

Analyzing Trends of Urbanization and Concomitantly Increasing Environmental Cruciality—A Case of the Cultural City, Kolkata

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Abstract The environment in the city of Kolkata has suffered an extensive damage at hands of urban expansion. This study investigates the urban expansion in Kolkata over the last few decades and assesses its impact on environmental cruciality using satellite derived parameters. An Environmental Cruciality Indicator (ECI) was developed using the vegetation indices and the land surface temperature (LST). Landsat TM and ETM+ data for the years 1989, 2006, and 2010 have been employed for this study. Land use land cover (LULC) maps were prepared using supervised classification with an accuracy of 86–90 % (0.82–0.87 kappa). Urban expansion amounting up to 109 km² was observed in the city over the past two decades. These changes modified some other environmental variables such as the moisture intensity of the surface, LST, greenness, and the built-up intensity. These changes further impact the quality of environment that was analyzed using the ECI. The indices used were Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Normalized Difference Built-up Index (NDBI). Satellite derived ECI shows a degrading trend for environment in larger parts of the city. The magnitude and spatial extent of higher environmental cruciality are coherent with the urbanization (sparse and dense settlement) patterns in and around the city. LULC has been an important factor determining the health of the environment and hence influencing the local climate.

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1 Introduction

The urbanization process creates urban ecosystems characterized by impervious surfaces and built structures that alter the local climate in more ways than one (Ganeshan et al. 2013). These impervious areas exhibit diminished evapotranspiration, increased run off, enlarged storage, and transfer of sensible heat (Kato and Yamaguchi 2005). The built structures predominantly in cities often alter the urban geometry and albedo of the area (Akbari et al. 2009). These changes have an adverse impact on the local climate, environment and environmental variables such as land surface temperatures (Amiri et al. 2009), hydrology (O'Driscoll et al. 2010; Chelsea Nagy et al. 2012), human health (Tomlinson et al. 2011), landscape (Buyantuyev and Wu 2010), biodiversity (Biamonte et al. 2011) and quality of life. Given the current pace of urbanization globally as well as in India, cities continue to grow at a rapid pace. Thus, it becomes crucial to monitor the urban environment and control any potential threat of degradation.

Assessing the urban LST conditions is imperative to monitor the quality of urban environments, as temperature is a key parameter that controls a number of biological, physical and chemical processes of an ecosystem. LST is often used to study the thermal conditions of a region of an area. A lot of studies have focused on utilizing ground-based measurements for analyzing the thermal environments. Such measurements are good for studying the temporal variations. However, they show limited utility when it comes to spatial coverage and also suffer from lack of spatial continuity. With advances in remote sensing technology over the past few years, researchers have been able to use satellite data for thermal related studies at varying scales of both space and time.

Some of the satellites-based thermal data are provided by the National Oceanic and Atmospheric Administration's (NOAA's) Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat's Thematic Mapper (TM), Enhanced Thematic Mapper plus (ETM+) and Thermal Infrared Sensor (TIRS) (Joshi et al. 2013). All these varying in their spatial, temporal and spectral response functions, define their wide ranging utility for different types of studies. AVHRR, for instance, is more suitable for continental or global temperature mapping due to its 1 km spatial resolution. ASTER and MODIS provide multiple thermal bands that make these data more suitable for LST studies at various spatial scales. However, among all of these, MODIS is again more suitable for studies done at continental and global scales. Though ASTER is better to study the regional scale LST, these products are extremely expensive which serves as a deterrent in terms of availability. Landsat data is available free of

cost from NASA (<http://earthexplorer.usgs.gov/>) and have the satisfactory spatial resolution to study LST at the regional or local level (Li et al. 2012).

Normalized Difference Vegetation Index (NDVI) is another related feature that is closely linked with urbanization, as it is a direct indicator of greenness including the density and health of the green cover. Vegetation is an important component of the urban ecosystem. It influences the biological environment by supporting biodiversity and improving air quality. It also impacts the physical environment through selective absorption, reflection of incident radiations and the regulation of the sensible heat balance. Typical urban materials used in buildings and urban structures exhibit a reverse impact on both the biological and physical environment. The urban materials in general tend to absorb more heat and retain it for longer duration that gradually heats up the local environment resulting in formation of the Urban Heat Island (UHI). Normalized Difference Built-up Index (NDBI) has often been employed by researchers to study, identify, and extract built-up land features (Xu 2007). NDBI is also important for identifying and studying surface UHIs. Water is another crucial factor influencing the local climate as it plays an important role in energy exchange and balance. Normalized Difference Water Index (NDWI) is often used for delineating water bodies and studying the moisture status in the area of interest (Gao 1996). However, within a water body, NDWI values might not be constant as the reflectance may vary depending upon the depth and quality of water. With development of such indices (for instance NDVI and NDBI), and further improvement and modifications, researchers have been trying to study various aspects of environment and climate.

Based on the essential indices for vegetation (NDVI), built-up intensity (NDBI) water (NDWI) and LST, this study proposes a new index measuring the cruciality of the urban environment. The primary focus of this research is to map the urbanizing landscape of the city of Kolkata and to examine its impacts on the local environment. These impacts are studied using a set of indicators that are the green cover, built-up intensity, moisture intensity, and land surface temperature. The secondary objective of the study is to propose the Environment Cruciality Indicator (ECI) to understand the state of the physical environment of the landscape.

1.1 Data and Methods

1.1.1 Study Region

The area of interest for this study is the metropolitan city of Kolkata, formerly known as Calcutta. The city is the capital of the state of West Bengal, India. It is situated at 22.567° north latitude and 88.367° east longitude (Fig. 1) covering an area of 900 km². The city has been experiencing continuous growth since its inception in 1690. Kolkata is situated on the banks of river Hooghly. It is an important cultural center of India. This study is confined to the Kolkata Municipal Corporation (KMC) jurisdiction area and the surrounding suburbs taking a buffer of

5 km with a total areal extent of 1750 km². The city experiences tropical wet and dry climate with extremely hot and humid summers (temperatures soaring to 40 °C) and short winters when temperatures dip to 9 °C. The city experiences an annual rainfall of 1640 mm and often encounters cyclones as it falls in a cyclone prone region. Kolkata's land cover in past has been dominated by wetland ecosystems but with increasing pressure due to population explosion, much of these wetlands have been transformed into various urban land uses.

1.1.2 Data Used

Geometrically and radiometrically corrected Landsat data (TM and ETM+) images of Kolkata city (path/row: 138/44) used in this study were taken in the GeoTIFF format from the Earth Resources Observation and Science (EROS) Data Centre of the U.S. Geological Survey (USGS) (<http://eros.usgs.gov/>). The data were projected in the UTM projection (zone 45) and WGS84 datum. The datasets used were acquired on January 19, 1989, January 26, 2006, and January 21, 2010. The data consists of seven bands; the first three of these are visible bands (red, green, blue). The fourth band is near-infrared, the fifth and the seventh bands are shortwave infrared and the sixth is a longwave infrared thermal band (Table 1). ETM+ data differs from TM in terms of enhanced spatial resolution of thermal band (band 6) and that it possess an additional panchromatic band.

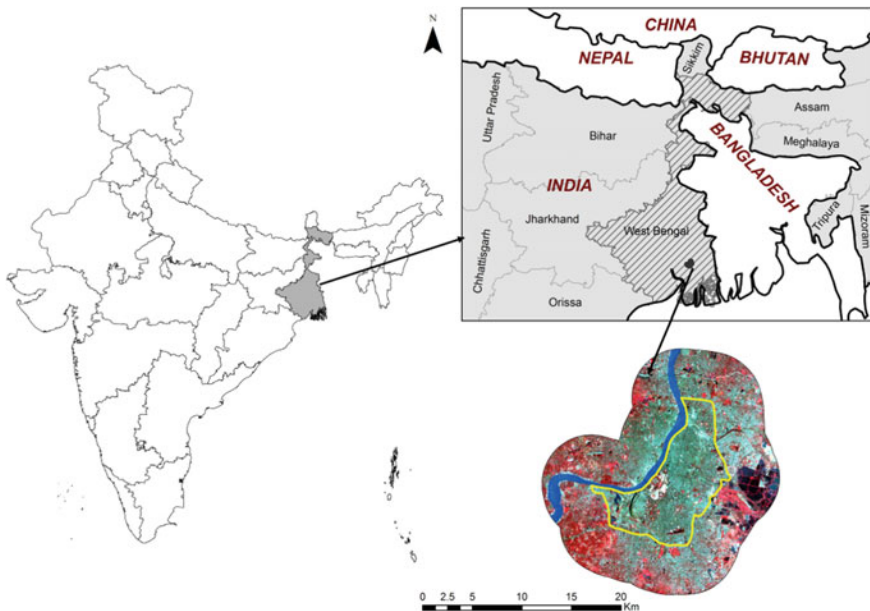


Fig. 1 Location of the study area

Table 1 Indices and their calculation

Index	Indicator of	Formula
NDVI	Greenness or vegetation	$\frac{NIR - R}{NIR + R}$
NDBI	Built-up intensity	$\frac{MIR - NIR}{MIR + NIR}$
NDWI	Water or moisture status	$\frac{NIR - MIR}{NIR + MIR}$
LST	Land surface temperature	Mono-window algorithm
ECI	Environment cruciality or criticality	$\frac{LST + NDBI}{NDVI + NDWI}$

1989 and 2010 data were TM datasets with 30 m spatial resolution for band 1 (blue), band 2 (green), band 3 (red), band 4 (NIR), band 5 (MIR1) and band 7 (MIR2), and band 6 (TIR) with 120 m. The bands had spectral resolutions of 0.45–0.52, 0.52–0.60, 0.63–0.69, 0.76–0.90, 1.55–1.75, 10.4–12.5, and 2.08–2.35 μm, respectively. ETM+ data bands possessed the same spectral resolutions. The spatial resolution was also 30 m for all the bands except band 6 which had a resolution of 60 m. ETM+ data had an extra panchromatic band having 15 m spatial and 0.45–0.90 μm spectral resolution.

1.1.3 Derivation of Variables

Since different wavelengths provide information about different parameters of land environment, different bands and diverse band ratios were computed to retrieve information about various environmental parameters. The greenness of the area under study was estimated using the NDVI, which extracts information from red and near infrared (NIR) bands. The built-up intensity represented by NDBI (Zhang et al. 2009) and wetness characterized by the NDWI (Gao 1996; Jackson et al. 2004) were calculated using the NIR and the shortwave mid-infrared (MIR) band which is the fifth band. The land surface temperature for the area was retrieved from the thermal infrared (TIR) band (Chen et al. 2006) using Qin et al.’s (Qin et al. 2001) mono-window algorithm (Sun et al. 2010) and the emissivity correction was done using NDVI to obtain the final LST images.

With rapid urbanization, more and more vegetation is being replaced with impervious urban structures. Concrete urban structures such as buildings and pavements have a tendency to absorb more heat and store it for a longer time resulting in elevated land surface temperatures. High LST manifests itself in the form of the development of the Urban Heat Island or UHI in the city. UHI in turn has adverse implications for human health, biodiversity, and energy demand especially in a hot and humid city like Kolkata. Thus, as the LST increases, the condition of the local environment becomes more critical.

Scattering or reflectance from the spongy mesophyll cells in plants exhibit high leaf reflectance in the NIR. Thus greater the number of leaf layers in a healthy, mature canopy, the greater is the infrared reflectance. Also, due to chlorophyll absorption in red band and due to very high reflectance in NIR, a healthy green leaf has a very low reflectance in red. Thus more and healthier the vegetation is, higher is the NDVI. With urbanization, there is a greater loss of green cover causing the decrease of reflectance in the near-infrared band and an increase in the red band resulting in lower NDVI values. Loss of vegetation has more direct impacts on the local climate with an increase in temperature, air pollution and a loss of habitat of local biodiversity. Thus, a decreasing NDVI in urban area indicates a degrading environment.

MIR is sensitive to water and soil moisture and very effective in distinguishing water pixels. With increasing moisture content, the MIR reflectance decreases and the NDWI thus increases. Presence of water bodies and vegetation moisture increases the NDWI. However, with increase in impervious urban structures and decrease in vegetation with urban sprawl, the NDWI would decrease indicating deterioration of the local environment.

Urban structures are low in moisture content and tend to have high MIR values with a low NIR reflectance. Thus, higher the built-up intensity of an area, more is the NDBI value. A higher NDBI that represents a higher built-up intensity is also indicative of depleting moisture content in the area. Increasing NDBI would thus be a fair indication of critical urban environments.

1.1.4 ECI Computation

An integrated Environment Cruciality Index was calculated using the various indicators discussed above. According to this index, an urban environment with a high LST and NDBI and a low NDVI and NDWI are more crucial and exhibit high ECI values. A lesser crucial urban environment would have a low LST and NDBI with a high NDVI and NDWI values. Based on this information, ECI was developed as given in Table 1. All the variables were normalized to a range of 0–255 for this purpose.

1.1.5 LULC Mapping

An insight into the land use and land cover changes is highly crucial for understanding different environmental changes taking place in an area. Supervised classification (Jensen 2015) was applied to map LULC for 1989, 2006, and 2010 Landsat datasets using parametric classifier with maximum likelihood based on Mahalanobis metric algorithm. Eight LULC classes were recognized that include: (i) water, (ii) wetland water, (iii) wetland vegetation, (iv) agricultural fallow, (v) vegetation, (vi) open area, (vii) built-up (Table 2).

Table 2 LULC classification scheme

LULC class	Description
Water	This class is covered by River Hooghly that crosses through the study area along with other water bodies such as tanks or ponds
Wetland water	This class consists of water present in wetland area towards western parts of study area
Wetland vegetation	Land covered with vegetation in wetland area
Agricultural fallow	This is comprised of agricultural land that is presently fallow or harvested
Vegetation	Vegetation class encompasses all kinds of vegetation except that related to agricultural activities and wetland vegetation
Open area	Open area in this classification scheme refers to large open playground, airport and other vast stretches of land that are not covered by vegetation or built-up structures
Built-up	This is comprised of land parcels under human settlement including buildings and other man-made constructions

2 Results

2.1 *Lulc and Land Transformations*

The temporal LULC maps of different time periods (1989, 2006, and 2010) were utilized to study the urban expansion. The overall accuracy of the LULC maps for 1989, 2006, and 2010 are 90, 88, and 86 %, respectively. The Kappa statistics for 1989, 2006, and 2010 are 0.8726, 0.8455, and 0.8212, respectively. The LULC statistics for different years are given in (Table 3).

The statistics show significant changes in LULC distribution areas over time. The built-up in and around the city is 88.7 km² in 1989, 144.6 km² in 2006, and 197.7 km² in 2010, thus showing an increase of 109 km² in the two decades. Maps show that the expansion has been more towards the eastern and south-eastern parts of the city engulfing the peri-urban agricultural regions and surrounding the wetlands in the process (Fig. 2).

Table 3 LULC distribution in the study area

LULC class	1989	2006	2010
Water	19.0	19.6	19.9
Wetland water	20.0	15.4	14.1
Wetland vegetation	34.2	21.2	15.0
Agricultural fallow	49.9	37.1	21.2
Vegetation	178.4	164.1	109.8
Open area	20.2	8.3	32.8
Built-up	88.7	144.6	197.6

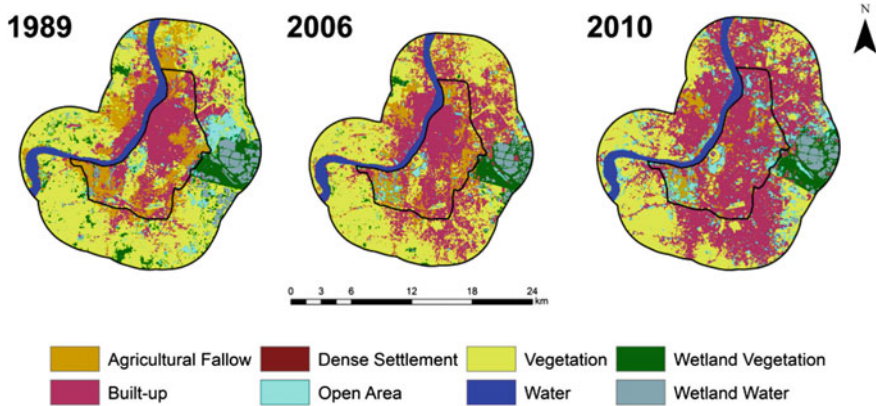


Fig. 2 Land use/land cover maps 1989, 2006, and 2010 (Sharma et al. 2015)

2.2 Spatiotemporal Patterns of Variables

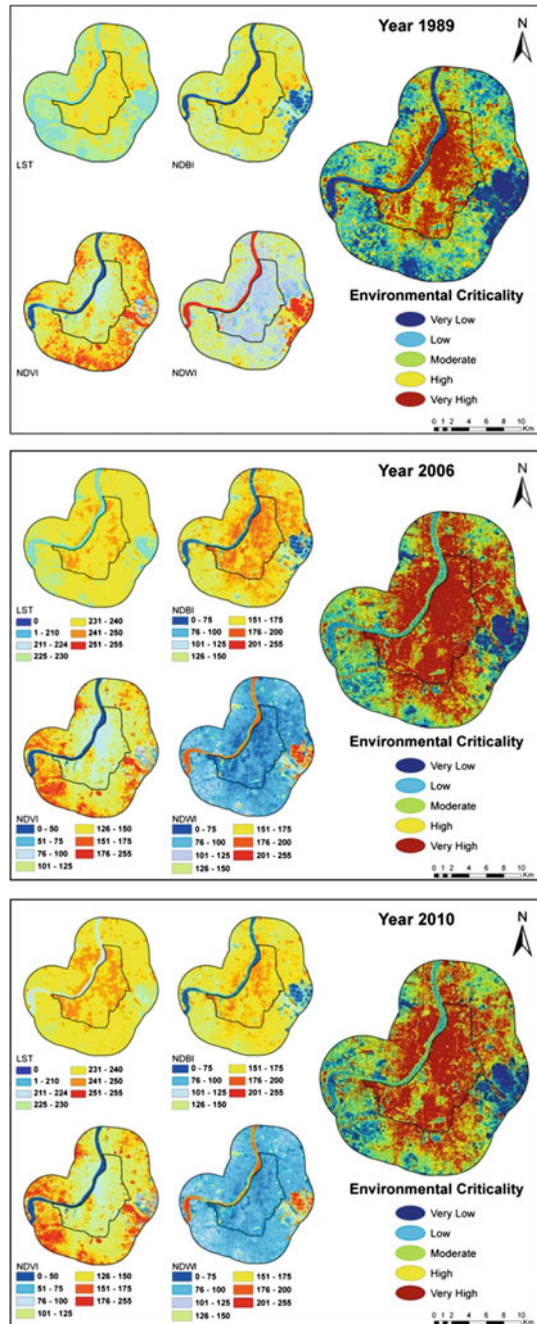
The forms of surface components, their distribution and their spatial complexities often have an impact on the local air and surface temperature. Thus, the land transformations taking place in the study region have also influenced the LST distribution in the city. The LST values in the area have been increasing over the years. The mean surface temperature in 1989 was 27.4 °C, which increased to 30.0 °C in 2006 and finally to 33.0 °C in 2010. Similarly, the minimum temperature and maximum temperature values for the study region are 18.5 and 38.4 °C, 20.0 and 39.5 °C, and 19.4 and 42.0 °C for the years 1989, 2006, and 2010, respectively. The magnitude and extent of the estimates of LST are observed to be in consistency with the urbanization pattern of the city. The NDBI values were also found to follow the same pattern, while the NDVI and the NDWI followed a reverse pattern (Fig. 3).

2.3 Dynamics of Environmental Cruciality

To assess the impact of urbanization on the environmental health, ECI computation was processed for the three years (Fig. 3). Analysis of the LULC and other variables indicated that the wetlands are particularly at threat due to rapid land transformations. This is because wetland ecosystems are highly sensitive.

In order to study the impact of urban land transformations particularly on wetland ecosystem, the ECI changes were studied for the areas that have been reclaimed from wetland. Subtracting latter year's ECI from former one assessed ECI changes for the two time periods. A greater damage to environment is indicated by greater ECI change. ECI changes in the time period 1989–2006 are more evident and are of greater magnitude (~ 2.2) and are larger in spatial extent. However, from

Fig. 3 Environmental cruciality for Kolkata; 1998, 2006, and 2010



2006 to 2010, the ECI changes are less intense and spread in smaller patches. These changes are confined to a range of 0.1 to 1.5. This indicates that massive degradation in the environmental health of wetlands had taken place in earlier time period (Fig. 4). This could, however, also be due to the smaller time frame that has been considered in the latter instance (4 years) as compared to the former one (17 years). Also, on 31st March 2006, The East Kolkata Wetlands (Conservation and Management) Act, 2006, was passed by Government of West Bengal, which seems to have contributed to minimizing the damage and increasing the protection and conservation of these wetlands.

The ECI varied on the basis of the LULC of the surface. In order to understand the variation of ECI based on the LULC, ECI images were classified into 5 zones: zone 1 (0–1), zone 2 (1–2), zone 3 (2–3), zone 4 (3–4), and zone 5 (>4). These zones were then used to study the impact of variation in land use on the environmental quality using the doughnut charts (Fig. 5).

Water class was mainly dominated by zone 2 (95–98 %). Only a small fraction of water land use class is influenced by zone 3 in 2006 (2 %) and 2010 (4 %) and a very small fraction (2 %) came under zone 1 in 1989. A similar pattern is observed for the vegetation class. Agricultural fallow and built-up classes were dominated by ECI zone 2. However, the two categories are fundamentally different from each other. Agricultural fallow is a temporary land use which when it gets covered with crops in another season, automatically moves back into zones 1 and 2. On the contrary, built-up is a more permanent land use and hence it always remains confined to higher classes of ECI.

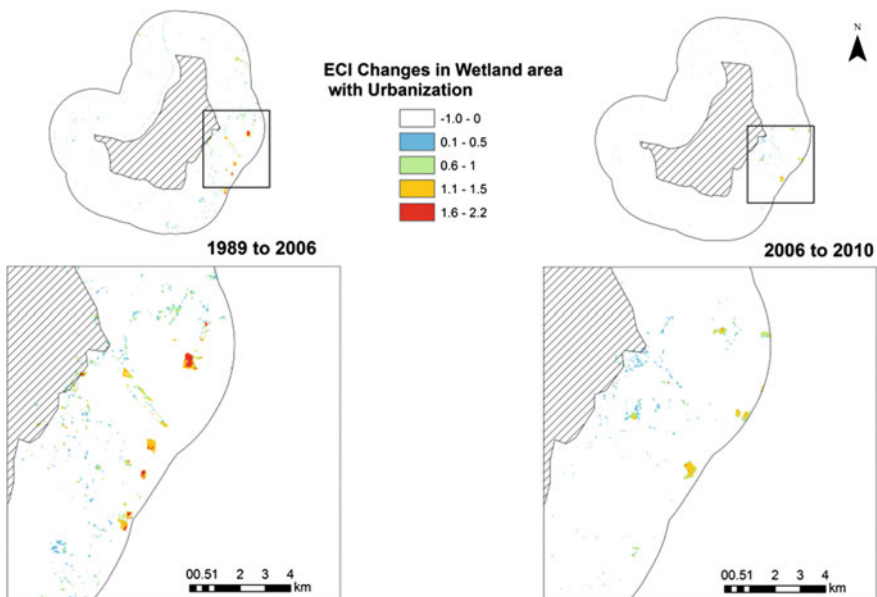


Fig. 4 Dynamics of ECI

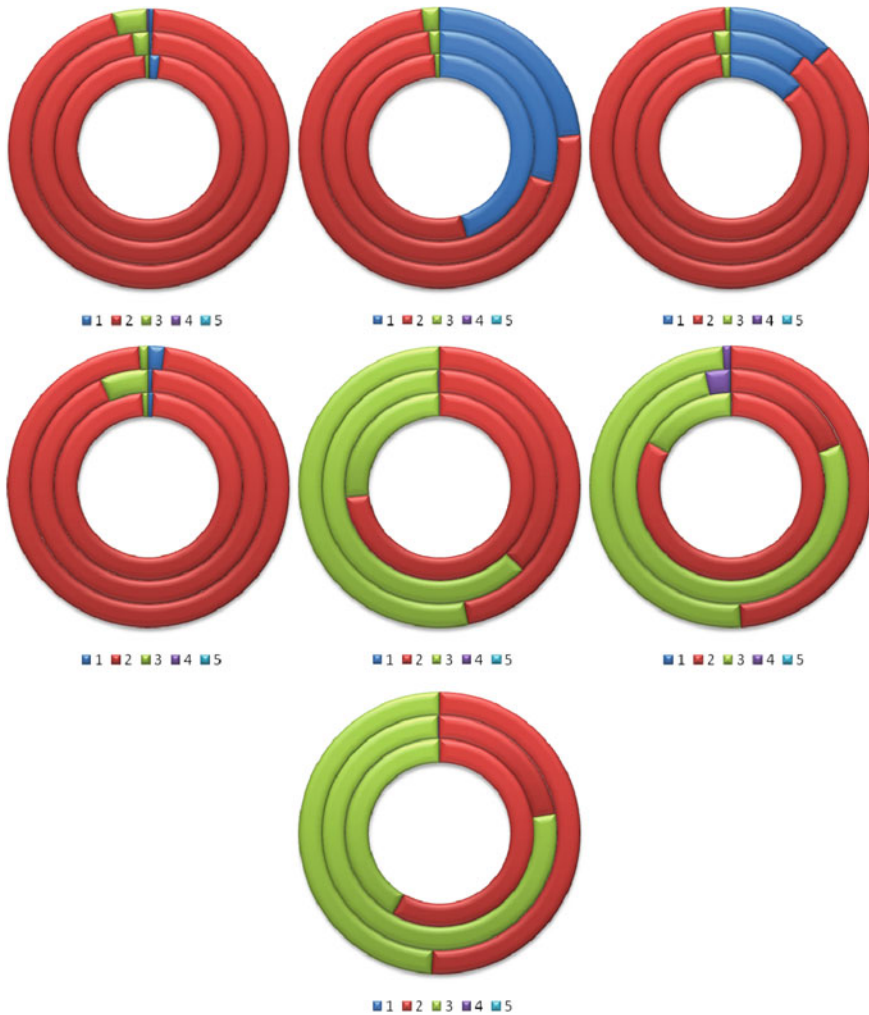


Fig. 5 ECI zone and LULC statistics for water, wetland water, wetland vegetation, vegetation, agricultural fallow, open area, and built-up (The inner most layer of doughnut represents year 1989, middle one represents year 2006 and outermost is for year 2010)

Wetland water (25–45 %) and wetland vegetation (11–13 %) are the only two LULC classes that have huge fractions that come under ECI Zone 1. This further reinforces the fact that wetland ecosystems help maintain the environmental health and quality. But as we move from the inside of doughnut to the outer layers i.e. from the year 1989 to 2010, we find that the proportion of wetland water and vegetation in the ECI zone 1 decreases, indicating an increasing disturbance in these sensitive ecosystems over the years.

3 Conclusion

LULC is an important aspect influencing the environmental quality of an area. Kolkata city has witnessed tremendous urban expansion in over the past two decades. This urban expansion has been accompanied with changes in the environmental variables of the area, namely, temperature, soil moisture, and vegetation cover. Satellite derived biophysical variables used in this study indicate that the LST (measuring surface temperature) and the NDBI (indicative of built-up intensity) is increasing, while the NDVI (representing vegetation intensity and health) and the NDWI (assessing the moisture status) have been decreasing. These disturbances have adversely impacted the environment. The Environment Cruciality Index measures how the transforming land use is influencing the local environment. Wetlands more specifically have been found to be deteriorating and disappearing to provide land for urbanization.

However, urbanization in silos could be dangerous not only for the environment but also for humans as well. Thus, a more interdisciplinary approach towards urbanization is required that can drive cities towards a more sustainable development that would be in harmony with the social and natural systems. Urban planners need to give special attention to sensitive areas such as wetlands while planning to ensure that the process of urbanization does not cause any disturbance to the cities. The governments and policy makers also need to come up with more stringent policies and laws while dealing with encroachment issues in such sensitive ecosystems as urbanization causes irreversible changes in land use and the damage to ecosystem is permanent. Thus, a more precautionary approach is required in this context.

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