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Insights to urban dynamics through landscape spatial pattern analysis

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ABSTRACT

Urbanisation is a dynamic complex phenomenon involving large scale changes in the land uses at local levels. Analyses of changes in land uses in urban environments provide a historical perspective of land use and give an opportunity to assess the spatial patterns, correlation, trends, rate and impacts of the change, which would help in better regional planning and good governance of the region. Main objective of this research is to quantify the urban dynamics using temporal remote sensing data with the help of well-established landscape metrics. Bangalore being one of the rapidly urbanising landscapes in India has been chosen for this investigation. Complex process of urban sprawl was modelled using spatio temporal analysis. Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. The Study area was divided into four zones and each zone is further divided into 17 concentric circles of 1 km incrementing radius to understand the patterns and extent of the urbanisation at local levels. The urban density gradient illustrates radial pattern of urbanisation for the period 1973–2010. Bangalore grew radially from 1973 to 2010 indicating that the urbanisation is intensifying from the central core and has reached the periphery of the Greater Bangalore. Shannon's entropy, alpha and beta population densities were computed to understand the level of urbanisation at local levels. Shannon's entropy values of recent time confirms dispersed haphazard urban growth in the city, particularly in the outskirts of the city. This also illustrates the extent of influence of drivers of urbanisation in various directions. Landscape metrics provided in depth knowledge about the sprawl. Principal component analysis helped in prioritizing the metrics for detailed analyses. The results clearly indicates that whole landscape is aggregating to a large patch in 2010 as compared to earlier years which was dominated by several small patches. The large scale conversion of small patches to large single patch can be seen from 2006 to 2010. In the year 2010 patches are maximally aggregated indicating that the city is becoming more compact and more urbanised in recent years. Bangalore was the most sought after destination for its climatic condition and the availability of various facilities (land availability, economy, political factors) compared to other cities. The growth into a single urban patch can be attributed to rapid urbanisation coupled with the industrialisation. Monitoring of growth through landscape metrics helps to maintain and manage the natural resources.

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1. Introduction

Urbanisation and Urban Sprawl: Urbanisation is a dynamic process involving changes in vast expanse of land cover with the progressive concentration of human population. The process entails switch from spread out pattern of human settlements to compact growth in urban centres. Rapidly urbanising landscapes attains inordinately large population size leading to gradual collapse in the urban services evident from the basic problems in housing, slum, lack of treated water supply, inadequate infrastructure, higher pollution levels, poor quality of life, etc. Urbanisation is a product of demographic explosion and poverty induced rural-urban migration. Globalisation, liberalization, privatization are the agents fuelling urbanisation in most parts of India. However, unplanned urbanisation coupled with the lack of holistic approaches, is leading to lack of infrastructure and basic amenities.

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Hence proper urban planning with operational, developmental and restorative strategies is required to ensure the sustainable management of natural resources.

Urban dynamics involving large scale changes in the land use depend on (i) nature of land use and (ii) the level of spatial accumulation. Nature of land use depends on the activities that are taking place in the region while the level of spatial accumulation depends on the intensity and concentration. Central areas have a high level of spatial accumulation of urban land use (as in the CBD: Central Business District), while peripheral areas have lower levels of accumulation. Most economic, social or cultural activities imply a multitude of functions, such as production, consumption and distribution. These functions take place at specific locations depending on the nature of activities – industries, institutions, etc.

Unplanned growth would involve radical land use conversion of forests, surface water bodies, etc. with the irretrievable loss of ground prospects (Pathan et al., 1989, 1991, 1993, 2004). The process of urbanisation could be either in the form of townships or unplanned or organic. Many organic towns in India are now influencing large-scale infrastructure development, etc. Due to the impetus from the National government through development schemes such as JNNURM (Jawaharlal Nehru National Urban Renewal Mission), etc. The focus is on the fast track development through an efficient infrastructure and delivery mechanisms, community participation, etc.

The urban population in India is growing at about 2.3% per annum with the global urban population increasing from 13% (220 million in 1900) to 49% (3.2 billion, in 2005) and is projected to escalate to 60% (4.9 billion) by 2030 (Ramachandra and Kumar, 2008; World Urbanisation Prospects, 2005). The increase in urban population in response to the growth in urban areas is mainly due to migration. There are 48 urban agglomerations/cities having a population of more than one million in India (in 2011).

Urbanisation often leads to the dispersed haphazard development in the outskirts, which is often referred as sprawl. Thus urban sprawl is a consequence of social and economic development of a certain region under certain circumstances. This phenomenon is also defined as an uncontrolled, scattered suburban development that depletes local resources due to large scale land use changes involving the conversion of open spaces (water bodies, parks, etc.) while increasing carbon footprint through the spurt in anthropogenic activities and congestion in the city (Peiser, 2001; Ramachandra and Kumar, 2009). Urban sprawl increasingly has become a major issue facing many metropolitan areas. Due to lack of visualization of sprawl a priori, these regions are devoid of any infrastructure and basic amenities (like supply of treated water, electricity, sanitation facilities). Also these regions are normally left out in all government surveys (even in national population census), as this cannot be grouped under either urban or rural area. Understanding this kind of growth is very crucial in order to provide basic amenities and more importantly the sustainable management of local natural resources through decentralized regional planning.

Urban sprawl has been captured indirectly through socioeconomic indicators such as population growth, employment opportunity, number of commercial establishments, etc. (Brueckner, 2000; Lucy and Philips, 2001). However, these techniques cannot effectively identify the impacts of urban sprawl in a spatial context. In this context, availability of spatial data at regular interval through space-borne remote sensors are helpful in effectively detecting and monitoring rapid land use changes (e.g., Chen et al., 2000; Epstein et al., 2002; Ji et al., 2001; Lo and Yang, 2002; Dietzel et al., 2005). Urban sprawl is characterised based on various indicators such as growth, social, aesthetic, decentralisation, accessibility, density, open space, dynamics, costs, benefits, etc. (Bhatta, 2009a,b, 2010). Further, Galster et al. (2001), has identified parameters such as density, continuity, concentration, clustering, centrality, nuclearity, proximity and mixed uses for quantifying sprawl. Urbanisation and sprawl analysis would help the regional planners and decision makers to visualize growth patterns and plan to facilitate various infrastructure facilities. In the context of rapid urban growth, development should be planned and properly monitored to maintain internal equilibrium through sustainable management of natural resources. Internal equilibrium refers to the urban system and its dynamics evolving harmony and thus internally limiting impacts on the natural environment consequent to various economic activities with the enhanced growth of population, infra-structure, services, pollution, waste, etc. (Barredo and Demicheli, 2003). Due to globalisation process, the cities and towns in India are experiencing rapid urbanisation consequently lacking appropriate infrastructure and basic amenities. Thus understanding the urban dynamics considering social and economic changes is a major challenge. The social and economic dynamics trigger the change processes in urban places of different sizes ranging from large metropolises, cities and small towns. In this context, the

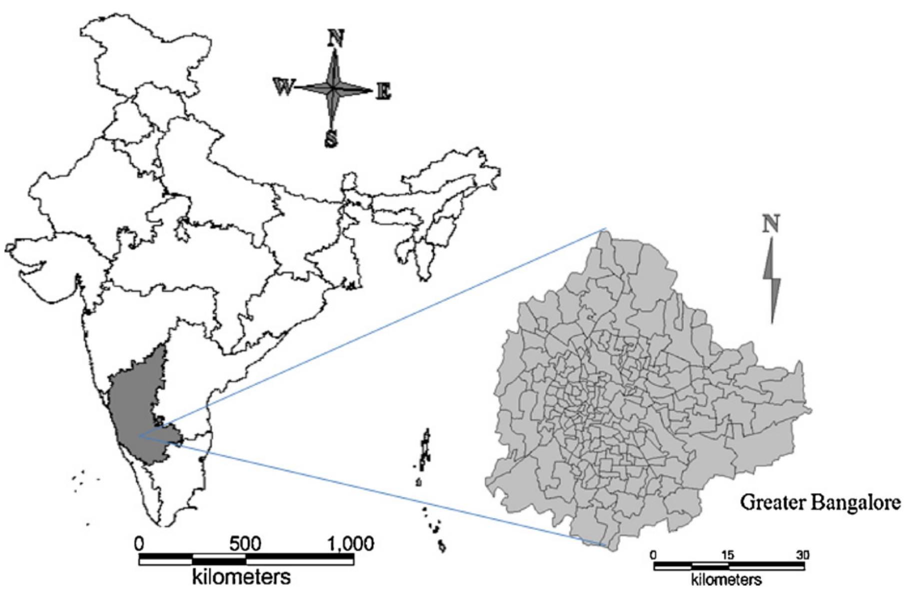

Fig. 1. Study area: Greater Bangalore.

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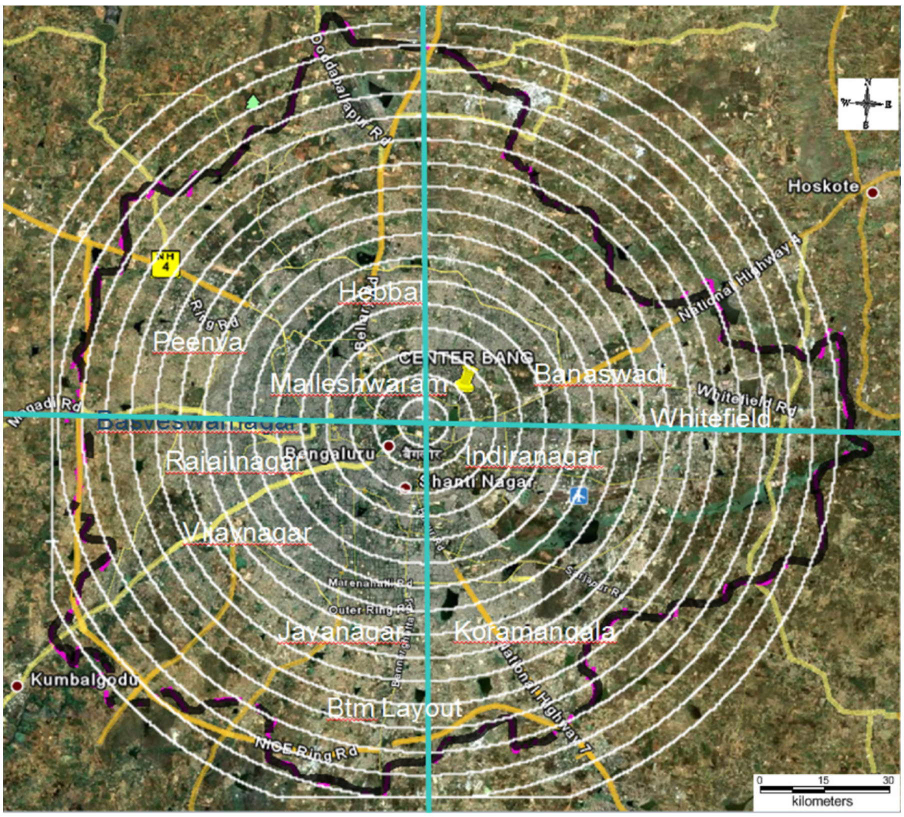
Table 1
Materials used in the analysis.

Data	Year	Purpose
Landsat Series Multispectral sensor (57.5 m)	1973	Land use analysis
Landsat Series Thematic mapper (28.5 m) and enhanced thematic mapper sensors	1992, 1999, 2002, 2006, 2010	Land use analysis
Survey of India (SOI) toposheets of 1:50,000 and 1:250,000 scales		Boundary and base layers
Census data	2001	Population density ward-wise

analysis of urban dynamics entails capturing and analyzing the process of changes spatially and temporally (Sudhira et al., 2004; Tian et al., 2005; Yu and Ng, 2007).

Land use Analysis and Gradient approach: The basic information about the current and historical land cover and land use plays a major role in urban planning and management (Zhang et al., 2002). Land-cover essentially indicates the feature present on the land surface (Janssen, 2000; Lillesand and Kiefer, 2002; Sudhira et al., 2004). Land use relates to human activity/economic activity on piece of land under consideration (Janssen, 2000; Lillesand and Kiefer, 2002; Sudhira et al., 2004). This analysis provides various uses of land as urban, agriculture, forest, plantation, etc., specified as per USGS classification system (http://landcover.usgs.gov/pdf/anderson.pdf) and National Remote Sensing Centre, India (http://www.nrsc.gov.in). Mapping landscapes on temporal scale provide an opportunity to monitor the changes, which is important for natural resource management and sustainable planning activities. In this regard, "Density Gradient metrics" with the time series spatial data analysis are potentially useful in measuring urbanisation and sprawl (Torrens and Alberti, 2000). Density gradient metrics include sprawl density gradient, Shannon's entropy, alpha and beta population densities, etc. This paper presents temporal land use analysis for rapidly urbanising Bangalore and density gradient metrics have been computed to evaluate and monitor urban dynamics. Landscape dynamics have been unraveled from temporally discrete data (remote sensing data) through spatial metrics (Crews-Meyer, 2002). Landscape metrics (longitudinal data) integrated with the conventional change detection techniques would help in monitoring land use changes (Rainis, 2003). This has been demonstrated through the application in many regions (Kienast, 1993; Luque et al., 1994; Simpson et al., 1994; Thibault and Zipperer, 1994; Hulshoff, 1995; Medley et al., 1995; Zheng et al., 1997; Palang et al., 1998; Sachs et al., 1998; Pan et al., 1999; Lausch and Herzog, 1999).

Further, landscape metrics were computed to quantify the patterns of urban dynamics, which helps in quantifying spatial patterns of various land cover features in the region (McGarigal and Marks, 1995) and has been used effectively to capture urban dynamics similar to the applications in landscape ecology (Gustafson, 1998; Turner et al., 2001) for describing ecological relationships such as connectivity and adjacency of habitat reservoirs (Geri et al., 2010; Jim and Chen, 2009). Herold et al. (2002, 2003) quantifies urban land use dynamics using remote sensing data and landscape metrics in conjunction with the spatial modelling of urban growth. Angel et al. (2007) have considered five metrics for measuring the sprawl and five attributes for characterizing the type of sprawl. Spatial metrics were used for effective characterisation of the sprawl by quantifying landscape attributes (shape, complexity,



Source: Google earth

Fig. 2. Division of the study area into concentric circles of incrementing radius of 1 km.

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Table 2
Prioritised landscape metrics.

	Indicators	Type of metrics and formula	Range	Significance/description
1	Number of urban patches	Patch metrics NPU = n NP equals the number of patches in the landscape	NPU > 0, without limit	Higher the value more the fragmentation
2	Perimeter Area Weighted Mean Ratio. PARA_AM	*Edge metrics* PARA _AM = P_{ij}/A_{ij} P_{ij} = perimeter of patch ij A_{ij} = area weighted mean of patch ij $\mathrm{AM} = \sum_{j=1}^{n} x_{ij}\left[\left(\frac{a_{ij}}{\sum_{j=1}^{a} a_{ij}}\right)\right]$	≥0, without limit	PARA AM is a measure of the amount of 'edge' for a landscape or class. PARA AM value increases with increasing patch shape complexity
3	Landscape Shape Index (LSI)	Shape Metrics $\mathrm{LSI} = \frac{e_i}{\min e_i}$ e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i = minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces (see below)	LSI > 1, without limit	LSI = 1 when the landscape is a single square or maximally compact patch; LSI increases without limit as the patch type becomes more disaggregated
4.	Clumpiness	Compactness/contagion/dispersion metrics $\mathrm{CLUMPY} = \left[\begin{matrix} \frac{G_i - P_i}{P_i} & \text{for} \quad G_i < P_i \& P_i < 5,\ \text{else} \\ \frac{G_i - P_i}{1 - P_i} & \end{matrix}\right]$ $G_i = \left(\frac{g_{ii}}{\sum_{k=1}^{m} g_{ii}} - \min e_i\right)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) I based on the *double-count* method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method. min − e_i = minimum perimeter (in number of cell surfaces) of patch type (class) i for a maximally clumped class. P_i = proportion of the landscape occupied by patch type (class) i	−1≤ CLUMPY ≤1	It equals 0 when the patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated
5.	Aggregation index	Compactness/contagion/dispersion metrics $AI = \left[\sum_{i=1}^{m}\left(\frac{g_{ii}}{\max \rightarrow g_{ii}}\right) P_i\right] \times 100$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of patch type class i based on single count method. P_i = proportion of landscape comprised of patch type (class) i.	1≤AI≤100	AI equals 1 when the patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch.
6.	Interspersion and Juxtaposition	Compactness/contagion/dispersion metrics $\mathrm{IJI} = \frac{-\sum_{i=1}^{m}\sum_{k=i+1}^{m}[(e_{ik}/E)\ln(e_{ik}/E)]}{\ln(0.5[m(m-1)])} \times 100$ e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k. E = total length (m) of edge in landscape, excluding background m = number of patch types (classes) present in the landscape, including the landscape border, if present.	0 ≤ IJI ≤ 100	IJI is used to measure patch adjacency. IJI approach 0 when distribution of adjacencies among unique patch types becomes increasingly uneven; is equal to 100 when all patch types are equally adjacent to all other patch types

etc.). Jiang et al. (2007) used 13 geospatial indices for measuring the sprawl in Beijing and proposed an urban Sprawl Index combining all indices. This approach reduces computation and interpretation time and effort. However, this approach requires extensive data such as population, GDP, land-use maps, floor-area ratio, maps of roadways/highways, urban city center spatial maps, etc. This confirms that landscape metrics aid as important mathematical tool for characterising urban sprawl efficiently. Population data along with geospatial indices help to characterise the sprawl (Ji et al., 2006) as population is one of the causal factor driving land use changes. These studies confirm that spatio-temporal data along with landscape metrics, population metrics and urban modelling would help in understanding and evaluating the spatio temporal patterns of urban dynamics.

2. Objective

The objective of this study is to understand the urbanisation and urban sprawl process in a rapidly urbanising landscape, through spatial techniques involving temporal remote sensing data, geographic information system with spatial metrics. This involved (i) temporal analysis of land use pattern, (ii) exploring interconnection and effectiveness of population indices, Shannon's entropy for quantifying and understanding urbanisation and (iii) understanding the spatial patterns of urbanisation at landscape level through metrics.

3. Study area

The study has been carried out for a rapidly urbanising region in India. Greater Bangalore is the administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India with an area of 741 sq km and lies between the latitude 12°39′00″ to 13°13′00″N and longitude 77°22′00″ to 77°52′00″E. Bangalore city administrative jurisdiction was redefined in the year 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. Bangalore has grown spatially more

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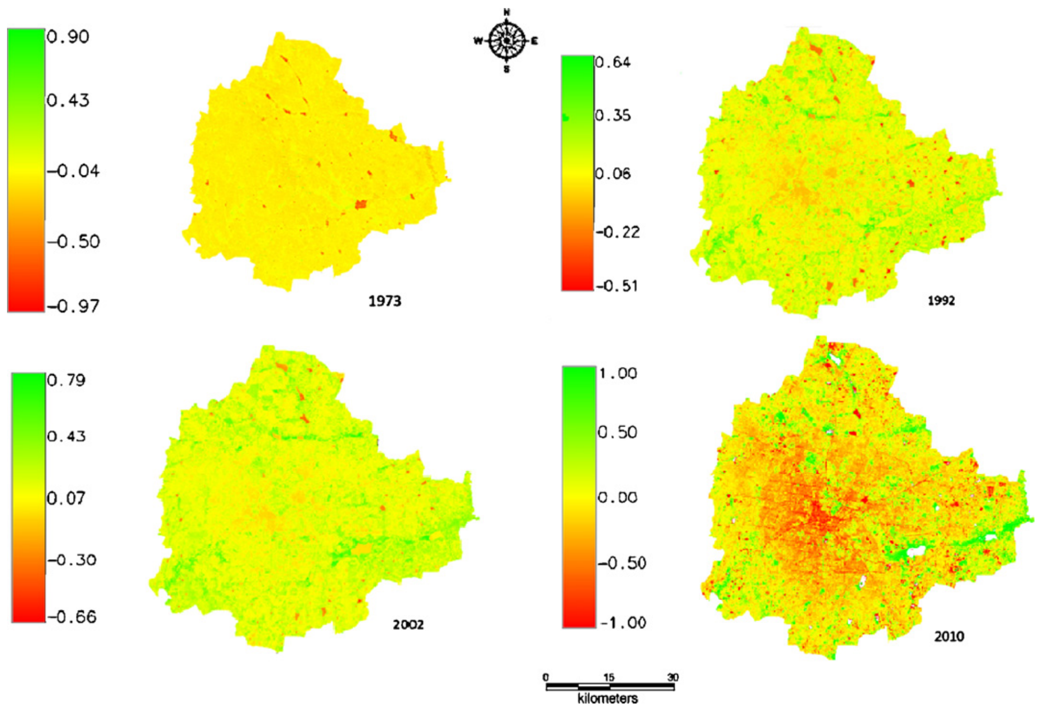

Fig. 3. Land cover changes from 1973 to 2010.

than ten times since 1949 (∼69–716 square kilometres) and is the fifth largest metropolis in India currently with a population of about 7 million (Ramachandra and Kumar, 2008, 2010; Sudhira et al., 2007). Bangalore city population has increased enormously from 6,537,124 (in 2001) to 9,588,910 (in 2011), accounting for 46.68% growth in a decade. Population density has increased from as 10,732 (in 2001) to 13,392 (in 2011) persons per sq. km. The per capita GDP of Bangalore is about $2066, which is considerably low with limited expansion to balance both environmental and economic needs (Fig. 1).

4. Material and methods

Urban dynamics was analysed using temporal remote sensing data of the period 1973–2010. The time series spatial data acquired from Landsat Series Multispectral sensor (57.5 m), Thematic mapper and enhanced thematic mapper plus (28.5 m) sensors for the period 1973–2010 were downloaded from public domain (http://glcf.umiacs.umd.edu/data). Survey of India (SOI) toposheets of 1:50,000 and 1:250,000 scales were used to generate base layers of city boundary, etc. City map with ward boundaries were digitized from the BBMP (Bruhat Bangalore Mahanagara Palike) map. Population data was collected from the Directorate of Census Operations, Bangalore region (http://censuskarnataka.gov.in). Table 1 lists the data used in the current analysis. Ground control points to register and geo-correct remote sensing data were collected using handheld pre-calibrated GPS (Global Positioning System), Survey of India Toposheet, Google earth, Bhuvan (http://earth.google.com, http://bhuvan.nrsc.gov.in).

5. Data analysis involved

5.1. Pre-processing

The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been 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. The Landsat satellite 1973 images have a spatial resolution of 57.5 m × 57.5 m (nominal resolution) were resampled to 28.5 m comparable to the 1989–2010 data which are 28.5 m × 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.

5.2. Vegetation cover analysis

Normalised Difference Vegetation Index (NDVI) was computed to understand the changes in the vegetation cover during the study

Table 3
Temporal land use dynamics.

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

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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 builtup. Zero indicates the water cover. Moderate values represent low-density vegetation (0.1–0.3), while high values indicate thick canopy vegetation (0.6–0.8).

5.3. Land use analysis

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 and (v) 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 supervised pattern classifier – Gaussian maximum likelihood algorithm. This has been proved superior classifier as it uses various classification decisions using probability and cost functions (Duda et al., 2000). Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Accuracy assessment to evaluate the performance of classifiers (Mitrakis et al., 2008; Ngigi et al., 2008; Gao and Liu, 2008), was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients (Congalton et al., 1983; Sha et al., 2008) and proportion of correctly allocated cases (Gao and Liu, 2008). 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.

Table 4
Kappa values and overall accuracy.

Year	Kappa coefficient	Overall accuracy (%)
1973	0.88	72
1992	0.63	77
1999	0.82	76
2002	0.77	80
2006	0.89	75
2010	0.74	78

Table 5
Shannon entropy.

	NE	NW	SE	SW
1973	0.173	0.217	0.126	0.179
1992	0.433	0.509	0.399	0.498
1999	0.504	0.658	0.435	0.607
2002	0.546	0.637	0.447	0.636
2006	0.65	0.649	0.610	0.695
2010	0.771	0.812	0.640	0.778

Application of maximum likelihood classification method resulted in accuracy of 76% in all the datasets. Land use was computed using the temporal data through open source program GRASS – Geographic Resource Analysis Support System (http://grass.fbk.eu/). Land use categories include (i) area under vegetation (parks, botanical gardens, grass lands such as golf field), (ii) built up (buildings, roads or any paved surface, (iii) water bodies (lakes/tanks, sewage treatment tanks), and (iv) others (open area such as play grounds, quarry regions, etc.).

5.4. 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 (Fig. 2) based on the Central pixel (Central Business district). The growth of the urban areas in respective zones was monitored through the computation of urban density for different periods.

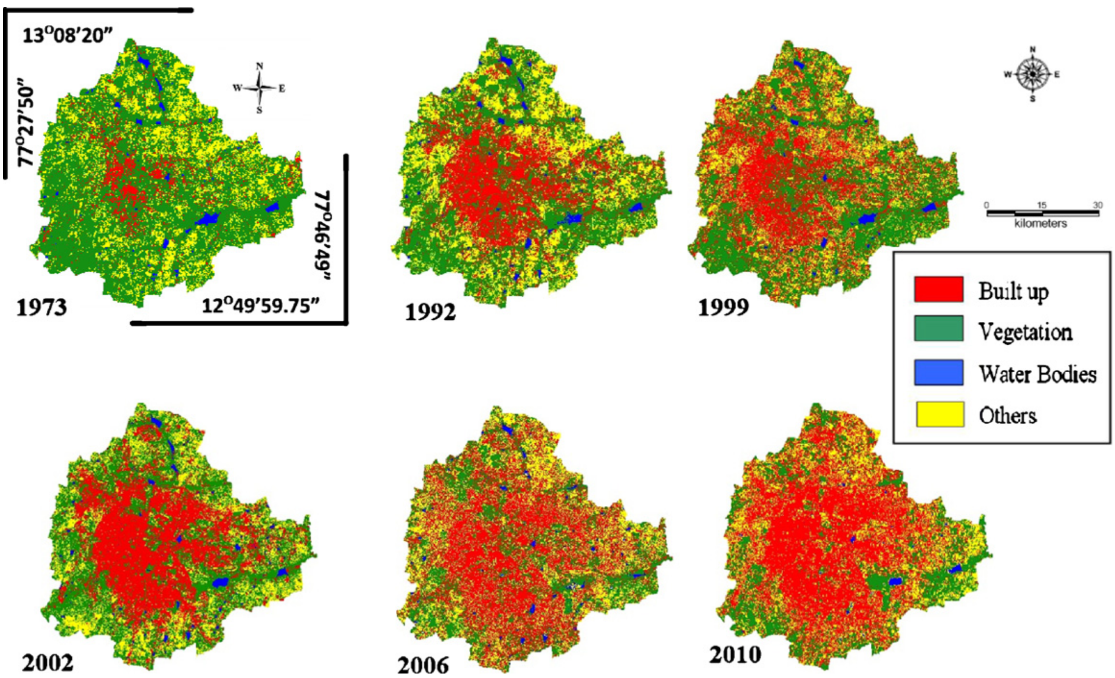

Fig. 4. Land use changes in Greater Bangalore.

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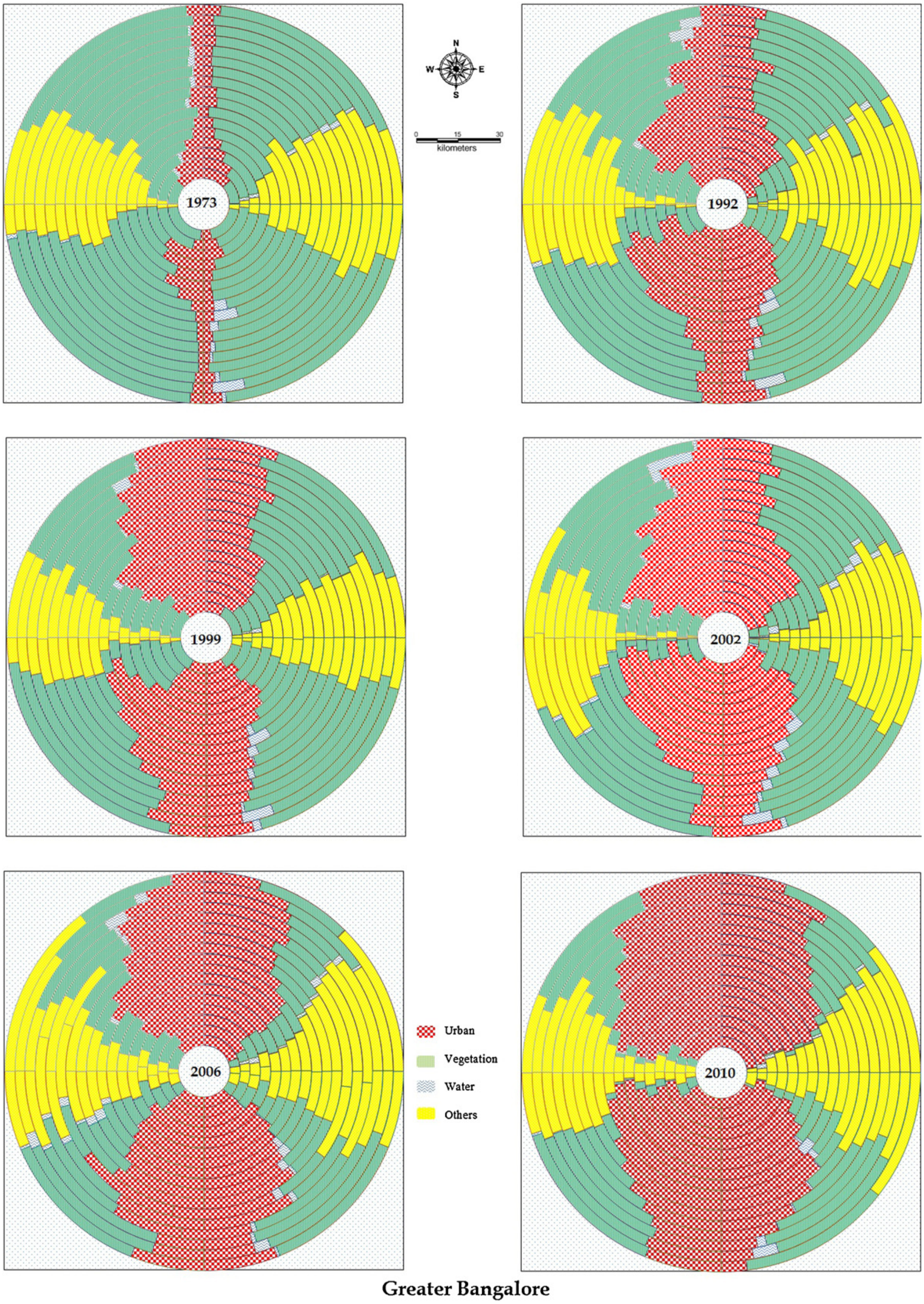

Fig. 5. Zone-wise and Gradient-wise temporal land use.

5.5. Division of these zones to concentric circles and computation of metrics

Further each zone was divided into concentric circle of incrementing radius of 1 km from the centre of the city (Fig. 2), 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. This helps in identifying the causal factors and locations experiencing various levels (sprawl, compact growth, etc.) of urbanisation in response to

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the economic, social and political forces. This approach (zones, concentric circles) also helps in visualizing the forms of urban sprawl (low density, ribbon, leaf-frog development). The built up density in each circle is monitored overtime using time series analysis.

5.6. *Computation of Shannon's entropy*

To determine whether the growth of urban areas was compact or divergent the Shannon's entropy (Yeh and Liu, 2001; Li and Yeh, 2004; Lata et al., 2001; Sudhira et al., 2004; Pathan et al., 2004) was computed for each zones. Shannon's entropy (H_n) given in Eq. (1), provides the degree of spatial concentration or dispersion of geographical variables among '*n*' concentric circles across Zones.

$$H_n = -\sum_{i=1}^{n} \mathrm{Pi}\log(Pi) \quad (1)$$

where *Pi* is the proportion of the built-up in the *i*th concentric circle. As per Shannon's entropy, if the distribution is maximally concentrated in one circle the lowest value zero will be obtained. Conversely, if it is an even distribution among the concentric circles will be given maximum of log *n*.

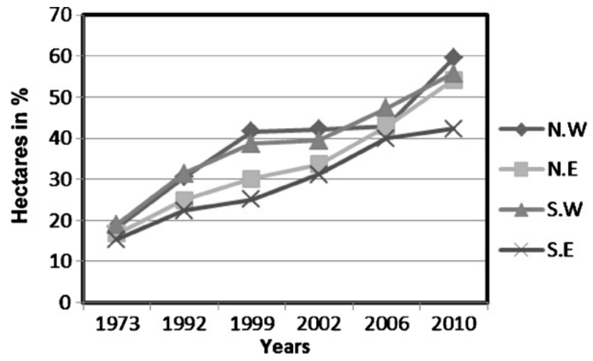

Fig. 6. Built up density across years from 1973 to 2010.

5.7. *Computation of alpha and beta population density*

Alpha and beta population densities were calculated for each circle with respect to zones. Alpha population density is the ratio of total population in a region to the total builtup area, while Beta population density is the ratio of total population to the total

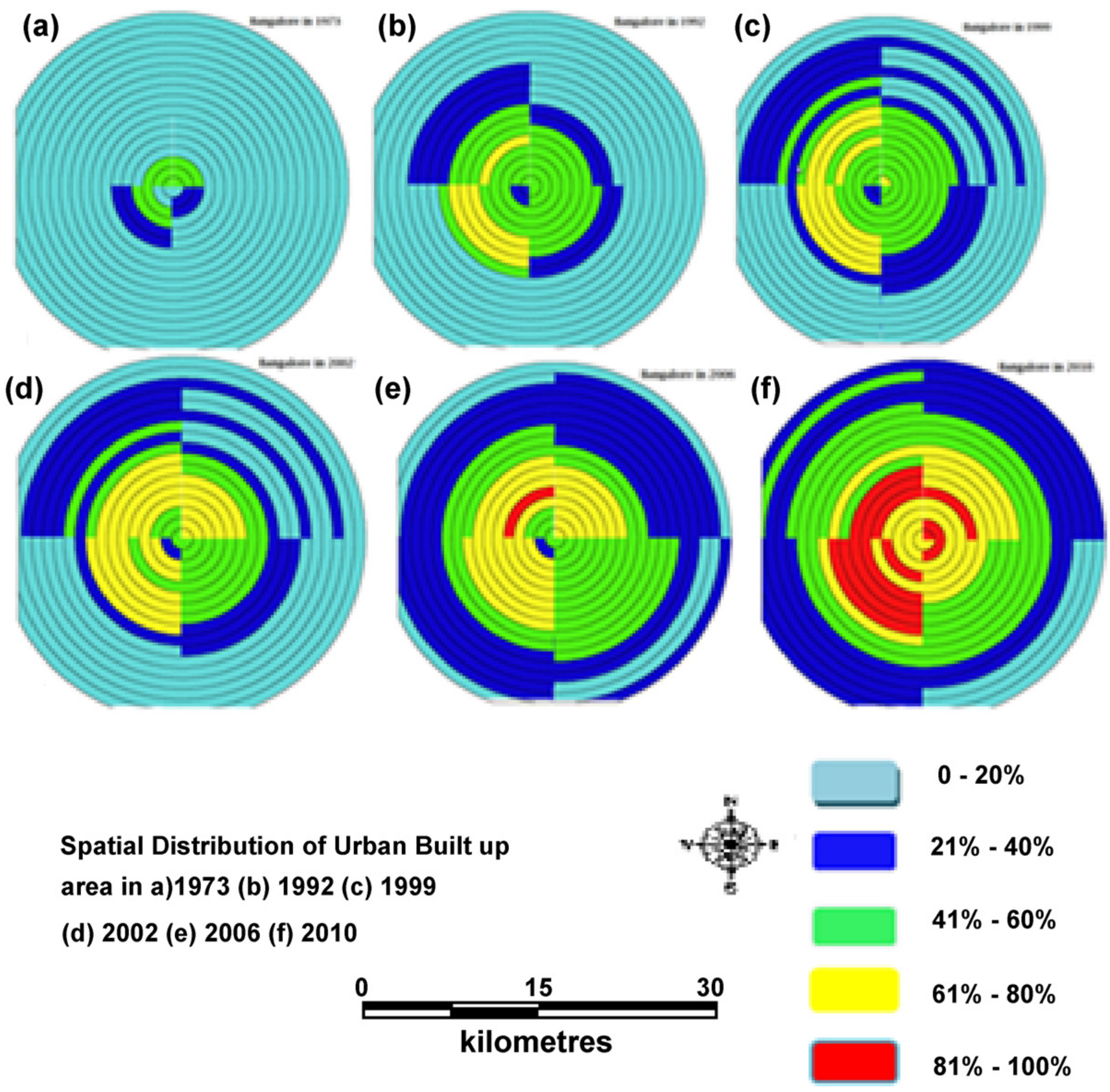

Fig. 7. Gradient analysis of Greater Bangalore- Builtup density circlewise and zonewise.

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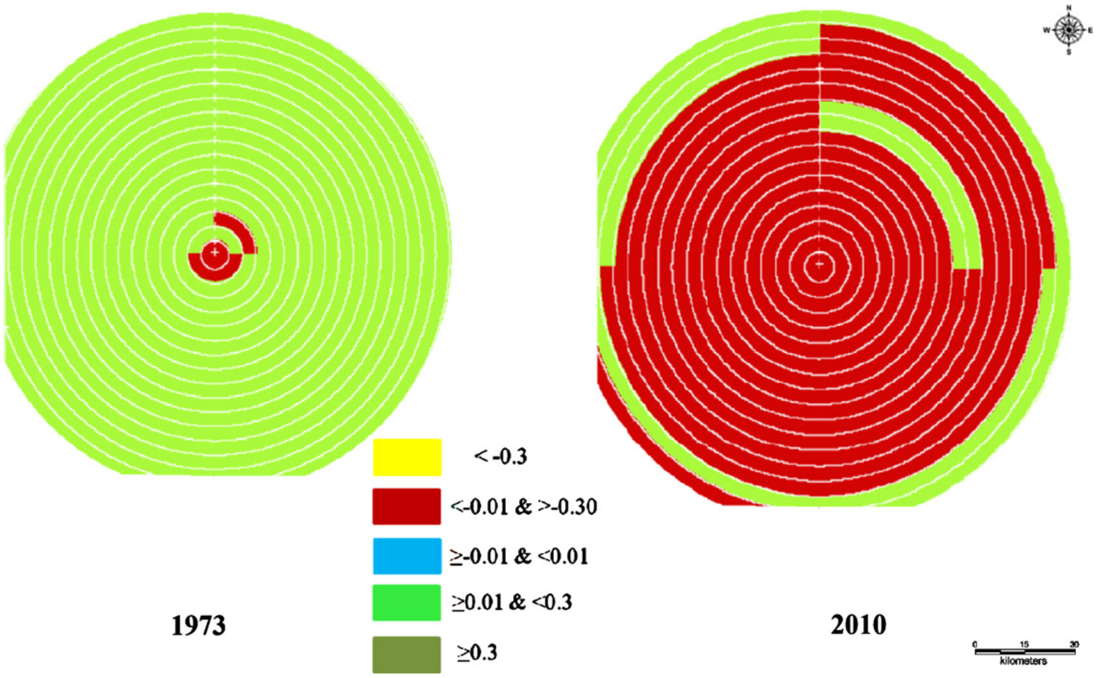

Fig. 8. NDVI gradients – circlewise and zone wise.

geographical area. These metrics have been often used as the indicators of urbanisation and urban sprawl and are given by:

$$\alpha\,\text{density} = \frac{\text{total population}}{\text{total built up}} \tag{2}$$

$$\beta\,\text{density} = \frac{\text{total population}}{\text{total geographic area}} \tag{3}$$

5.8. Gradient analysis of NDVI images of 1973 and 2010

The NDVI gradient was generated to visualize the vegetation cover changes in the specific pockets of the study area.

5.9. Calculation of landscape metrics

Landscape metrics provide quantitative description of the composition and configuration of urban landscape. 21 spatial metrics chosen based on complexity, centrality and density criteria (Huang et al., 2007) to characterize urban dynamics, were computed zone-wise for each circle using classified land use data at the landscape level with the help of FRAGSTATS (McGarigal and Marks, 1995). The metrics include the patch area (built up (total land area), Percentage of Landscape (PLAND), Largest Patch Index (percentage of landscape), number of urban patches, patch density, perimeter-area fractal dimension (PAFRAC), Landscape Division Index (DIVISION)), edge/border (edge density, area weighted mean patch fractal dimension (AWMPFD), perimeter area weighted mean ratio (PARA_AM), mean patch fractal dimension (MPFD), total edge (TE), shape (NLSI – Normalized Landscape Shape Index), Landscape Shape Index (LSI)), epoch/contagion/dispersion (Clumpiness, percentage of like adjacencies (PLADJ), total core area (TCA), ENND coefficient of variation, Aggregation Index, interspersion and juxtaposition). These metrics were computed for each region and principal component analysis was done to prioritise metrics for further detailed analysis.

5.10. Principal component analysis

Principal component analysis (PCA) is a multivariate statistical analysis that aids in identifying the patterns of the data while reducing multiple dimensions. PCA through Eigen analysis transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible (Wang, 2009). PCA helped in prioritizing six landscape metrics based on the relative contributions of each metrics in the principal components with maximum variability (Table 2).

6. Results and discussion

Vegetation cover of the study area was analysed through NDVI. Fig. 3 illustrates that area under vegetation has declined from 72% (488 sq. km in 1973) to 21% (145 sq. km in 2010).

6.1. Land use analysis

a. 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 3. Fig. 4 provides the land use in the region during the study period. Overall accuracy of the classification was 72% (1973), 77% (1992), 76% (1999), 80% (2002), 75% (2006) and 78% (2010) respectively. There has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. Fig. 5 illustrates the zone-wise temporal land use changes at local levels. Table 4 lists kappa statistics and overall accuracy.
b. Urban density is computed for the period 1973–2010 and is depicted in Fig. 6, which illustrates that there has been a linear

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Table 6
Alpha and beta density in each region – zone wise, circle wise.

Radius	North east		North west		South east		South west	
	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
1	1526.57	1385.38	704.71	496.05	3390.82	2437.32	3218.51	2196.83
2	333.99	288.58	371.00	280.41	983.51	857.04	851.23	555.33
3	527.99	399.83	612.02	353.50	904.02	701.47	469.19	369.67
4	446.99	343.51	360.72	286.39	602.14	441.66	308.47	262.52
5	152.43	122.74	255.11	226.72	323.07	243.02	236.56	188.26
6	123.16	94.91	370.22	324.12	306.48	203.54	58.57	51.12
7	73.65	57.96	254.49	207.29	54.77	32.64	77.07	73.09
8	38.16	27.80	71.54	62.38	57.22	30.52	61.85	57.29
9	44.99	29.54	92.73	69.97	51.74	26.00	37.60	31.90
10	48.43	25.22	93.51	55.75	33.31	17.44	25.99	16.61
11	50.32	23.77	100.55	56.56	22.69	11.63	35.90	18.75
12	42.34	17.92	67.36	34.36	27.12	11.29	25.52	10.86
13	59.87	22.20	40.87	17.71	30.66	9.44	35.59	11.92
14	54.10	18.38	24.51	9.91	24.16	5.35	19.77	5.49
15	60.81	20.73	21.48	8.98	19.52	3.50	26.41	6.56
16	62.17	23.79	46.81	12.83	16.92	2.96	66.19	17.35
17	16.54	24.76	53.30	14.58	16.45	2.02	41.40	10.36

growth in almost all directions (except NW direction, which show stagnation during 1999–2006). Developments in various fronts with the consequent increasing demand for housing have urbanised these regions evident from the drastic increase in the urban density during the last two decades. In order to understand the level of urbanisation and quantification at local level, each zone is further divided into concentric circles.

6.2. Density gradient analysis

Study area was divided into concentric incrementing circles of 1 km radius (with respect to centroid or central business district). The urban density gradient given in Fig. 7 for the period 1973–2010, illustrates radial pattern of urbanisation and concentrated closer to the central business district and the growth was minimal in 1973. Bangalore grew intensely in the NW and SW zones in 1992 due to the policy of industrialization consequent to the globalisation. The industrial layouts came up in NW and housing colonies in SW and urban sprawl was noticed in others parts of the Bangalore. This phenomenon intensified due to impetus to IT and BT sectors in SE and NE during post 2000. 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 urbanisation in many localities. This also led to the compact growth at central core areas of Bangalore and sprawl at outskirts which are deprived of basic amenities. The analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanisation has intensified from the city centre and reached the periphery of Greater Bangalore. Gradients of NDVI given in Fig. 8 further corroborate this trend. Shannon entropy, alpha and beta population densities were computed to understand the level of urbanisation at local levels.

6.3. Calculation of Shannon's entropy, alpha and beta densities

Shannon entropy was calculated for the years 1973, 1992, 1999, 2002, 2006, 2010 listed in Table 5. The value of entropy ranges from zero to $\log(n)$. Lower entropy values indicate aggregated or compact development. Higher the value or closer to $\log(n)$ indicates the sprawl or dispersed or sparse development. Grater

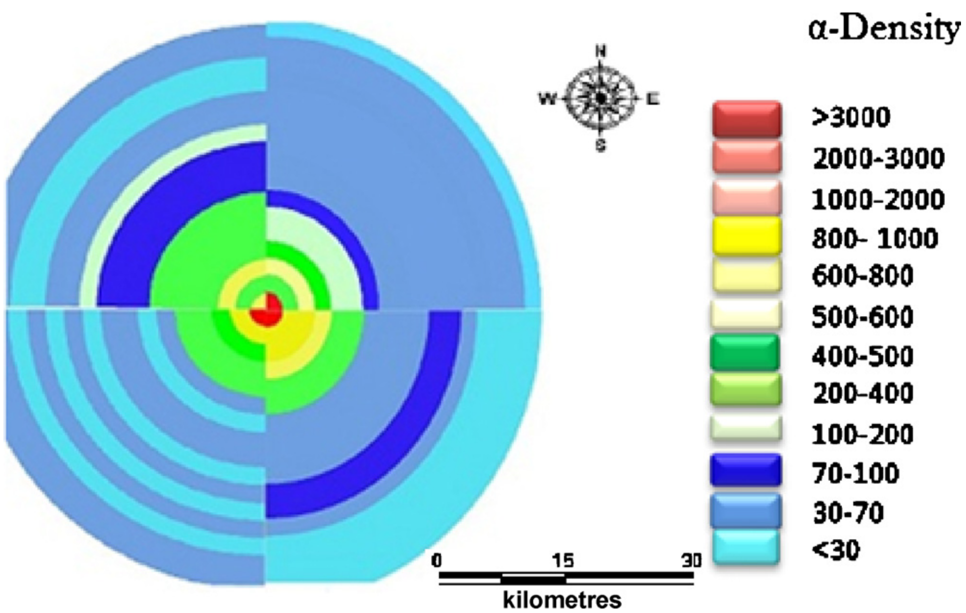

Fig. 9. Alpha density– zonewise for each local regions.

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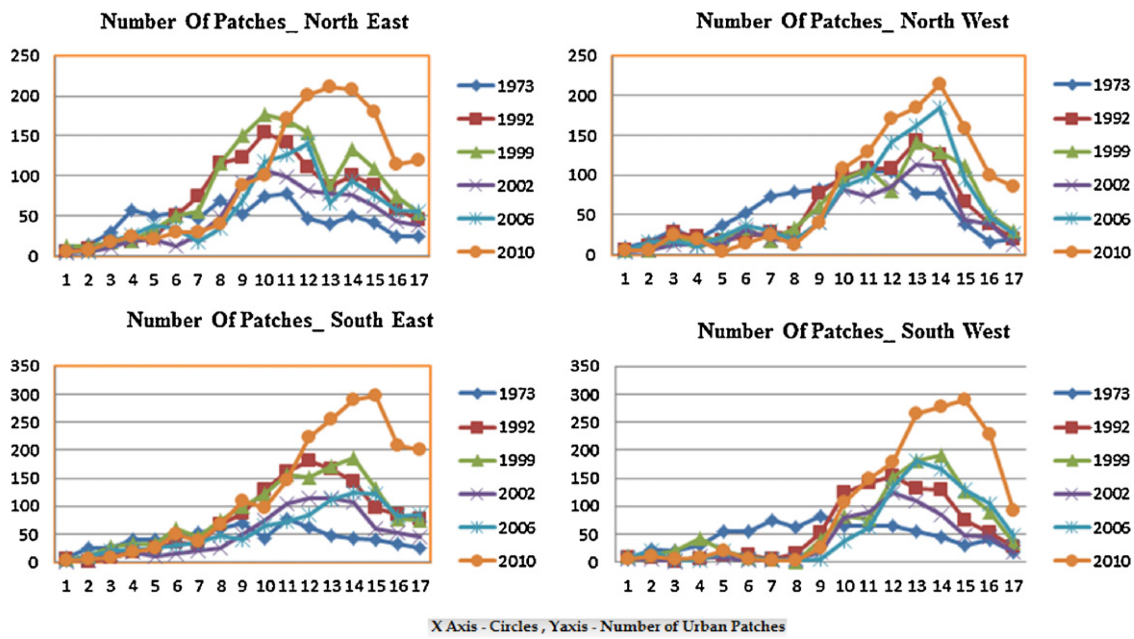

Fig. 10. Number of patches – direction-wise/circle-wise.

Bangalore grew and has almost reached the threshold of growth ($\log(n) = \log(17) = 1.23$) in all directions. Lower entropy values of 0.126 (SE), 0.173 (NE), 0.170 (SW) and 0.217 (NW) during 1970s show aggregated growth. However, the dispersed growth is noticed at outskirts in 1990s and post 2000s (0.64 (SE), 0.771 (NE), 0.812 (NW) and 0.778 (SW)).

Shannon's entropy values of recent time confirm dispersed haphazard urban growth in the city, particularly in city outskirts. This also illustrates the extent of influence of drivers of urbanisation in various directions. In order to understand this phenomenon, alpha and beta population densities were computed.

Table 6 lists alpha and beta densities zone-wise for each circle. These indices (both alpha and beta densities) indicate that there has been intense growth in the centre of the city and SE, SW and NE core central area has reached the threshold of urbanisation.

Gradients of alpha and beta densities is given in Fig. 9, illustrates urban intensification in the urban centre and sprawl is also evident NW and SW regions.

6.4. Landscape metrics

Landscape metrics were computed circle-wise for each zones. Percentage of Landscape (PLAND) indicates that the Greater Bangalore is increasingly urbanised as we move from the centre of the city towards the periphery. This parameter showed similar trends in all directions. It varied from 0.043 to 0.084 in NE during 1973. This has changed in 2010, and varies from 7.16 to 75.93. NW also shows a maximum value of 87.77 in 2010. Largest patch index indicate that the city landscape is fragmented in all direction during 1973 due to heterogeneous landscapes. However, this has aggregated

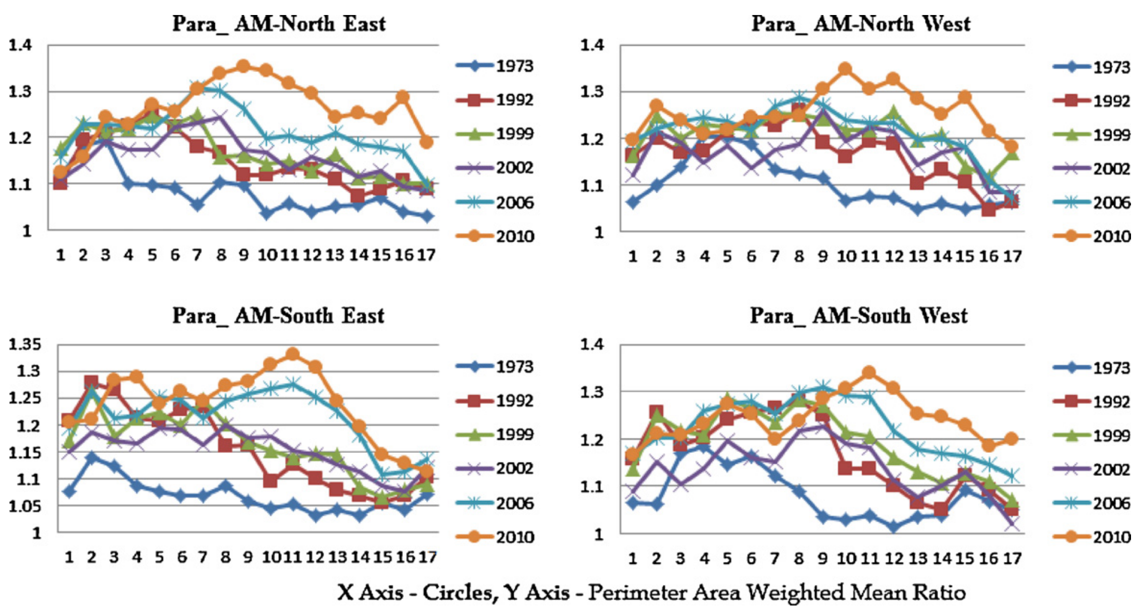

Fig. 11. PARA_AM – direction-wise/circle-wise.

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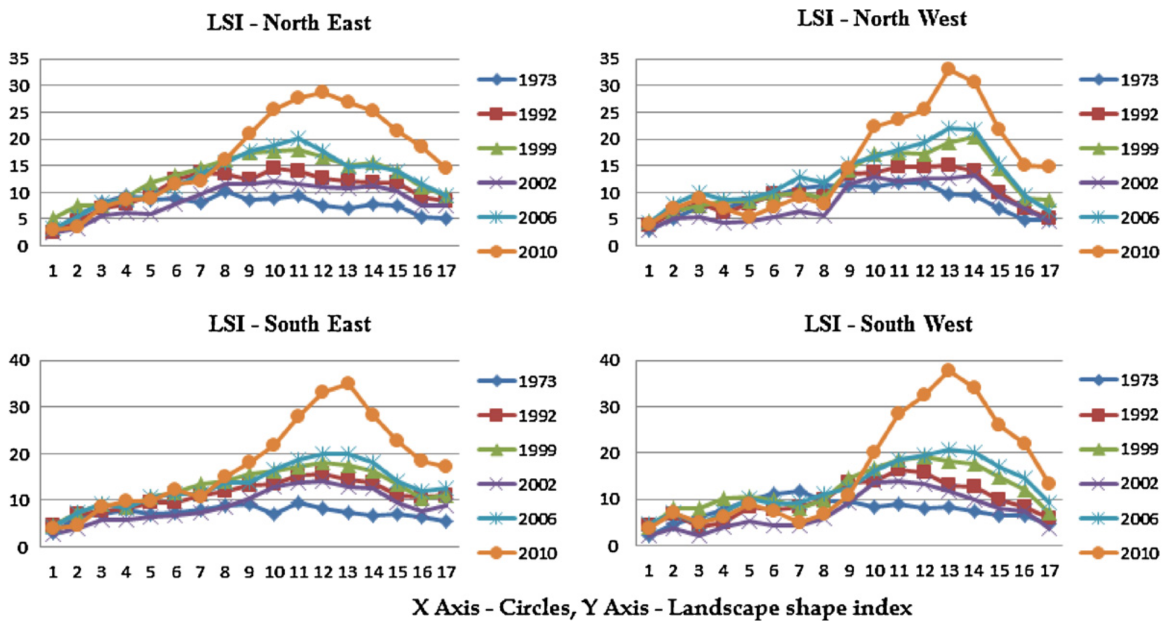

Fig. 12. LSI – direction-wise/circle-wise.

to a single patch in 2010, indicating homogenisation of landscape. The patch sizes were relatively small in all directions till 2002 with higher values in SW and NE. In 2006 and 2010, patches reached threshold in all directions except NW which showed a slower trend. Largest patches are in SW and NE direction (2010). The patch density was higher in 1973 in all directions due to heterogeneous land uses, which increased in 2002 and subsequently reduced in 2010, indicating the sprawl in early 2000s and aggregation in 2010. PAFRAC had lower values (1.383) in 1973 and maximum of 1.684 (2010) which demonstrates circular patterns in the growth evident from the gradient. Lower edge density was in 1973, increased drastically to relatively higher value 2.5 (in 2010). Clumpiness index, Aggregation index, Interspersion and Juxtaposition Index highlights that the centre of the city is more compact in 2010 with more clumpiness in NW and SW directions. Area weighted Euclidean mean nearest neighbour distance is measure of patch context to quantify patch isolation. Higher v values in 1973 gradually decrease by 2002 in all directions and circles. This is similar to patch density dynamics and can be attributed to industrialization and consequent increase in the housing sector. Analyses confirm that the development of industrial zones and housing blocks in NW and SW in post 1990s, in NE and SE during post 2000 are mainly due to policy decision of either setting up industries or boost to IT and BT sectors and consequent housing, infrastructure and transportation

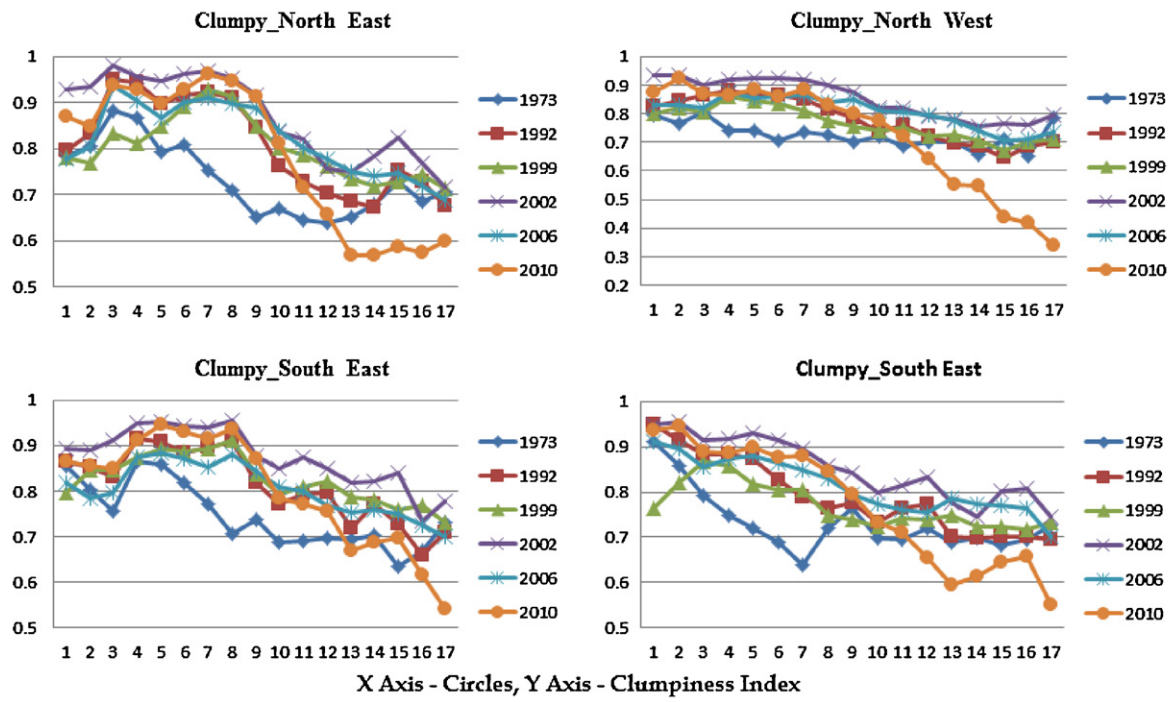

Fig. 13. Clumpiness Index – direction-wise/circle-wise.

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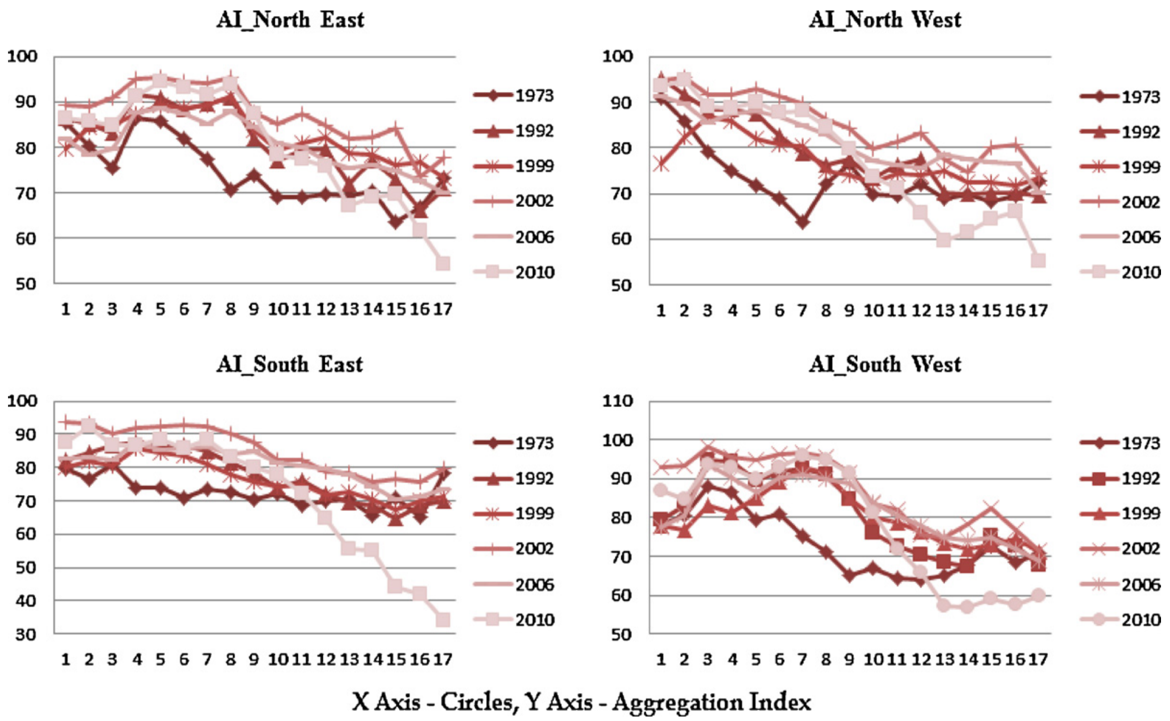

Fig. 14. Aggregation Index – direction-wise/circle-wise.

facilities. PCA was performed with 21 metrics computed zonewise for each circle. This helped in prioritising the metrics (Table 2) while removing redundant metrics for understanding the urbanisation, which are discussed next.

i. Number of urban patches has steadily decreased in the inner core circles from 1973 to 2010, which indicates aggregation. A sharp increase in the urban patches in the periphery (outer rings) from 25 to 120 indicates of numerous small urban patches pointing to the urban sprawl. Urban sprawl is thus effectively visualized by this index, evident with SW, SE and NE zones in Fig. 10. The outer circle having on an average 120 urban patches compared to 5 in inner circles.
ii. Perimeter area weighted mean ratio (PAWMR) reflects the patch shape complexity and is given in Fig. 11. The values closer to zero in the inner circles indicate the simple shape, whereas the outer circles show the increasing trends in all directions. This highlights an enhanced rate of anthropogenic interventions and hence the process of Sprawl.
iii. Landscape shape index indicates the complexity of shape, close to zero indicates maximally compact (at city centre) and higher values in outer circles indicate disaggregated growth in 2010

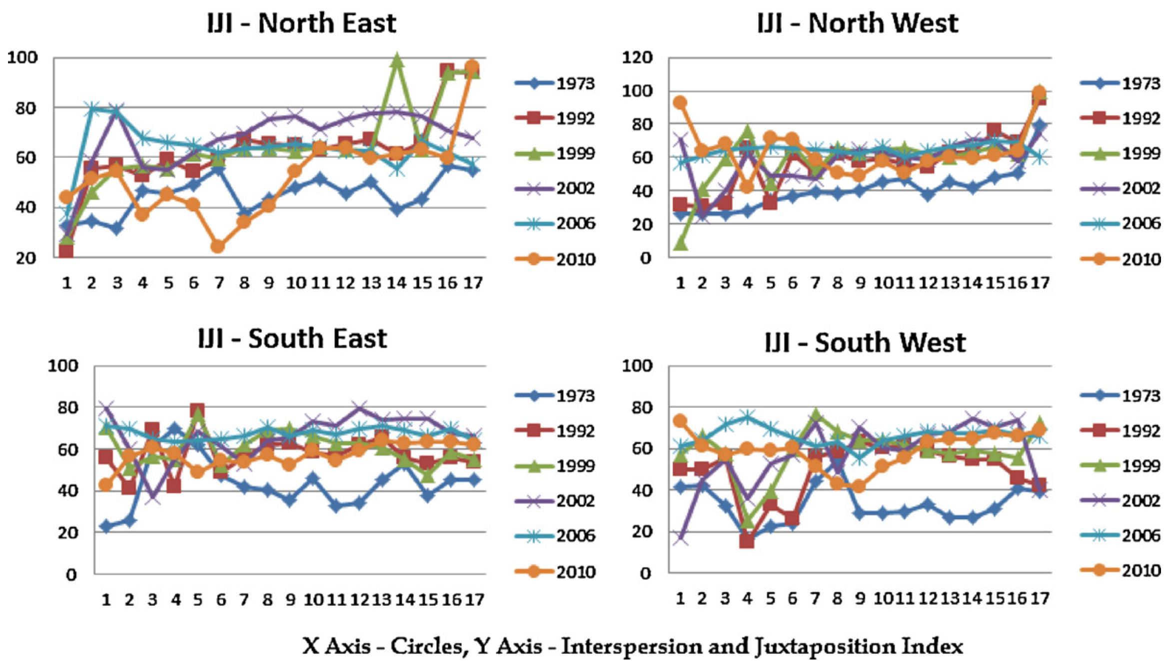

Fig. 15. Interspersion and Juxtaposition – direction-wise/circle-wise.

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(Fig. 12). The trend of sprawl at city outskirts as well as at the centre was noticed till 1980s. However, post 1980s values indicate of compactness at city centre, while outer rings show disaggregated growth.

iv. Clumpiness index represents the similar trend of compact growth at the center of the city which gradually decreases towards outer rings indicating the urban agglomeration at centre and phenomena of sprawl at the outskirts in 2010 (Fig. 13). This phenomenon is very prominent in Northeast and Southwest direction.

v. Aggregation Index indicated that the patches are maximally aggregated in 2010 while it was more dispersed in 1973, indicating that city is getting more and more compact (Fig. 14).

vi. Interspersion and Juxtaposition Index was very high as high as 94 in all directions which indicate that the urban area is becoming a single patch and a compact growth towards 2010 (Fig. 15). All these metrics point towards compact growth in the region, due to intense urbanisation. Concentrated growth in a region has telling influences on natural resources (disappearance of open spaces – parks and water bodies), traffic congestion, enhanced pollution levels and also changes in local climate (Ramachandra and Kumar, 2009, 2010)

The discussion highlights that the development during 1992–2002 was phenomenal in NW, SW due to Industrial development (Rajajinagar Industrial estate, Peenya industrial estate, etc.) and consequent spurt in housing colonies in the nearby localities. The urban growth picked up in NE and SE (Whitefield, Electronic city, etc.) during post 2000 due to State's encouraging policy to information technology and biotechnology sectors and also setting up International airport.

7. Conclusion

Urban dynamics of rapidly urbanising landscape – Bangalore has been analysed to understand historical perspective of land use changes, spatial patterns and impacts of the changes. The analysis of changes in the vegetation cover shows a decline from 72% (488 sq. km in 1973) to 21% (145 sq. km in 2010) during the last four decades in Bangalore.

Land use analyses show that there has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Temporal analyses of greater Bangalore reveals an increase in urban built up area by 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. Urban growth pattern of Greater Bangalore has been done in four directions through landscape metrics and gradient analysis across six time periods. The urban density gradient illustrates radial pattern of urbanisation during 1973–2010 indicating of intense urbanisation at central core and sprawl at outskirts, which conform with Shanon's entropy, alpha and beta population densities. Landscape metrics further highlight of compact growth in the region.

Gradients of alpha and beta densities illustrate urban intensification in the center and sprawl in NW and SW regions. Landscape metrics point towards compact growth in the region, due to intense urbanisation in 2000. The analysis confirms that the nature of land use depended on the activities while the level of spatial accumulation depended on the intensity and concentration of urban builtup. Central areas have a high level of spatial accumulation and corresponding land uses, such as in the CBD, while peripheral areas have lower levels of accumulation. Unplanned concentrated growth or intensified developmental activities in a region has telling influences on natural resources (disappearance of open spaces – parks and water bodies), traffic congestion, enhanced pollution levels and also changes in the local climate.

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Influence of Catchment Land Cover Dynamics on the Physical, Chemical and Biological Integrity of Wetlands

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Abstract

Land use and land cover (LULC) changes in the wetland catchments are the direct and indirect consequence of human actions to secure essential resources. These changes encompass the greatest environmental concerns of human populations today, including loss of biodiversity, pollution of water and soil, and changes in the climate. Monitoring and mitigating the negative consequences of LULC while sustaining the production of essential resources has therefore become a major priority today. This communication investigates the effect of land-cover and water quality on distribution of diatoms in selected wetlands of Bangalore. In this respect, water quality (chemical and biological) was assessed along with LULC of respective wetland catchments. Spatial analysis has been done using remote sensing data and geographic information system (GIS). Diatoms, the major primary producers of aquatic ecosystem, respond quickly to environmental perturbations aid as bioindicators. The results showed gradients in physical, chemical and biological parameters across wetlands with different LULC. The diatom community results, when compared to chemical analyses, proved useful in providing an indication of the quality of waters. Pollution tolerant taxa such as *Nitzschia palea* dominated at sites with heavy inflow of sewage while, *Cymbella* sp. and *Gomphonema* sp. present abundantly at less pollution sites. Across the land-cover types, wetlands catchment comprising more of built-up area reflected higher nutrient and ionic levels, whereas wetlands with high vegetation cover showed oligotrophic water quality conditions. Species belonging to the genera *Gomphonema, Cyclotella, Nitzschia* and *Achnanthidium* expressed clear ecological preferences. This study emphasizes the need for conservation efforts at catchment level for conservation of wetlands biota.

Keywords: Land use land cover (LULC), landscape, landscape dynamics, wetlands. Diatoms, Water quality

Introduction

Wetlands being one of the productive ecosystems play a significant role in the ecological sustainability of the region, providing the link between land and water resources (Ramachandra, 2008). The quality and hydrologic regime of the water resource is directly dependent on the integrity of its watershed. In recent years, the rapid urbanization coupled with the unplanned anthropogenic activities has altered the wetland ecosystem severely across globe (Vitousek *et al.,* 1997; Grimmond, 2007). Changes in land use and land cover (LULC) in the wetland catchments influence the water yield in the catchment. Apart from LULC changes, the inflow of untreated domestic sewage, industrial effluents, dumping of solid wastes and rampant encroachments of catchment has threatened the sustenance of urban wetlands. This is evident from the nutrient enrichment and consequent profuse growth of macrophytes, impairing the functional abilities of the wetlands. Reduced treatment capabilities of the wetlands have led to the decline of native biodiversity affecting the livelihood of wetland dependent population. Decline in the services and goods of wetland ecosystems have influenced the social, cultural and ecological spaces as well as of water management. This necessitates regular monitoring of wetlands to mitigate the impacts through appropriate management strategies. LULC analysis is done using remote sensing data acquired through the space-borne sensors. Factors related to water quality are the most important pressure driving heterogeneity of biotic components at an intermediate spatial and temporal scale.

Algae, the primary producers are linked with the changes in various physical (landscape) and chemical (nutrients) variables and indeed have been used as bioindicators of water quality. Among several groups, diatom-based pollution monitoring has proved to be rapid, efficient and cost-effective technique has been implemented worldwide to monitor rivers, streams and lakes (Taylor *et al.,* 2007; Juttner *et al.,* 2010; Karthick *et al.,* 2011). Diatoms are the species-rich group of photosynthetic eukaryotes, with enormous ecological significance and great potential for environmental application. During the last two decades, diatoms have gained considerable popularity throughout the world as a tool to provide an integrated reflection of water quality (Atazadeh *et al.,* 2007). The sensitivity and tolerance of diatoms to specific physical and chemical variables such as pH, electrical conductivity, nitrates, phosphates and biological oxygen demand (BOD) and inherent ecological patterns has been investigated across countries (Sabater et al., 2007; Taylor et al., 2007; Jüttner et al., 2009; Alakananda et al., 2011).

Diatom community structure respond to the LULC changes in the catchment (Cooper, 1995), nutrient concentration (Potapova and Charles, 2002), riparian disturbance (Hill et al., 2000) and decreasing species richness, evenness and diversity from agriculture / forest areas to urban area (Bere and Tundisi, 2011). Walsh and Wepener (2009) report the dominance of *Nitzschia* sp. in the catchment with high intensity agriculture, while *Navicula* sp. was dominant at low intensity agriculture regions. However, studies on water chemistry of wetlands with the catchment LULC conditions and its impacts on diatom assemblages in urban scenario is scarce and needs to be investigated to evolve location specific catchment restoration measures and to mitigate the impact of anthropogenic activities in the fragile ecosystem's catchment.

Wetlands play a prominent role of meeting the domestic and irrigation needs of the region apart from being habitats for wide variety of flora and fauna. Bangalore, with a population of 9.5 million (as per 2011 census) has been rapidly urbanizing during the last three decades. Recent studies reveal that there has been 63.2% increase in built-up area with 78% loss of vegetation cover and 79% loss of wetlands (Ramachandra and Kumar, 2008). Wetlands have become vulnerable ecosystems evident from regular mass fish kill (Benjamin et al., 1996) reduction of migratory bird population (Kiran and Ramachandra, 1999) and ground water contamination (Shankar et al., 2008). Sustained inflow of the city's sewage and industrial effluents apart from conversion of wetlands for other activities have threatened the existence of these fragile ecosystems necessitating the interventions to restore and sustainable management with location specific appropriate conservation strategies. Failure to restore these ecosystems will result in extinction of species or ecosystem types and cause permanent ecological damage.

Wetlands function as kidneys of the landscape and help in treating the nutrients. However, the excess inflow of nutrients beyond the treatment capability results in the changes in the water quality impairing the ecological functions. Diatoms, the major primary producers of aquatic ecosystem, respond quickly to environmental perturbations, hence used as a bioindicator across continents. However, usage of diatoms as a part of environmental monitoring program in Southern Hemisphere is very limited due to inadequate knowledge on its taxonomy. Ecological optima of four dominant species were investigated for standardizing diatom indices for Indian conditions. Current study investigates the influence of LULC in the wetland catchment on diatom communities composition and distribution at spatial scale in an eco-region. LULC analysis was done using remote sensing data with Geographical Information System (GIS). Water quality was analyzed to investigate temporal variation in physicochemical parameters and their relationship with diatom community during pre-monsoon (August), monsoon (September and October) and post-monsoon (November) months.

Study area

Bangalore is located at 12^o 39' N and 13^o 18' N and longitude of 77^o 22' E and 77^o, almost equidistant from both eastern and western coast of the South Indian peninsula, and is situated at an altitude of 920 m above mean sea level. Major soil types are red loamy and laterite soil and physiography variations ranges from rocky upland, plateau and flat-topped hills forming slope at south and south east, and pedi-plains along western parts (http://cgwb.gov.in). The mean annual total rainfall is about 880 mm with about 60 rainy days a year over the last 10 years. The summer temperature ranges from 24 to 38 °C, while the winter temperature ranges from 12 to 28 °C. Bangalore is located over ridges delineating four watersheds, viz. Hebbal, Koramangala, Challaghatta and Vrishabhavathi watersheds. 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 (Figure 1). Their creation is mainly attributed to the vision of Kempe Gowda and of the Wodeyar dynasty. This led to Bangalore having hundreds of such water bodies through the centuries. Recent studies reveal that there has been 63.2% increase in built-up area with 78% loss of vegetation cover and 79% loss of wetlands (Ramachandra and Kumar, 2008).

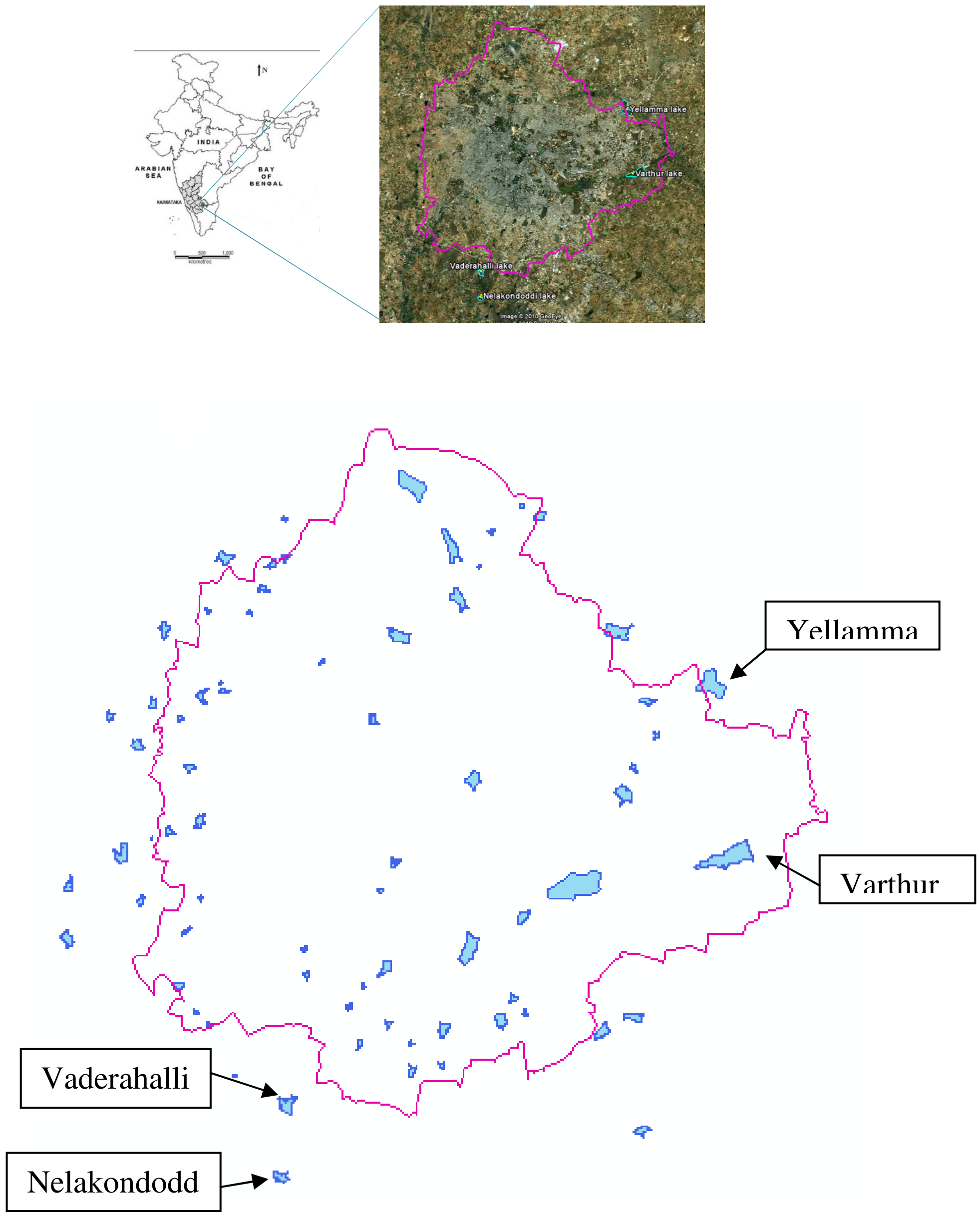

Figure 1: Study area with India Map and Bangalore map with 4 lakes marked on the digitized vector layer of Bangalore

Four wetlands were selected for the current study. Among these Yellamallappa chetty (110 ha) and Varthur (166.87 ha) are located in Bangalore urban district and drained from densely populated area of Bangalore metropolitan (Mahadevapura zone, Population of 5,19,663). Industrial waste and agricultural runoff (Usha et al., 2008) contaminated Yellamappa chetty and Varthur together with macrophyte growth and severe sludge deposition (Ramachandra, 2008). Two other wetlands Vaderahalli (55ha) and Nelakondoddi (36 ha) are located in Bangalore Rural district with less human population and more of plantation and forested land in catchment area.

Table 1: Variation in physical and chemical parameters across months at Varthur and Yellamma Wetland

Sampling site	VARTHUR INLET (Vri VTI)				VARTHUR OUTLET (VroVTO)				YALLAMMA INLET (YMI)				YALLAMMA OUTLET (YMO)			
Sampling months	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**		**Nov**	**Aug**	**Sep**	**Oct**	**Nov**
pH	7.46	7.25	7.10	8.50	7.84	7.58	8.00	8	7.49	8.90		7.5	7.5	8.00	7.20	8
Water temperature (^{0}C)	25	27.00	26.00	24.00	29.5	27.50	26.50	26	25.3	29.00		-	26.2	28.60	-	-
Electric conductivity (µScm^{-1})	823	948.00	-	-	798	890.00	-	-	1083	1120.00		-	1092	863.00	-	-
Total dissolved solids (ppm)	654	730.00	-	-	636	700.00	-	-	865	850.0		-	870	654.00	-	-
Salinity (ppm)	403	550.00	-	-	385	563.00	-	-	538	620.0		-	537	490.00	-	-
Turbidity (NTU)	92.5	110.00	82.20	-	83.5	81.30	62.20	-	42.7	44.00		70.8	42.8	60.50	-	38.5
Dissolved Oxygen (mgL^{-1})	0.813	0.00	1.22	0	4.065	7.15	1.63	4.06	4.227	0.00		-	5.04	1.95	0.00	-
Biological oxygen Demand (mgL^{-1})	49.95	71.54	56	95	46.28	55.28	44.7	-	33.74	117.07		35	24.29	104.07	87.9	30
Chemical oxygen demand (mgL^{-1})	293.33	197.73	133.00	314.67	192.00	298.67	-	234.66	581.33	213.33		85.33	570.66	218.67	186.70	74.67
Nitrates (mgL^{-1})	0.05	0.27	0.157	0.299	0.03	0.28	0.162	0.24	2.57	0.85		-	0.394	0.57	0.179	-
Phosphates (mgL^{-1})	0.21	1.94	3.217	1.637	0.05	1.73	4.175	0.718	0.51	0.61		1.94	2.98	0.44	3.3	1.813
Total Hardness (mgL^{-1})	268	256.00	240.00	336	264	236.00	292.00	420	276	320.00		360	300	284.00	296.00	288
Calcium Hardness (mgL^{-1})	120	120.00	144.00	88.17	132	112.00	200.00	188.17	372	132.00		68.93	280	124.00	196.00	57.71
Magnesium Hardness (mgL^{-1})	189.92	136.00	96.00	28.261	85.392	124.00	92.00	48.757	185.232	188.00		45.838	231.68	160.00	100.00	35.107
Alkalinity (mgL^{-1})	520	55.00	440.00	140	260	56.00	-	120	420	90.00	**	1700	560	65.00	400.00	1580
Chlorides (mgL^{-1})	136.32	153.36	147.68	150.52	119.28	142.00	-	142	107.92	193.12		227.2	167.56	190.28	221.52	213
Sodium (ppm)	33.6	34.30	3.1	20.05	34.6	31.50	-	18.93	40.6	40.30		22.83	49.5	39.70	3.9	23.39
Potassium (ppm)	6.8	7.00	4.4	0	6.7	6.30	0	0	7.7	7.80		0	8.5	8.20	5	0

** No sampling was carried out due to the Ganesha immersion.

Table 2: Variation in physical and chemical parameters across months at Nelakondoddi and Vaderahalli Wetland

Sampling site	NELAKONDODDI INLET (NiNKI)				NELAKONDODDI OUTLET (NoNKO)				VADERAHALLI INLET (VdiVHI)				VADERAHALLI OUTLET (VdoVHO)			
Sampling months	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**	**Aug**	**Sep**	**Oct**	**Nov**
pH	8.05	8.36	8.20	8.60	7.95	7.94	8.10	8.60	9.4	9.11	8.30	8.20	8.5	9.00	8.20	8.20
Water temperature (^{0}C)	28.4	26.30	26	26.00	26	29.50	24.5	25.00	29	27.10	24	26.00	29.5	26.10	24	25.00
Electric conductivity (µScm^{-1})	711	541.00	-	-	661	582.00	-	-	550	687.00	-	-	480	608.00	-	-
Total dissolved solids (ppm)	564	390.00	-	-	496	441.00	-	-	300	433.00	-	-	295	468.00	-	-
Salinity (ppm)	351	218.00	-	-	301	256.00	-	-	255	265.00	-	-	220	278.00	-	-
Turbidity (NTU)	22.9	24.00	17.7	14.60	24.4	22.50	-	8.06	17.5	57.10	7.05	12.40	12.2	24.40	8.77	9.85
Dissolved Oxygen (mgL^{-1})	10.98	6.50	8.29	10.4	7.2	7.80	6.50	11.05	5.854	9.88	1.22	-	6.667	10.73	2.76	-
Biological oxygen demand (mgL^{-1})	5.42	6.50	5.42	18.44	14.92	16.26	3.25	13	20.34	15.00	2.03	13.7	16.00	14.00	3.9	14
Chemical oxygen demand (mgL^{-1})	32.00	20.00	13.33	17	23.00	26.67	17.60	18	32.00	26.00	8.00	16	23.00	19.50	16.00	14.4
Nitrates (mgL^{-1})	0.08	0.18	0.085	0.254	0.06	0.11	0.084	0.153	0.06	0.14	0.634	0.149	0.08	0.06	0.161	0.327
Phosphates (mgL^{-1})	0.017	0.16	0.046	0.052	0.004	0.02	0.225	0.11	0.025	0.13	0.008	0.046	0.1	0.04	0.098	0.028
Total Hardness (mgL^{-1})	300	232.00	160.00	160	364	240.00	204.00	180	284	148.00	148.00	172	144	148.00	160.00	500
Calcium Hardness (mgL^{-1})	16	88.00	80.00	24.04	36	68.00	88.00	32.06	160	36.00	60.00	32.06	76	44.00	44.00	32.06
Magnesium Hardness (mgL^{-1})	296.096	144.00	80.00	24.388	355.216	172.00	116.00	24.384	244.96	112.00	88.00	22.432	125.456	104.00	116.00	4.86
Alkalinity (mgL^{-1})	400	87.50	240.00	666.66	420	70.00	300.00	700	340	77.50	100.00	733.33	360	67.50	260.00	566.66
Chlorides (mgL^{-1})	31.24	187.44	130.64	113.6	39.76	184.60	136.32	122.12	31.24	139.16	127.80	136.32	34.08	130.64	110.76	127.8
Sodium (ppm)	60.9	44.20	3.4	19.49	71.5	44.10	3.4	18.38	32.1	35.20	2.8	18.381	31	34.70	2.6	18.93
Potassium (ppm)	3.1	2.40	1.7	0	3.7	2.60	1.6	0	3	3.20	2.5	0	2.8	3.30	2.1	0

Materials and Methods

Water quality analysis: Water samples from all four wetlands were collected during 4 months viz., August, September, October and November 2010. Samples collected from 10 to 30 cm below the surface of water during the morning hours and stored in disinfected plastic bottles. On-site water analysis included water temperature, pH, turbidity, salinity, electrical conductivity, total dissolved solids and dissolved Oxygen. No preservatives were added as the samples were transported to laboratory and refrigerated for subsequent analysis. Laboratory analysis includes total alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, calcium hardness, Magnesium hardness, Potassium, Sodium, nitrates (NO^{3-}), inorganic phosphates (PO_4^{3-}) and chlorides (Cl^-). These water analyses were followed as per standard procedures published by the American Public Health Association (APHA, 1998) and Chemical and Biological methods for water pollution studies, (Trivedy and Goel, 1986).

Diatom analysis: Diatoms have been collected from habitats such as epilithic, (found in stones) epiphytic (found in plants) and episammic (found in sediments) of four wetlands were collected during the month of September 2010. Cleaning and identification of samples is done following Laboratory procedure as per Taylor *et al.,* 2005 and Karthick *et al.,* 2010. Samples are cleaned following Hot HCl and $KMnO_4$ method and slides were prepared using Pluerax as the mounting medium. Relative abundance of each taxon was determined after counting at least 400 valves in each sample using light microscope. Identification of diatoms has been done following key characters mentioned by Krammer and Lang-Bertalot (1986-1991), Round *et al.,* (1990) and Gandhi (1957a-1959d).

LULC analysis: Shuttle Radar Topography Mission (SRTM) data is downloaded from CGIAR Consortium for Spatial Information (CGIAR-CSI). Digital Elevation Model (DEM) was generated using ENVI 4.7 version. The digitized Wetlands were overlayed on the DEM. The drainages were digitized using toposheet of Bangalore, 1972. Catchment of these four Wetlands was delineated using the topographic maps of 1:50000 and referring the digitized drainages. LULC for each catchment was assessed using IRS 1D data (October 2006). IRS data was geo-referenced using image-to-image registration. Training data is collected from field using pre-calibrated handheld Global Positioning System (GPS). IRS data were classified using supervised classification techniques with the Gaussian maximum likelihood classifier into three classes – vegetation, water body and built up. Accuracy assessment was done to validate the classified data.

Statistical analysis: Variation in water quality and diatom species distribution across sites is analysed using PAST software, version 2.11. Canonical correspondence analysis (CCA) included data of 8 abundant diatom taxa (RA >10% at least in 1 sampling site), 17 environmental across 8 sampling sites during 4 month period to evaluate role of environmental variables (water quality and land cover type) in structuring diatom communities.

Results and Discussion

Water Quality Analysis

Varthur Wetland: The overall water quality parameters measured are listed in Table 1. pH was recorded as neutral to slightly alkaline with lowest and highest at VTI (7.1) in October and VTI (8.5) in November respectively. Electric conductivity and total dissolved solids values were consistent with a narrow range of 823 to 948 mgL^{-1} and 636 to 730 mgL^{-1} respectively. Hypoxic and even anoxic condition due to low dissolved oxygen was observed at VTI site (1.22 mgL^{-1}) and at VTO site as well with a range of 1.63 -7.15 mgL^{-1}. This attributed to the presence of water hyacinth covering the water surface with heavy domestic organic load and decomposition of organic matter. This condition is also reflected in elevated concentrations of BOD and COD with exceeding permissible limits at all sampling sites across months (Table 1). Total hardness (236-420 mgL^{-1}), alkalinity (55-440 mgL-1) and chlorides (119.28-153.36 mgL^{-1}) were recorded very high due to sewage inflow.

Yellamma Wetland: pH was recorded as neutral to slightly alkaline with lowest at YMO (7.20) in the month of October and highest at YMI (8.90) in the month of September. Electric conductivity and total dissolved solid values show a significant range. In September, YMO showed a less EC value of 863 μScm^{-1} and Yellamma inlet showed high value of 1120 μScm^{-1} owing to high ionic concentrations inflow from industrial wastes. Dissolved oxygen content varied in both inlet and outlet ranging from 0 to 5.04 mgL^{-1}. DO was less than measurable amount in the month of October in YMO and September in YMI reasoning to high organic load. In the month of August DO of 4.22 mgL^{-1} in YMI and 5.04 mgL^{-1} in YMO was observed. The discharge of sewage containing organic material from the nearby factories contributed to this situation. This condition was also reflected in elevated concentrations of BOD and COD with exceeding permissible limits at all sampling sites across months (Table 1). In the month of October no sampling could be done in Yellamma inlet due to blockage on account of immersion of idols (Ganesha).

Nelakondoddi Wetland: pH ranged from 7.94 at NKO site (Sep) to 8.60 at both the sites (Nov) indicating slightly neutral to alkaline nature of water and within the permissible limits (Table 2). EC, TDS and salinity ranged from 480 to 687 μScm^{-1}, 295 to 468 ppm and 220 to 278 ppm respectively indicating low mineralization in this Wetland. However, slight gradation was observed in September due to monsoon climate. DO at all sampling sites was within the permissible limit and ranged from 6.5 mgL^{-1} at NKI to 11.05 mgL^{-1} at NKO. The higher DO recorded during monsoon and post monsoon seasons (i.e., Oct and Nov) may be due to the impact of rain water resulting in aeration (Ayoade et al., 2006). A huge variation in BOD (5.42 to 16.26 mgL^{-1}) and COD (13.33 to 32 mgL^{-1}) was studied across months, the highest value of BOD being in the November month (18.44 mgL^{-1} at NKI) and COD being highest at both sites in August month (Table 2).

Vaderahalli Wetland: The pH in both sites indicates slightly alkaline ranged from 8.20 to 9.11 (Table 2). Water temperature varied depending on the time of sampling with a range of 24 to 29.5 ^{0}C. EC, TDS and salinity ranged from 541 to 711 μScm^{-1}, 390 to 564 ppm and 218 to 351 ppm respectively indicating low mineralization in this Wetland. However, slight gradation was also observed in September due to monsoon climate. DO at all sampling sites was within the permissible limit and ranged from 5.854 mgL^{-1} at VHI to 10.73 mgL^{-1} at VHO except in October where the DO was observed to be very low. A huge variation in BOD (2.03mgL^{-1} to 20.34 mgL^{-1}) and COD (8 mgL^{-1} to 32 mgL^{-1}) was studied across months being within the permissible limits, the highest value of BOD and COD being in the August month. (Refer Table 2).

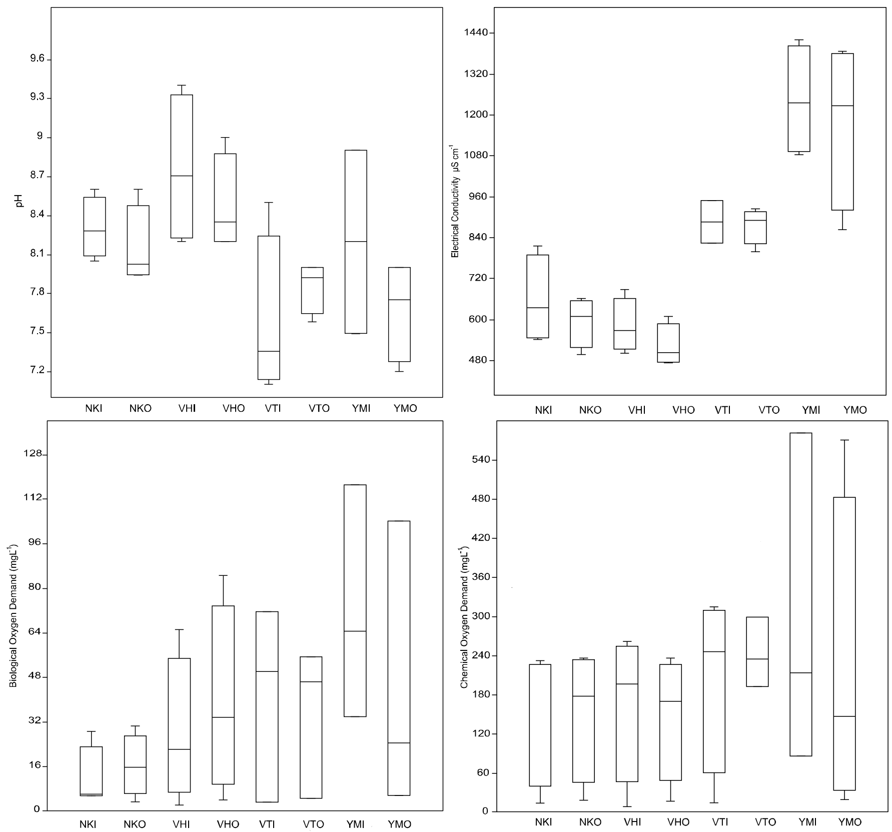

Figure 2: Variation in water quality across sampling sites [For sampling sites and its codes refer annexure I](a) pH (b) Electric conductivity (c) Biological oxygen demand (d) Chemical oxygen demand

Water Quality across Wetlands

The level of pollution status and spatial distribution of Wetlands from urbanized area is well reflected by water quality. Across Wetlands, pH was recorded as slightly alkaline with minimum of 7.6 at Varthur inlet and maximum of 8.75 at Vaderahalli inlet. EC, turbidity and TDS at Varthur and Yellamallappa chetty was in extremely high concentrations due to high cation concentrations. EC was more than the permissible limit at Yellamallappa chetty inlet (1101.50μScm^{-1}) and high turbidity of 94.9mgL^{-1} in Varthur inlet and high TDS of 857.5 was observed in Yellamallappa chetty inlet. These parameters were low in Vaderahalli inlet with 6.18$\mu Scm^{-1}$of EC, turbidity of 13.81 NTU and total dissolved solids of 366.50 mgL^{-1}. These parameters show marked seasonal variations (Awasthi and Tiwari, 2004). As in figure 2and 3, BOD and COD values reflected high pollution at Varthur, Yellamallappa chetty and Nelakondoddi sampling sites but contradictory values were observed in Nelakondoddi and Vaderahalli with a range of 8.959 to 12.97 mgL^{-1}. The study by Atobatele et al., 2008 shows pH, conductivity, temperature and dissolved oxygen as important parameters contributing to the annual variability of Wetland water. Dissolved oxygen concentration was found very less in all sampling sites of Varthur Wetland and Yellamallappa chetty Wetlands compared to other two Wetlands, which is quite evident by heavy organic load and macrophyte cover and hence reduces redox potential of the system.

Diatom Distribution

Fifty eight species belonging to 29 genera has been recorded and are listed in annexure 1. The dominant taxa were *Achnanthidium* sp., *Gomphonema*. *parvulum* (Kutzing var. *parvulum* f. *parvulum*) *Gomphonema* sp., *Nitzschia palea* (Kutzing) W.Smith, *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot, *C. meneghiniana* Kutzing, *Cymbella* sp. and *Fragilaria* sp. Most of the species occurred in polluted regions are recorded as cosmopolitan (Taylor *et al.,* 2007). The diatom community structure shows a strong correlation with various environmental variables (Soininen *et al.,* 2004). The species such as *G. parvulum, C. meneghiniana, N. palea* and *N. umbonata* are tolerant to high electrolyte and organic rich condition (Karthick *et al.,* 2009) which inhabited Varthur and Yellamallappa chetty Wetlands. This clearly signifies that both these Wetlands are polluted and eutrophic in condition. Nelakondoddi and Vaderahalli show low electric conductivity, BOD and COD values and were dominated by *Achnanthidium* sp., *Gomphonema* sp. and *Cymbella* sp. These species were recorded as inhabiting in moderate pollution.

Temporal variation and diatom distribution across Wetlands

The monthly variation in water quality was reflected by diatom community composition. *G. parvulum* and *N. palea* were dominated in all months at Varthur outlet while *N. linearis* was recorded as abundant in October at Varthur inlet notifying the pollution level. *C. meneghiniana* and *N. palea* was dominant across months at both sampling sites in Yellamallappa chetty followed by *G. parvulum* in October at Yellamallappa chetty outlet. Diatom species such as *Achnanthidium sp, Gomphonema sp* and *C. kappi* (Cholnoky) Cholnoky being dominant at Vaderahallli Wetland resembled a different community structure than former Wetlands. Ecological significance of *Achnanthidium* sp. needs to be studied as it shows a wide range of occurrence, from oilgotrophic to slightly mesotrophic condition.

Temporal variation is a significant factor responsible for changes in diatom distribution and its abundance (Sivaci *et al.,* 2008). In Nelakondoddi outlet (NKO), *N.palea*, which was dominant in the month of August, was replaced by *C. kappi* and *Mastogloia smithi* Thwaites in September. However, *Achnanthidium* sp. dominated in October followed by *Achnanthidium* sp. together with *Navicula* sp. in November. *C.kappi* was dominant in September which was followed by *N. amphibia* Grunow *f.amphibia* and *Achnanthidium* sp. reflecting moderate trophic status. The eutrophic status and electrolyte rich was significant in November with the dominance of *Fragillaria. biceps* (Kutzing) Lange-Bertalot and *N. linearis* (Agardh) W Smith.

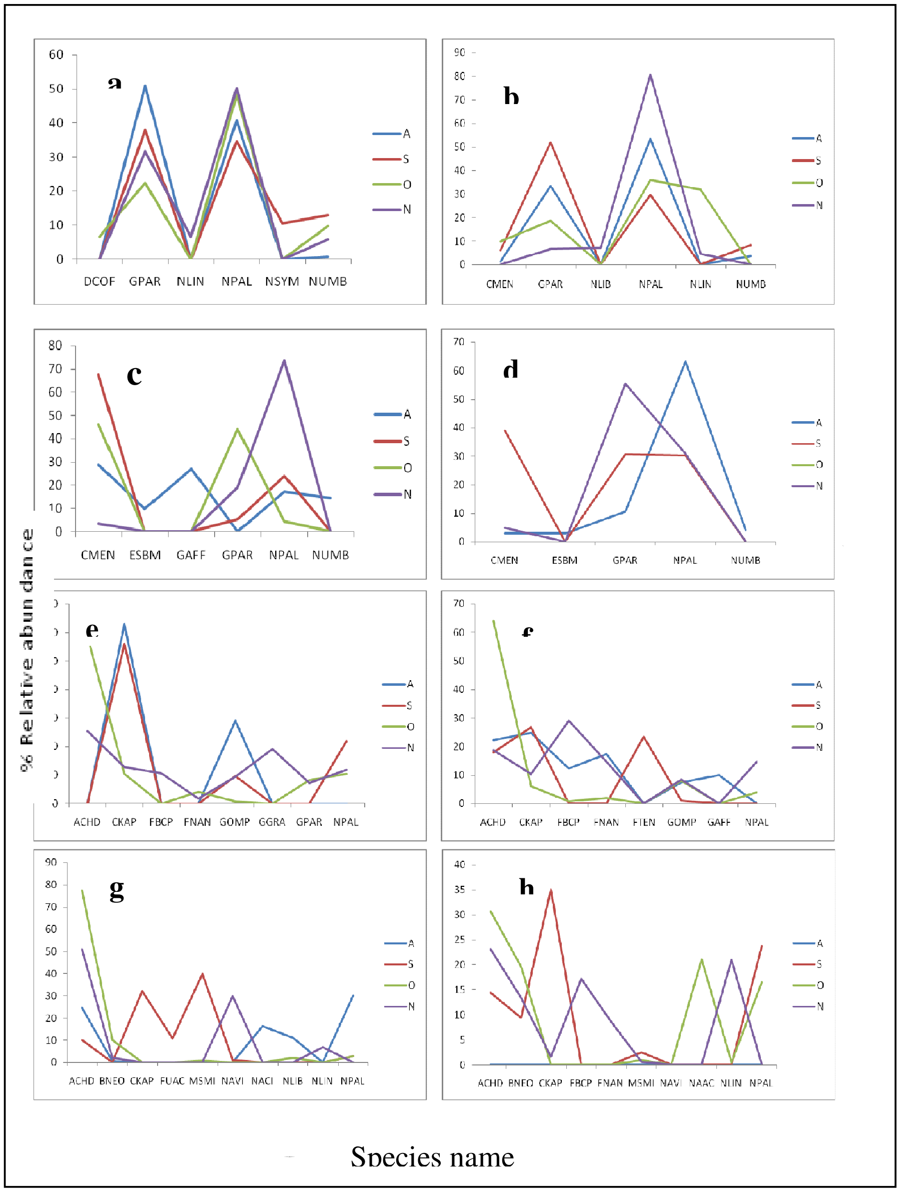

Figure 3: Percentage relative abundance of species across months [A-August, S-September, O-October, N-November] (a) Varthur Siddapura (b) Varthur Fishing (c) Yallamma Outlet (d) Yallamma Inlet (e) Vaderahalli Outlet (f) Vaderahalli Inlet (g) Nelakondoddi Outlet.

Relationship between dominant taxa and Water Quality

CCA triplot explained 65.43% of the variability in the diatom and environmental data with 45.92% in axis 1 and 19.51% in axis 2 (Figure 4; Table 3). Monte Carlo permutation test (n=1000) showed that both axes were statistically significant ($p<0.01$). The ordination of sampling sites was based on the species composition and their relationship with environmental and land-cover variables. The axis 1 represented an urban to rural gradient, where rural sampling sites were ordinated towards the right side and urban sites were on the left side. The sampling sites on the right side were Vaderahalli and Nelakondoddi sites while clustered on the left side were Varthur sampling sites. Axis 2 represented Nelakondoddi and Vaderahalli sites and dominance of ACHD on the right side of the axis. Axis 1 was significantly negatively correlated with variables such as EC, TDS, Turbidity, P, K and % built up and taxa such as NUMB, GPAR and NPAL Likewise, a significant positive correlation of axis 1 was observed with DO, pH and % vegetation along with dominance of CKAP and GGRA. There was no significant correlation of BOD, COD, sodium and chlorides with both axes.

Table 3 Correlation coefficients between selected environmental variables and the first two CCA axes (Significant correlation $p<0.01$).

CCA axes		
Variables	**1**	**2**
Eigen value	**0.725**	**0.308**
pH	0.621	0.25
Conductivity	-0.8588	-0.137
TDS	-0.876	-0.155
Turbidity	-0.77	-0.006
P	-0.6566	-0.095
N	-0.367	0.256
K	-0.909	-0.021
Sodium	-0.211	0.365
BOD	-0.380	0.227
COD	-0.36	0.257
DO	0.663	0.170
Chlorides	-0.414	0.14
% Built up	-0.920	-0.084
% Vegetation	0.928	0.075

Ecological preference of dominant taxa

Figure 5 illustrates the occurrence of dominant taxa at differing water quality. The dominant taxa *G. parvulum* (GPAR), *C. meneghiniana* (CMEN), *Achnanthidium* sp. (ACHD) and *N. palea* (NPAL) at varying pH and EC show the dominance of particular taxa at respective pH and EC optima . *G. parvulum* was persistent across months and abundant at pH ranging from 7.6 to 8 and was less towards alkaline pH. The electric conductivity more than 850 μScm^{-1} attributed to *G.parvulum* optima while sampling sites less than 700 μScm^{-1} comprised a different composition with *G parvulum* as less in abundance. *C. meneghiniana* was recorded to be more dominant at pH of 7.7 to 7.9 and as the EC increases (>900 µScm^{-1}). This range of pH and EC limits the distribution of *G.parvulum* and *C. meneghiniana* to extremely eutrophic water condition. The sensitivity and tolerance of diatoms to such specific environmental factors attributed towards the species- specific ecological characterization (Sabater *et al.,* 2007).

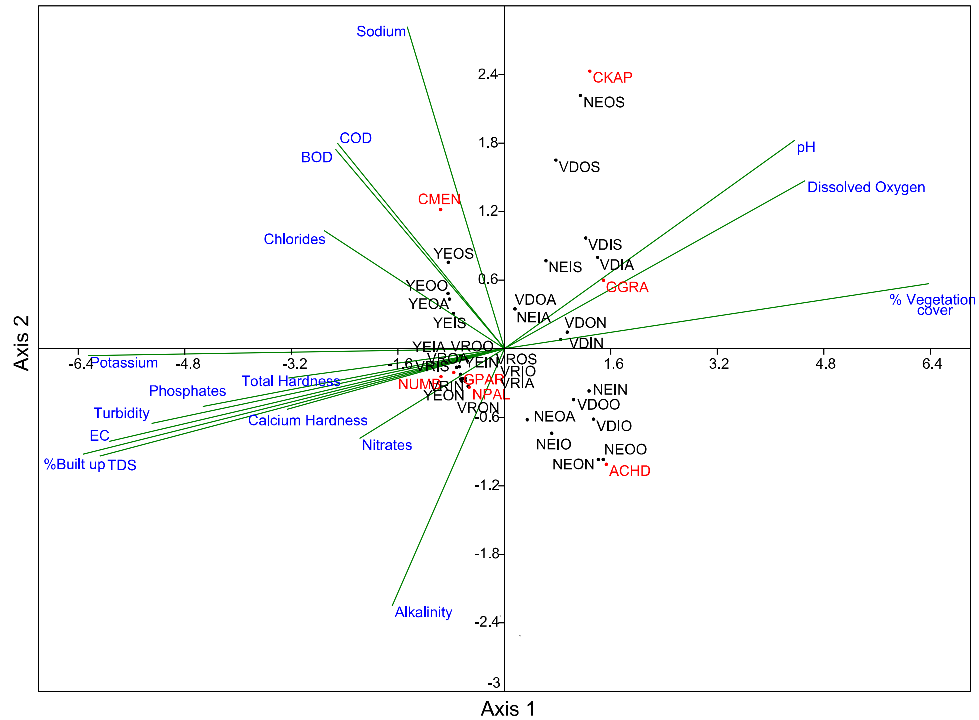

Figure 4 Canonical correspondence analysis (CCA) plot explaining impact of land use/ land cover on species distribution.

Achnanthidium sp. was present at all sampling sites whilst, the abundance was optimum at pH 8.1 to 8.2 and at EC 600 to 650 µScm^{-1} and later decreased at elevated EC concentration. *N. palea* was present at all sampling sites and revealed a wide range of optima though was less abundant at alkaline pH. *N. palea* was also abundant at its optima of EC i.e., more than 850 µScm . Low EC concentration (<800 µScm^{-1}) was limiting the distribution of *N. palea*. Thus, in consideration with observed species autecological values the sampling sites with profuse *Achnanthidium* sp. can be classified as oligo to slightly eutrophic at the same time as, the sampling sites with *N.palea* can be classified as in eutrophic status and extremely polluted. However, many studies have investigated autecological status of indicator species (Taylor *et al.,* 2007; Álvarez-Blanco *et al.,* 2010), very less study contributes to species optima of *Nitzschia* sp., *Gomphonema* sp., and *Achnanthidium* sp. and further none of the study come from Asia region. However, ecological optima of *N. palea* can be classified as eutrophic status. Performing the ecological optima for few more taxa that commonly occur in wetlands of Bangalore can lead to developing specific diatom indices for bioassessment practices.

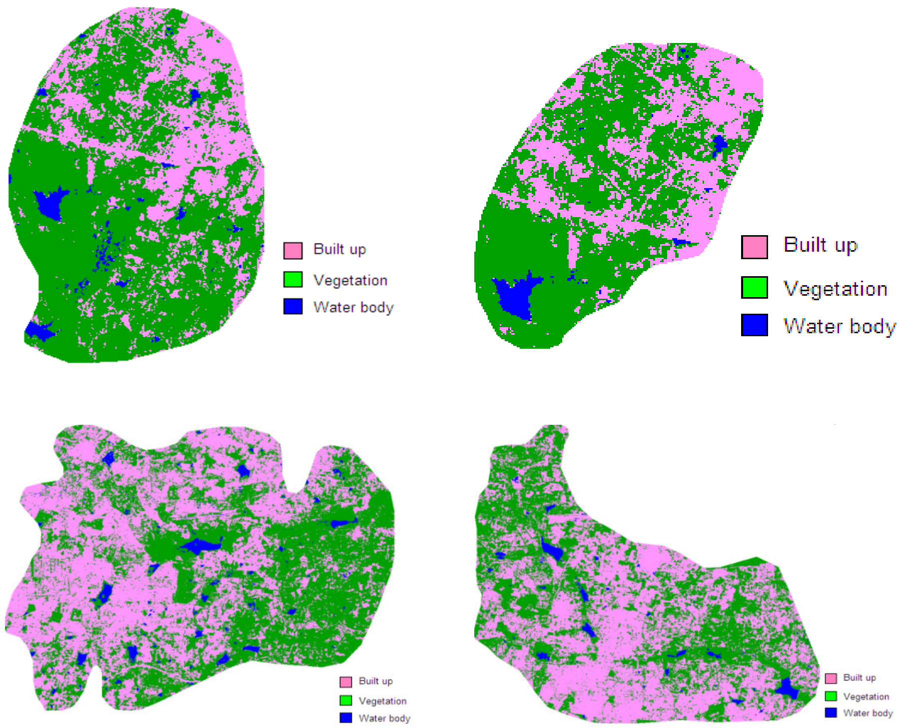

Figure 6: Land use in the catchments of . (a) Nelakondoddi, (b) Vaderahalli, (c) Varthur and (d) Yellamma wetlands.

Chattopadyay et al., (2005) also report of the similar scenario of urban landuse with poor water quality throughout the year. The increased amount of organic concentration and degradation in water quality is mainly due to increasing urbanization (built up) at Yellamma and Varthur regions (Chandrasekhar et al., 2003). In contrast to this situation, vegetation in Vaderahalli catchment (61.21%) and Nelakondoddi catchment (65.98%) is higher compared to the built up land (35.96% and 31.48% respectively). This analysis also shows that the influence of anthropogenic activity was less in these two wetlands. Majority of the area is under vegetation (with less human interventions) and thus less chances of contamination of water compared to the wetlands situated in urban region. LULC changes influence varying diatom community composition (Soininen et al., 2004, Weijter et al., 2009). Yallamallappa chetty and Varthur Wetlands are having high percent of built-up with high sewage and industrial inflow into the Wetland. Diatom community comprised of pollution tolerant species reflecting trophic status. The high percent of vegetation (including forest) cover at Nelakondoddi and Vaderahalli Wetland comprised species, which inhabit oligo to slightly mesotrophic conditions.

Pandey and Verma, (2008) study illustrates that the catchment integrity is significant in determining ecosystem properties of freshwater Wetlands. Li et al., (2010) focused on rapid landscape change and regional environmental dynamics in the Lianyungang bay area from 2000 to 2006 based on remote sensing data indicating that the area has a widespread urban–rural interface with rapid land-use changes, urban expansion and wetland degradation. Rapid increase in urban built-up land has led to large-scale salt wetlands degradation. Allan et al., (1997) highlight that in streams, habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to stream sites. Understanding the effects of changes in land use and land cover (LULC) is important for maintaining a desired level of water quality and also for restoring water quality in affected areas (Gove et al., 2001).

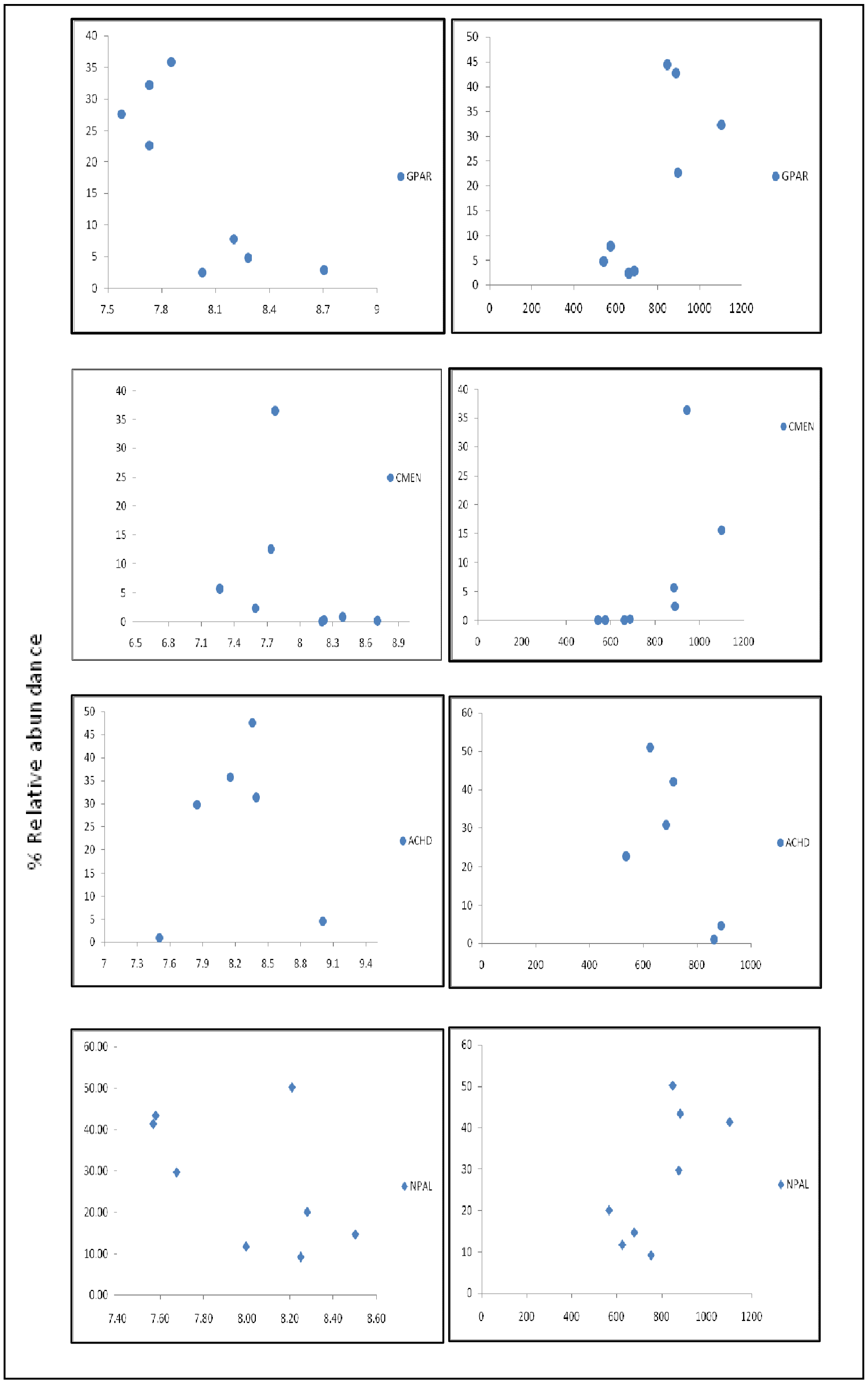

Figure 5 Distribution and autecology of dominant taxa across pH and Electric conductivity

Table 4 Land use/ Land cover classification of selected 4 Wetlands of Bangalore

Class (%)	Nelakondoddi	Vaderahalli	Varthur	Yellamma
Vegetation*	65.98	61.21	45.85	42.90
Built up**	31.48	35.96	55.16	51.68
Water body	2.61	2.82	2.46	1.92

*Vegetation includes cropland, plantation, forest and algal cover.
**Built up include open space also.

Conclusion

LULC changes in the wetland catchment alter the physical and chemical integrity of the system, which influences the diatom community structure. Wetlands with eutrophic water quality conditions were dominated by pollution tolerant diatoms, whereas less polluted wetlands were characterized with diatoms corresponds to oligotrophic – mesotrophic class. Water quality is a decisive parameter in diatom community structure in the respective wetland, even though rainfall seems to have certain influence on diatom succession.

More area of built up in the catchment of Varthur and Yellamallappa chetty increase stress on these wetlands which in turn result in high pollution. Vaderahalli and Nelakondoddi wetlands which is having more vegetation than built up is comparatively facing less disturbance and thus less polluted. Varthur and Yellamallappa chetty wetlands are located in densely populated region with tolerant species whereas wetlands such as Vaderahalli and Nelakondoddi are situated in sparsely populated area and have sensitive species. These results signify that urban wetlands are under severe stress. Thus, catchment characteristics are critical in determining biota of freshwater bodies, thus plans for conservation of wetlands should also be seen at catchment scale, rather than looking wetlands as isolated ecosystem. Ecological preference observed in this study will also lead to development of diatom indices, which can be applicable to monitoring of tropical Asian wetlands.

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Ecological and Socio-Economic Assessment of Varthur Wetland, Bengaluru (India)

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Wetlands are the most productive ecosystems, recognized globally for their vital role in sustaining a wide array of biodiversity and provide goods and services But presently increased anthropogenic activities such as intense agriculture practices, indiscriminate disposal of industrial effluents and sewage wastes have altered the physical, chemical as well as biological processes of wetlands, which is evident from the present study carried out to assessVarthur wetland in India Coastal wetland ecosystem in the world has 14,785/ha US$ annual economic value An earlier study of relatively pristine wetland in Bengaluru revealed the value of ₹ 10,435/ha/day while the polluted wetland showed the value of ₹ 20/ha/day On the contrary Varthur, a sewage fed wetland has a value of ₹ 118.9/ha/day The pollutants and subsequent contamination of the wetland-Varthur has telling effects such as disappearance of native species, dominance of invasive exotic species (such as African catfish), in addition to profuse breeding of disease vectors and pathogens Water quality analysis revealed high phosphate (4 22-5 76 ppm) level in addition to the enhanced BOD (119-140 ppm) and decreased DO (0-1 06 ppm) The amplified decline of ecosystem goods and services with degradation of water quality necessitates the implementation of sustainable management strategies to recover the lost wetland benefits of Varthur

Key words : *Urban wetlands, ecosystem services, water quality, urbanization, conservation strategies*

Introduction

Wetlands represent a combination of aquatic and terrestrial environment, in which the soil is seasonally or permanently covered by shallow water and the water table is close to or near the surface[1 2]. Wetland covers thousands of square kilometers; at spatial scale ranging from a crack in the rock to rain forest or ocean Being highly productive, in terms of biodiversity and as well ecosystem's benefits; human community derive, directly or indirectly from ecosystem functions Ecosystem functions refer varyingly to the habitat, physical and biological benefits/processes of the ecosystem[3]. On a larger scale, anthropogenic activities impact physical, chemical and biological processes, which impair the ecosystem functioning[4] causing decline and degradation of ecosystem services and also economic value of the wetland[5]. Wetlands predominantly endure change in wetland hydrology and habitat, loss of catchment area adjacent to urban growth, increasing runoff of nutrients and pollution, introduced species replacing indigenous species, land clearance and over-use of resources by losing its subsistence economies of that region mainly due to urbanization The benefits which may be lost are not effectively quantified in viable markets and also in terms comparable with economic services, are often specified with too little weight in policy decisions Hence, quantifying economic values of ecosystem are essential to respite human activities apart from accounting their services in the regional planning

Valuation entails assigning an economic value in direct market for all the benefits (such as food, fodder, remediation, clean water, biodiversity, groundwater recharge, etc) of wetlands Nevertheless, the possible way of addressing the economic value is to estimate the value which is exactly the price payable to replicate the natural ecosystem[3] or the price estimated/ paid for the same in direct market by means of economic valuation

Economic valuation

Economic valuation is an attempt to assign values in terms of market price for the goods and services offered by the ecosystem In Economic terms, the goods and services are broadly grouped as use and non-use values[6] as indicated in **Table 1** Valuation technique includes "willingness to pay" reflecting individual's choice for the ecological commodities (aesthetic value, recreational opportunities), wood products and intrinsic values[7,8] and also captures its values in an economic value framework[9]. The commonly used technique for the valuation is the contingent valuation technique based on personal interactions with the local people using questionnaires; information on willing to pay for something they value or willing to receive in compensation for tolerating a cost

The zero ecosystem benefits imply zero human welfare[3], thus economic value of a wetland varies from a pristine

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Table 1: Classification of total economic value for wetland

Use Values			Non - Use Values
Direct use values	**Indirect use values**	**Option value & Benefits**	**Existence value**
Fish, Agriculture, Fuel wood, Fodder, Recreation,(Boating, Fauna, Walking) Transport, Wildlife, harvesting, Peat/ Energy Education	Nutrient retention, Flood control,Storm protection,Ground water recharge,External ecosystem support, Filtration,Micro-climate, Shoreline stabilization	Potential future use (as per direct and indirect use). Future value of information, e g., pharmaceuticals, education.	Biodiversity,Culture, Heritage,Bequest

Source [14]

(natural benefits) to polluted (degraded ecosystem's benefits) wetland; influenced by a defined set of environmental conditions Wetland value increases with quality of goods and services derived and vice versa.

Numerous studies on economic valuation of wetlands have been carried out around the world; however, most of these studies have focused on wetlands in developed countries[11]. Economic studies for Indian wetland are meager addressing serious threats due to agricultural conversion, hydrological alteration followed by urbanization in recent years owing to 60 % loss

Several studies across countries in the past few decades support the estimation of economic value of a wide variety of goods and services. The annual value of wetland was estimated to be second highest, US$ 14 785/ha based on the assessment of 17 ecosystem services in 16 biomes which emphasize that ecosystem functions provide an important portion to the total contribution to human welfare[3] Other studies include wetlands of Africa[11], China[12], Bangladesh[13] and the European water framework directive of European Union (EU) (2000/60/EC). Assessment of the health of wetlands in China highlights that among all factors, water quality, ecosystem function and structure of waterfront area as the main factors that limit the wetlands value. Study of Mississippi Alluvial Valley focuses on the restoration of wetland ecosystem services in the floodplain area which has profound consequences due to habitat loss, fragmentation, flood storage loss and water quality degradation due to non point source runoff[14]

Many wetlands in India including those in Bengaluru are being degraded due to the apathy of the decision makers and planners. These wetlands, urban as well as rural, paved way to residential layouts, industrial complexes and indiscriminate disposal of urban wastes which has led to the deteriorating water quality and significant changes in local climate. Number of wetlands has dwindled from 250 to 81 (1985) and 33 in 2006[15]. Population of Bengaluru reached 7 million in 2007[16] due to the spurt in unplanned urbanization and consequent land use activities Effect of sustained inflow mainly of sewage, industrial effluents and agricultural runoff is evident from the results of regular monitoring of water quality at Hebbal, Varthur, Madiwala, Rachenahalli and Amruthalli wetlands[17]. A comparative evaluation of Amruthhalli lake with the relatively unpolluted Rachenahalli lake[2] brings out the impact of degrading ecological integrity of wetlands evident from the drastic decline of values from ₹ 10, 435/ha/day (Rachenahalli lake) to ₹ 20/ha/day (Amruthalli lake). Lower value is mainly due to eutrophication and water being unavailable for any use with an excessive nutrient inflow (sewage and industrial effluents) and storm water. Discharge and dumping of waste into catchment area lead to high levels of phosphates, Total Suspended Solids (TSS), Alkalinity, Hardness, Odour, weed infestation and low dissolved oxygen (DO) Study of Hebbal lake also reflects decreased water quality due to excessive sewage and industrial effluents inflow from surrounding area The Contingency valuation technique employed for preliminary socio-economic survey reveal high level of dependency on wetlands for groundwater, food, fodder, fuel and so on. The lake supports irrigation, provides food (fish, etc.) and fodder to the livestock in the surrounding areas The investigation of causes of mass fish mortality in Sankey Lake[18] revealed that the death was due to a sudden and considerable fall in dissolved oxygen (DO) levels in some locations caused by sewage let into the lake resulting in asphyxiation. An incidence of mass-scale fish mortality in Bengaluru reported from Ulsoor Lake[19] supported the above study These studies highlight the significance of maintaining wetland's quality to ensure sustained ecological functions contributing to economic values.

Bengaluru was known for its lush greenery with numerous wetlands, Varthur wetland being one of the largest amongst all. Rapid unplanned urbanization coupled with the increase in population has affected both Bengaluru and its surrounding towns and villages, including Varthur[15]. Varthur lake constructed 1000 years ago by Ganga rulers, today receives almost 40% of Bengaluru sewage to the extent of 450-500 minimum lethal dose per day (MLD/day). Part of city's untreated sewage passes through the network of interconnected lakes such as Bellandur and Ulsoor apart from many households directly in the immediate vicinity in a span of 220 hectares. The quantum of sewage exceeds the wetlands ability to assimilate contaminants and hence water quality has declined and has become unfit for human consumption. The contaminated water from Varthur ultimately flow downstream connecting Dakshina Pinakini River. Considering the dependence and impaired livelihood due to decline in ecological functional ability and capability consequent to sustained inflow of sewage and effluents, necessitates the ecological restoration of the lake. This entails understanding of the physico-chemical aspects with the wetland dynamics and the valuation of ecosystem services and goods. The study was carried out with a hypothesis that accumulation of contaminants has been responsible for degradation of water quality and consequent erosion of ecosystem services and goods. In this backdrop, Varthur wetland was investigated for water quality and valuation of the benefits to understand the drivers responsible for wetland degradation and impairment of economic benefits.

The study objectives were to: 1 assess physicochemical water quality variables and 2 economic valuation of wetlands through contingent valuation technique, focusing on the causes for wetland degradation and appropriate allocation of wetland use.

The study region

The study was carried out in Varthur wetland, one of the largest wetland located to the south of Bengaluru with 12.940699°N and 77.746596°E geographic position and a surface area of 220 sq. km. The wetland water accounts to irrigate 625 hectares of agricultural fields in the command area, for growing crops like rice, ragee, coconut, flowers and a variety of fruits and vegetables. It provides habitat for a wide variety of flora and fauna, including resident and migratory waterfowl. The inlet receives sewage and industrial wastes, contaminating not only wetland water quality but also Pinakini river at the downstream. Decreased water quality in recent years has influenced the economical significance of wetlands. **Fig.1** represents the study area and sampling points.

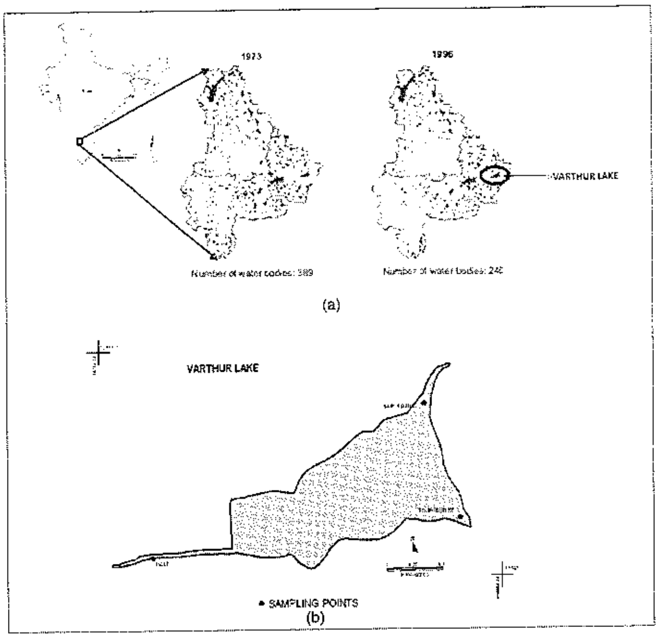

Fig. 1: (a) No. of water bodies in Bengaluru in 1973 and 1996 and (b) Varthur Lake with samplig points (inlet, north outlet and south outlet)

Methods

Water quality analysis

Water samples (triplicates) were collected from three sites viz. inlet (12°56'35.99"N lat. and 77°44'5.32"E long.), south-outlet (12°56'43.91"N lat. and 77°44'48.21"E long.) and north outlet (12°57'22.86"N lat. and 77°44'40.56"E long.) in Varthur wetland during February 2009. Samples were stored in polythene bottles and were carried to laboratory for further analysis. Dissolved Oxygen was analyzed on-site using 125mL BOD bottles. Physical variables like pH, temperature (°C); total dissolved solids (mgL^{-1}); salinity (mgL^{-1}) and electric conductivity (μScm^{-1}) were measured using EXTECH EC500 Probe immediately after collection. Other water chemistry variables like chloride, hardness, magnesium, calcium, sodium, potassium, nitrates and phosphates were analyzed in laboratory and analyses were carried out as per the standard methods for the examination of water quality as mentioned[20]

Socio-economic survey

A contingency valuation technique was applied for the economic survey of wetland through a participatory approach involving local school students. 235 people from 43 randomly selected households from Varthur and nearby villages were interrogated using a standard questionnaire by KK High School students (VIII to X grade), Bengaluru. The questionnaire was made to quantify use-values of the lake including demographic information, domestic water usage, irrigation, fishing and aquaculture, water usage for livestock, livestock fodder, groundwater recharge, health effects and family history. Valuation of resources through the survey was aimed to evaluate the economic status and dependency of residents. Demographic information included total number of persons/houses, occupation and income per annum which relate to the dependency of residents on lake domestic water usage, irrigation, fishing and aquaculture, water usage for livestock and livestock fodder in turn the dependency of residents on lake water, aquatic plants and organisms The use of groundwater resources highlights the indirect association with the Varthur lake, responsible for recharging local aquifers.

Results

Water quality analysis

Characteristics of water collected from various sampling sites are mentioned in **Table 2**. pH ranged from 7.5-7.7 across sampling sites Conductivity was found to be high in inlet (1420 µS) compared to outlet sampling sites (South outlet, 1075 and North outlet, 1224 µS) Higher conductivity value at inlet was mainly due to the sustained sewage inflow and dissociation of minerals from soil Total Dissolved Solids which account for the amount of sedimentation did not show much variation (749-994 ppm) in lake Dissolved Oxygen (DO) was 0 ppm and 1.06 ppm as observed in inlet and north outlet respectively while at south outlet 8.16 ppm was recorded. Biological Oxygen Demand (BOD) was higher (119-140 ppm) at the inlet which confirms the inflow of higher amount of nutrients into the lake Chemical Oxygen Demand (COD) range (124-188 ppm) indicated the presence of increased oxidizable load. This highlights the anoxic conditions prevailing at inlets. Total hardness and alkalinity were found in the range of 236-288 ppm and 400-420 ppm respectively. The sodium and potassium values were174-180 ppm and 19-21 ppm respectively. Nitrates and phosphates varied from 0.31-0.55 ppm and 4.22-5.76 ppm respectively. Phosphate concentrations were found above the permissible limits.

Socio-economic survey

235 people from 43 houses were surveyed for evaluating the level of dependence for goods and services of Varthur Lake, which are listed in **Table 3**.

Domestic use: Few residents in the catchment area depend on lake for domestic usage due to its poor quality. Among all, 15 houses rely on bore wells Groundwater or bore well water usages are categorized as indirect use value as wetlands play significant role in recharging the groundwater sources in and around catchment area. On an average 5 individuals in a house utilize 200 liters of water per day. The dependency value is ₹ 25, 000 per house per year. For drinking water the amount spend on bottled water accounts to ₹ 30,000 per house per year.

Agriculture: Among 43 households surveyed, 35 houses depend on agriculture for livelihood. Wetland water is utilized for irrigating a total land area of 24.28 ha for growing mainly paddy, radish, carrot, tomato, chilly, coconut, beetle leaf and floriculture and the area under each crop is listed in **Table 3**. Apart from this, many paddy, coconut and beetle fields are cultivated nearby which are not included in this survey. The dependency for water for agriculture amounts to ₹ 12, 24,000 every year.

Table 2: Water quality analysis

Variables	Inlet	South outlet	North outlet	Surface Water Standards (permissible limit)
pH	7.70	7.50	7.50	6.5-8.5
Water Temperature (^{0}C)	29.00	30.00	26.00	—
Air Temperature (^{0}C)	28.00	31.00	29.00	
Salinity (ppm)	710.00	532.00	605.00	<400
IDS (ppm)	994.00	749.00	849.00	<500 ppm
Electric Conductivity (µS)	1420.00	1075.00	1224.00	<1200 µS
Total Alkalinity (ppm)	420.00	400.00	420.00	<600 mgL^{-1}
Dissolved Oxygen (mgL^{-1})	1.06	8.16	0.00	> 5 mgL^{-1}
Chlorides (ppm)	167.56	173.24	191.70	< 200 mgL^{-1}
Total Hardness (ppm)	252.00	236.00	288.00	< 300 mgL^{-1}
Calcium Hardness (ppm)	108.00	128.00	135.00	<80 mgL^{-1}
Biological Oxygen Demand (mgL^{-1})	122.40	119.50	140.80	< 3 mgL^{-1}
Chemical Oxygen Demand (mgL^{-1})	128.00	124.00	188.00	< 250 mgL^{-1}
Nitrates (ppm)	0.31	0.47	0.55	20 mgL^{-1}
Phosphates (ppm)	5.76	4.22	5.00	—
Sodium (ppm)	177.00	174.00	180.00	—
Potassium (ppm)	21.00	19.00	19.00	—

Table 3: List of resources and their economic values

Use values	Quantity of Resource	Wetland Value in Rupees (₹)
Domestic use (bathing, cooking)	25-50 litres/person/day	25,00,000/year
Agriculture (income)	4,080/house/month	12,24,000/year
Household	2,500/month	30,000/house/year
Fisheries	5 kg fish/person/yr	25,00,000 /year
Domestic animals	6 animals/house	10,000/year
Fodder for Domestic animals	720 kg/year	57,60,000/year
Fire wood	10,000/month	12,24,000/year
Total		Rs. 95,54,000/220 ha/year

Livestock : On an average 5 animals viz cows, buffaloes, sheep and goats were reared in each house. Water hyacinth and other aquatic weeds (*Eichornia crassipes.*, *Typha* sp , *Alternanthera* sp etc) are utilized as feed for cattles. Farms rely on the sale of dairy products for part of their income. The dependency for livestock (fodder) and for washing purposes amounts to ₹ 57, 60,000 and ₹ 10,000 per 6 cows every year respectively.

Fisheries : 5 residents depend on aquaculture for occupation. Fishing is the major source for people nearby. As per the survey consumption of fish is 5 kg/person/year and the value from fisheries amounts to ₹ 25,00,000/year.

Fire wood (Energy): The dependency of people for the fire wood on the wetland amounts to ₹ 10,000 per year.

Discussion

Residents are residing in the catchment of Varthur lake for nearly 30 years to more than 200 years and at least 60% of the families persist for over 100 years[2]. It plays a significant role in providing daily requirements for the local inhabitants such as for domestic use of water, irrigation, fuel and fodder for livestock; while undergoing the stress sequentially due to anthropogenic activities. Higher values of BOD, COD, Nitrates and Phosphates reveal that lake water is severely contaminated. DO of lake was quite low (1.06 ppm) in inlet mainly due to increased inflow of organic material through untreated sewage. DO decreases due to presence of inorganic reducing agents such as Hydrogen Sulphide (H_2S), ammonia, nitrites and certain oxidizable substances[21]. Profuse growth of macrophytes mainly water hyacinth, limits air water interface, light penetration and consequently there is a drop in the penetration of atmospheric oxygen as well as algal photosynthetic activities. This maximizes the probability of hypoxic and anoxic conditions in the lake making difficult for survival of aquatic organisms in the water. Higher values of alkalinity show the presence of more carbonates, bicarbonates and hydroxyl ions. Water quality analysis of Varthur during 2002 also reported similar conditions of low dissolved oxygen, alkaline pH and high nutrient inputs (Nitrates, Phosphates and Ammonia) Varthur contains significant amounts of the macronutrients in large quantities in order to grow and survive aquatic plants under higher concentrations of nitrates and phosphate. Elevated amount of nutrients mainly fortify the contamination of water with sewage and non-point sources - fertilizers[2]. Amplified water quality degradation observed when current status was compared with that of past study (**Table 5**), explaining due to the sustained and enhanced inflow of contaminants over time.

Table 4: Livelihood details

Livelihood	Hectares
Floriculture	11.74
Vegetables	10.32
Paddy	2.02

Calculation : ₹ 9554000/220 ha /year

= ₹ 43427.28/ha/year

= ₹ 118.978/ha/day

Water pollution

Varthur Wetland receives 450-500 MLD of sewage from households and industrial wastewater directly into wetland from Bellandur and surrounding localities. These contribute enriched nutrients and increased amount of toxic substances (heavy metals). Enhanced land cover changes have contributed to siltation and consequent sedimentation decreasing lake's depth. The degree of soil saturation of the wetland depends on the consistency of its freshwater flow. Effluents loading has gone beyond the ability to assimilate contaminants, further degrading the water quality. Along with effluents from households and industrial waste, household garbage, plastics and solid waste from commercial places are being dumped in lake bed.

Valuation of ecosystem highlights that due to the severe contamination of water the wetland's goods and services have declined impinging livelihood of dependent population and also local economy. Even though residing

Table 5: Comparison of major water quality parameters of Varthur (2003 and 2009)

General parameters	2003 (Outlet)			2009	
	October	November	January	Inlet	Outlet
pH	7.61	7.55	7.68	7.7	7.50
Temperature (^{0}C)	27	27	23	29	26
Electric conductivity (μS)	460	474	1420	1420	1224
Dissolved oxygen (mgL^{-1})	2	3	2.9	1.06	0
Chlorides (ppm)	-	100	170	167.56	191.7
Total hardness(ppm)	213.6	209.3	232.5	252.0	288
Calcium hardness(ppm)	132	124	158.1	108	135
Biological oxygen demand(ppm)	-	-	74.2	122.4	140.8
Chemical oxygen demand(ppm)	-	-	82.2	128.00	188
Phosphates(ppm)	-	>1	15.54	5.76	5.00

(Source: Ramachandra *et al.* 2003 and current survey)

community is dependent on lake for manifold use as mentioned in **Table 3** many problems are faced by the wetland for being beneficial. The total economic value of Varthur resources accounts to ₹ 95, 54,000/220 ha/year (ie ₹ 118.98/ha/day), which is much lower compared to a relatively unpolluted lake (₹10,450/ha/day)[3]. The dependency value on wetland water for domestic and agricultural use is maximum compared to other use-values

Causes of depreciation in lake values

Dumping of garbage and other non-degradable waste materials, inflow of untreated sewage from the residential areas and open defecation are the problems accountable for water quality. Such substances liberate toxic in to the water body; remains suspended; gets dissolved in water or set down on the water bed contributing to groundwater pollution. This majorly deteriorates water quality impinging on aquatic ecosystems. Few effects of these environments are :

- Utilization of contaminated lake water for irrigation purposes has a negative effect on the quality as well as the quantity of crops and this has influenced the major source of income for farmers reliant on agriculture.
- Possibility of contaminants especially heavy metals getting to food chain through fish (which accumulates higher concentrations of heavy metals- bioaccumulation[22]).
- Dumping of municipal solid waste in the lake catchment and letting untreated sewage and effluents into lake has affected the health of the local population due to increase of disease vectors and pathogens (mosquito -*Plasmodium* sp. causing Malaria) and flies population around Varthur region. Current survey also reports health problems like fever, dysentery and skin diseases (dermatitis) in most of the houses. Due to mosquito problem and health hazards, residents spend more than ₹ 30,000 per year in purchase of mosquito repellants (according to survey). Presence of *Eschericia coli* in water sample indicates the fecal matter contamination[3]. Fecal contamination is often associated with other types of pathogenic bacteria and viruses found in untreated sewage and survives for a prolonged period in turbid, warm temperature, mildly alkaline pH, and low oxygen levels in lake water.
- Profuse growth of exotic plant species such as water hyacinth (*Eichornia crassipes*) and exotic fish culture have also contributed to extinction of native species of fauna. Prolific macrophytes growth has roofed water surface completely lessening dissolved oxygen level and hindering photosynthesis process. Algal communities depending on photosynthetic activity have declined together with mortality of sensitive life stages inside water. Disturbance in food chain may also lead to changes in algal community and its metabolism.
- Poaching of waterfowl such as Purple Moorhen (*Gallinula chloropus*), Spot Billed Pelican (*Pelecanus philippensis*), Common Coot (*Fulica atra*) and White Breasted Waterhen (*Amaurornis phoenicurus*) by poachers were observed, resulting in its decline.

Dominant fish species reported in 1962, 1998 and 2009 are listed in **Table 6**. *Clarias batrachus*, *Heteropneustes fosslis*, *Mystus dittatus* and so on which once contributed substantially to fish community in earlier years has dwindled in their representation in the catches now. The invasive species currently harboring water body are *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal), *Clarias gariepinus* (African catfish), *Oreochromis mossambica* (Tilapia) and medium sized carps. Enhanced sewage and effluents inflow coupled with the overexploitation of wetland goods are prime reasons for the decline in indigenous fish species and consequent prevalence of invasive species during the last two decades.

Table 6: List of major fish species in Varthur wetland during 1962, 1998 and 2009

Species name	1962	1998	2009
Catla catla (Catla)	-	+	-
Labeo rohita (Rohu)	-	+	-
Cirrhinus mrigala (Mrigal)	-	+	-
Clarias gariepinus (African catfish)	-	+	+
Oreochromis mossambica (Tilapia)	-	+	-
Clarias batrachus	+	-	-
Heteropneustes fosslis	+	-	-
Mystus dittatus	+	-	-
Minor carps	-	+	-

(Source: current survey + indicates presence and - indicates absence of fish species.)

Comparative analysis of polluted and unpolluted wetlands reveals difference in fish composition and associated economic value. Varthur lake harbors only *Clarias gariepinus* (African catfish), whereas *Catla catla* (Catla), *Labeo rohita* (Rohu), *Cirrhinus mrigala* (Mrigal) and *Oreochromis mossambica* (Tilapia) were found in Rachenahalli while another eutrophic lake at Amruthahalli did not have any species. Varthur and Amruthahalli being eutrophicated with heavy sewage contamination and Rachenahalli is relatively unpolluted. Invasive exotic species, African catfish in Varthur water body has predated native fish and survives under eutrophic condition with the macrophytes covering the entire lake. Subsequently, huge amount of waste along with metals and ions (toxic substances) are accumulated inside fish gut due to bioaccumulation[23]. Consumption of fish rich in heavy metals has carcinogenic influence on humans. According to fishermen, Varthur provides 200-300 kg/day of catfish costing ₹ 50-60 /kg/day due to absence of fish variety while Rachenahalli accounts for ₹ 75 /kg/day specified by varieties of fishes mentioned above[9]. Economic value of fish in Varthur is less than in Rachenahhali mainly because of exotic species and decline of native species, water accomplished with sewage and prolific macrophytes growth in Varthur.

The socio-economic studies on Rachenahalli and Amruthalli lakes showed that the economic dependency in the case of Rachenahalli lake (₹ 10,435/ha/day) is more than that of polluted Amruthalli lake (₹ 20/ha/day). This is mainly because of better water quality in former lake while water quality with severe pollution by phosphates, weed infestations and oxygen deficiency in later case. Although in Varthur, Sorahumase and Valepura village, the land irrigated by utilizing the wetland water amounts to 4211.6/day with water quality indicating eutrophic lake containing high concentrations of organic wastes and phosphorus[2].

Management of wetlands to sustain goods and services

This study highlights the need to manage the wetlands to enhance the use-value of an ecosystem. The strategies include : 1. Restoration of wetlands – removal of contaminants; 2. Letting only treated sewage to the wetlands; 3. Letting the treated water through series of wetlands further improves the water quality; 4. Maintaining food chain in the ecosystem – involves removal of excess growth of macrophytes (if any) and exotic fish species, African cat fish, etc ; and 5. Regular water quality monitoring involving local schools. This would also help in functioning as watchdog to prevent any contamination (solid waste dump, direct inflow of sewage, etc.)

Conclusion

The socio-economic survey and water quality analysis show a decline of ecosystem goods and services with the decline of water quality. This has influenced the livelihood of the local population who are dependent on the goods and services provided by the wetland. The persistent hyper eutrophic condition is due to the sewage from Bellandur lake and also from the surrounding residential apartments. Water treatment plant for Varthur wetland benefits the local environment with better water and impassive sludge that can be utilized for agricultural fields as fertilizer instead of commercial inorganic fertilizers. With the improved water quality, introduction of indigenous and herbivorous fish species into water body along with the removal of African catfish will enhance the food availability. To retain existing reserve and bring back the lost resource, efforts such as restoration process should include wastewater treatment system, removal of over growth of invasive macrophytes and awareness among community and enhanced co-operation among government agencies to manage wetland. Management priorities should mainly include evolving sustainable managing strategies for maintaining water quality, control of invasive species, encroachment, drastic land cover changes in the catchment and identification of buffer zone, providing aquatic resources with adequate water quality and limiting the spread of exotic biota in a sustainable manner evolving managing strategies.

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