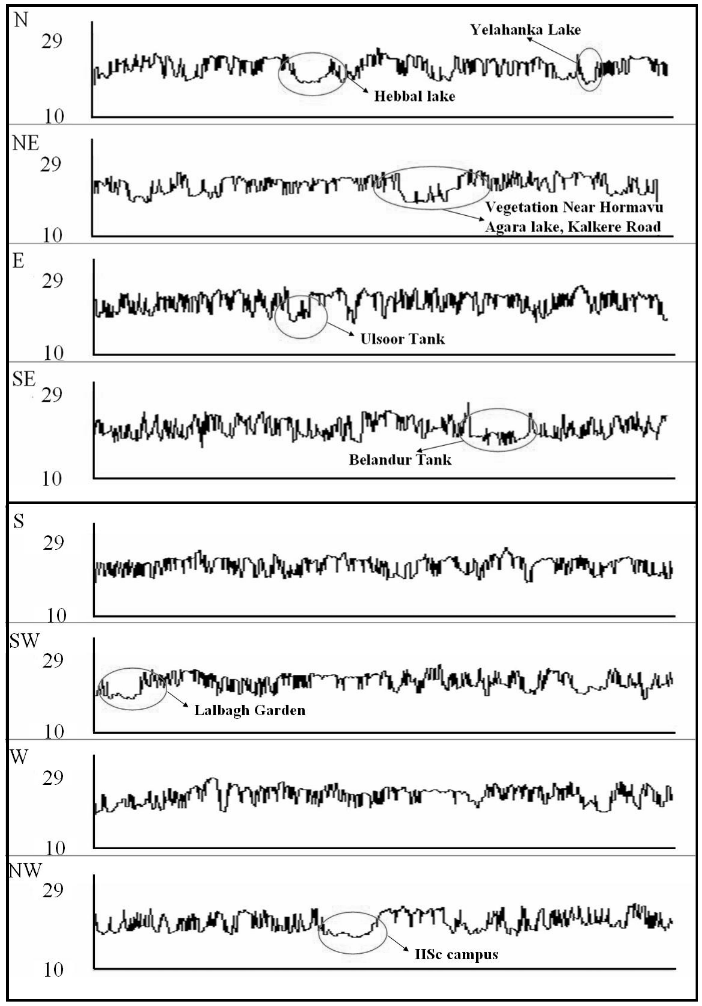

Figure 5: Temperature profile in various directions. X axis - Movement along the transacts from the city centre, Y-axis - Temperature (°C)

Bangalore, adopted by the state machinery, affecting severely open spaces and in particular water bodies. Some of the lakes have been restored in recent times by the city corporation and the concerned authorities.

The temperature profile plot fell below the mean when a vegetation patch or water body was encountered on the transact beginning from the centre of the city and moving outwards eight directions along the transact, as in Figure 5. It is evident that major natural green area and water bodies act as microclimate moderators responsible for lower temperature (marked with a circle in Figure 5).

Conservation and Management of Wetlands

The loss of ecologically sensitive wetlands is due to the uncoordinated pattern of urban growth happening in Bangalore. This is due to a lack of good governance and decentralized administration evident from a 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 worldwide.
- 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 nonpoint 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).

Conclusion

Urbanization and the consequent loss of lakes has led to a decrease in catchment yield, water storage capacity, wetland area, number of migratory birds, flora and fauna diversity, and groundwater table. Temporal land use analysis reveals 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 Bangalore mostly attributing to intense urbanization 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). The 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 Bangalore. The temperature profile analysis by overlaying the LST on the land use reveals higher temperatures in urban area, while vegetation and water bodies aided in moderating temperature at local levels (evident from at least 2 to 2.5° C lower temperature compared to urban pockets).

Frequent flooding in the city is a consequence of the drastic increase in impervious area (632% in four decades) and loss of wetlands (and interconnectivity of wetlands) with the high-density urban developments. The uncoordinated pattern of urban growth is 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. ■

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