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Mythili Madhusudhan, N.K. Ambujam

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An urban ecology approach to land-cover changes in the Adyar sub-basin: comparative analysis of NDWI, NDVI and NDBI using remote sensing

Mythili Madhusudhan*

School of Architecture,
Meenakshi College of Engineering,
12, Vembuli Amman Koil Street,
West K.K. Nagar, Chennai, 600078, India
Email: mythomadhu@gmail.com
*Corresponding author

N.K. Ambujam

Centre for Water Resources,
College of Engineering,
Anna University,
Sardar Patel Road, Guindy, Chennai, 600025, India
Email: nk.ambuj@gmail.com

Abstract: The impacts of urbanisation may be social, environmental or ecological. In this paper, studies on the characteristics of urbanisation and its impacts in Chennai, India, particularly the South Chennai region are discussed. The study involves use of Landsat images and comparison of normalised difference vegetation index (NDVI) corresponding to mentioned dates in 1977, 1998 and 2018. Also, the normalised index for water (NDWI) and the built-up index (NDBI) are mapped and compared for the same dates. The results show that for the years 1977, 1998 and 2018, the difference between the maximum and minimum values of NDVI are found to be 1.609, 1.026 and 1.288, of NDWI are found to be 1.802, 1.239 and 1.518, and of NDBI are found to be 1.785, 0.993 and 1.036, respectively. The trends in indices for the dates considered are found to correspond to human activity and the significance of these changes is discussed.

Keywords: urban ecology; normalised difference vegetation index; NDVI; normalised difference water index; NDWI; normalised difference built-up index; NDBI; Landsat; remote sensing; land use; South Chennai.

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Biographical notes: Mythili Madhusudhan is an Architect with a Master’s in Landscape Architecture. She currently works as a Professor in the School of Architecture, Meenakshi College of Engineering, Chennai, India and is currently pursuing her PhD.

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N.K. Ambujam is a Professor in the Centre for Water Resources, Anna University, Chennai, India. She has contributed widely to the field in her career spanning over 35 years.

1 Introduction

Urban areas grow as a result of migration of residents into preferred regions and the consequent growth of infrastructure. This paper discusses, within an urban watershed, the impacts on the ecosystem resulting from anthropogenic activities. Humans represent a keystone species and play a cardinal role in terms of maintaining biodiversity in urban systems. As Jennifer Nini of the organic farms' fame says, "We can't just consume our way to a more sustainable world." While at the local level cities may negatively impact water services, at the regional or national level they may provide benefits. A vital question is whether cities are worthwhile arenas for ecological research, which may hinge on how the case under discussion has embraced the local landscape. While ecology may be defined as "the scientific study of the processes influencing the distribution and abundance of organisms, the interactions among organisms, and the interactions between organisms and the transformation and flux of energy and matter" (Pickett and Cadenasso, 2017), urban ecology emphasises human ecosystems, which include organisms, the physical environment and conditions and the human population and its social structures and processes, as well as the built and technological components.

Urban ecology is a new and emerging science, structured by principles from different authors, significant among those being Richard T.T. Forman. Forman's view is that the ecology of urban areas is different from the ecology of wild places; that the processes that make up the each area manifest differently. Other researchers differ and have put forth that there is only one ecology as a pursuit of science while there are many systems in which it can apply. A thorough comprehension of the relationships between urban form and human activity within the ecosystem process is necessary to find solutions for the various problems humans encounter. Land use and land cover are crucial in this respect (Pauleit and Brueste, 2011), because they have a primary influence on the urban ecosystem process and can be controlled to some extent by planning measures. Land use has a functional connotation, (residential, commercial or industrial) and land cover deals with the existing elements on the land (forest, buildings, grassland or water body). It is interesting to note that MA (Millennium Ecosystem Assessment) 2005 has explained every ecosystem in the world, but omitted urban systems, while on the other hand, the World Bank (2009), the world's largest assessment of urbanisation, left out ecosystems (Pauleit and Brueste, 2011). This highlights the 'urban-environmental polarity' (Pauleit and Brueste, 2011). To study the various phenomena or ecosystem processes, one may conduct studies with multi-temporal and multi-resolution remote sensing images, which can provide basic data to analyse urban spatial information as it evolves over time. Hence, the scope of this paper will be to examine the impact of human activity, with the help of GIS, in terms of biodiversity and water systems. By using comparable indices, the growth of the built-up area is also mapped.

Adyar sub-basin is a river basin towards the southern region of the Chennai area. The river is an ephemeral one, whose catchment area includes Chennai City and its metropolitan periphery. 39% of its watershed lies within the Chennai Metropolitan Area while 61% lies in the neighbouring districts of Kanchipuram and Thiruvallur (Vanaja, 2013; Rukkumany and Vedamuthu, 2017). About 200 tanks in the Chennai Metropolitan Area discharge their surplus water into it (Bharadwaj et al., 2014; Rukkumany and Vedamuthu, 2017). The river basin consists of the 42.5 km long Adyar River, which has an average flood carrying capacity of 39,000 cu.ft. and a maximum flood carrying capacity of 60,000 cu.ft. (Kumar, 2016). As a result of its being located partly within the city boundaries and extending into the suburbs and the rural countryside, it is an ideal case to study urban growth. Being a watershed region comprising of a large number of tanks, it presents various cases of regional modifications including industrial development, development of urban infrastructure and influx of urban dwellers. As these typically impact biodiversity, water resources, soil and microclimate, one could examine the available data to gain insight into the ecology of this region.

Padmanaban et al. (2017) modelled urban sprawl for Chennai City using remotely sensed data. They have applied certain classifications on Landsat imageries from 1991, 2003 and 2016, and computed the required landscape metrics to identify the extent of urbanisation within a 10km sub-urban buffer of Chennai. The land cover for 2027 was projected using a land change model. A 70.35% expansion in urban areas was observed predominantly in the sub-urban periphery region of Chennai between 1991 and 2016. The projected land cover for 2027 is determined to be 13,670.33 ha, which amounts to 16.57% of the entire landscape being converted into urban areas, indicating a huge level of urban sprawl (Padmanaban et al., 2017). A similar study has been performed of the coastal landscape of Thoothukudi (Rajakumar and Sashikkumar, 2020), which has experienced a spurt of urban growth to the extent of 68.42% between 1997 and 2017, by using geospatial tools and satellite imagery.

There has been a massive spurt of urban growth in the South Chennai region, especially, the Adyar sub-basin. The IT[1] corridor, and the ensuing real estate development make it evident and in adjacent rural areas, major development has taken place. Adyar River basin also includes another drainage basin, which is the Pallikaranai Marsh, which plays a role in flood moderation and is sometimes referred to as the fourth drainage basin of Chennai (after the rivers, Kosasthalaiyar, Cooum and Adyar River basins). The Pallikaranai Marsh receives surplus flow from 34 water bodies (P.W. Department, no date) in the upstream area. This marsh is worthy of further study, particularly for its biodiversity value and the hydrology issues of the area. The marsh has reduced in extent to one-tenth of its original size viz., from 5,500 hectares to 650 hectares from 1965 to 2013 (Vencatesan, 2007; Vencatesan et al., 2014). The lost marsh land is attributed to change in land use of a large portion of built-up land use, as indicated by studies. Also, urban waste and construction debris have contributed to the receding of marsh land.

Pal et al. (2018) have conducted an environmental study of Pallikaranai wetland. Their results are as follows: the wetland is shrinking in size and is struggling for survival as it has been heavily polluted by contaminants from various sources. The Chennai Corporation has been continuously dumping the MSW[2] in the wetland and established a solid waste dump in the middle of the water body which is not just an eyesore but also has deteriorative ecological impacts. In addition, the sewage from the nearby areas is drained into the Pallikaranai wetland. The biological oxygen demand (BOD) of the wetland in some area is as high as 750 mg/L and the chemical oxygen demand (COD) is 226.1 mg/L (Pal et al., 2018). According to Jayanthi et al. (2012), groundwater contamination by the leachate generated by the waste dump, surface water contamination by the runoff from the waste dump, generation of inflammable gases like methane, fires within the dump, erosion and slope stability problem in the waste dump and acidity of the surrounding soil are prevalent issues in a solid waste dump. Vencatesan (2007) and Vencatesan et al. (2014) has also reviewed the marsh, and declared that the shrinkage of the marsh is due to the dumping of wastes and disposal of partially treated sewage in the dump yard. This scenario of interaction between the city and the environment is demonstrated by the principles of urban ecology described by Pickett and Cadenasso (2017) with Principle 1 stating "cities and urban areas are human ecosystems in which social-economic and ecological processes feedback to one another" and Principle 2 stating "urban areas contain remnant or newly emerging vegetated and stream patches that exhibit ecological functions."

This study details changes in the component regions of the entire Adyar sub-basin, over the years 1977, 1998 and 2018, using Landsat imagery from USGS Earth Explorer data. The objective is to obtain a relationship between vegetation, water and built-up indices by using remote sensing data and techniques, i.e., the normalised difference vegetation index (NDVI), normalised index for water (NDWI) and NDBI formulae, which is further discussed.

2 Methodology

This paper presents an analysis of vegetation index, water index and built-up index. Built-up index is a recent technique. A method of mapping built-up areas has been developed based on NDBI. The spectral response of built-up areas is different from that of greener land covers. Mapping of built-up areas is done through arithmetic determination of recoded NDVI and NDBI images derived from TM[3] imagery (Zha et al., 2003; Pattanayak and Diwakar, 2018). This is faster and may provide higher accuracy and faces less interference from the image analyst. NDBI is a linear combination of near infrared band (0.76–0.90 μm) and the SWIR[4] band (1.55–1.75 μm), used for extraction of built-up data.

Research objectives

The research objectives are to find and establish NDVI, NDWI and NDBI for the pre-determined territory (Adyar sub-basin in this case) for the selected time-periods and arrive at a relationship between the various calculated indices. We also try to advance these indices as a way to quantify the intensity of human activity and correlate with urban form.

Software used

- QGIS 3.4 Madeira
- ArcGis 10.

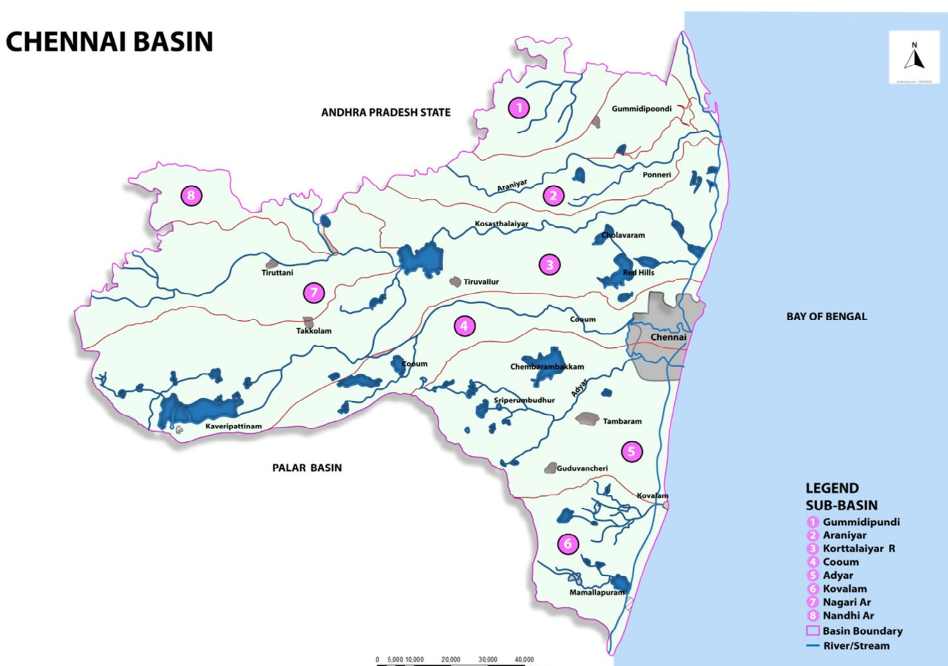
2.1 Study area

Chennai, formerly known as 'Madras' is the capital of the state of Tamil Nadu in India. The region under study, South Chennai, is a landscape dotted with water bodies and forms part of the sub-basin of the Adyar River. Chennai is a tier-I city in terms of population and a coastal city, boasting the second longest stretch of seashore in the world and an artificial harbour formed by running out masonry groins into the sea (Francis, 2001). The language spoken here is Tamil, one of oldest Dravidian languages. The city was founded in 1639 by the East India Company who bought it as a piece of land from Nayak rulers (Francis, 2001).

2.1.1 Geography

Chennai is located on the eastern coastal plains, on the southeast coast of India, towards the northeast of Tamil Nadu. The Cooum River divides the city into halves whereas the Adyar River divides the southern half into two parts, trisecting the city of Chennai. The rivers flow towards the east. Parallel to the coast, is the Buckingham Canal, running parallel almost to the entire length of the city. The soil consists of clay, sedimentary rocks and sandy soil. The protected estuary of the Adyar River and the wetlands which form a part of the basin, including Pallikaranai, form a natural habitat for several species of birds and animals. Redhills, Sholavaram and Chembarambakkam Lake form Chennai's water sources, among other sources.

Figure 1 Chennai basin map showing Adyar sub-basin (see online version for colours)



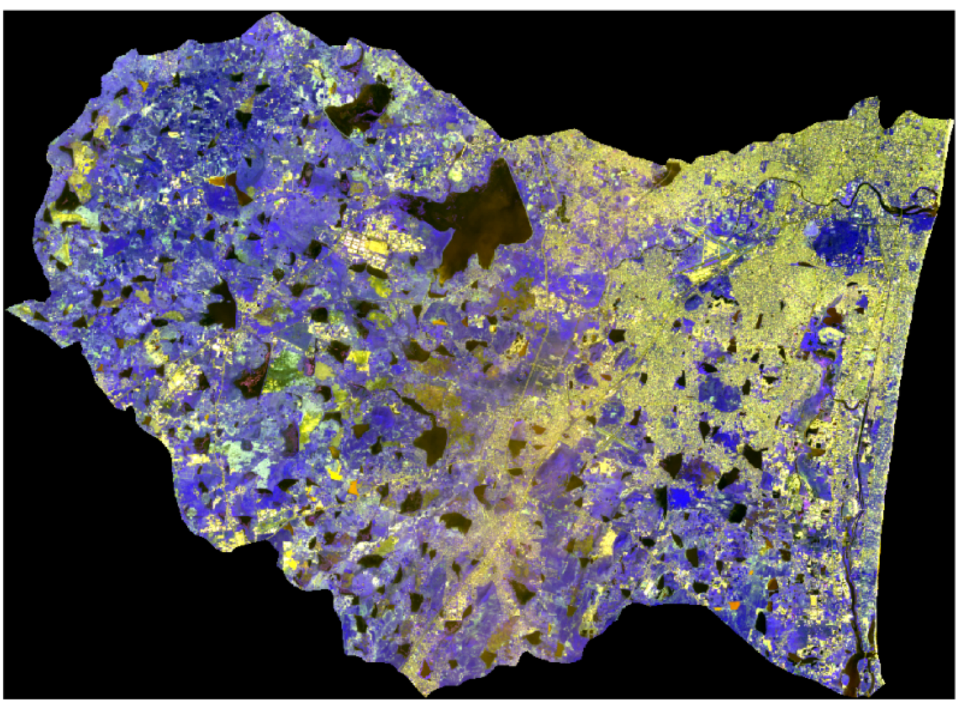
Source: Redrawn from http://www.google.com (Institute of Water Studies, Tharamani, Chennai)

The Adyar River originates from the Chembarambakkam tank, located in Thiruvallur District. It acts as a flood carrier for the city. The surplus discharge of Somangalam 'odai' (where 'odai' means stream), Manimangalam surplus and Guduvancherry 'odai' are discharged in the Adyar River (Kumar, 2016). It originates from Sriperumpudur block, passes through Poonamallee and the entire Chennai City and has its confluence at the Bay of Bengal. This does not serve for direct irrigation. However, it carries flood waters during the northeast monsoon. The sedimentary formations of Gondwana Quaternary and some alluvial deposits are found in the eastern part of the basin. They contain clay, shale, sandy clay, gravel and fine-to-coarse sand. This has no ground water potential for the Chennai Corporation. It comprises an area of about 1,082 sq.km. (Institute for Water Studies, no date).

2.1.2 Climate

Chennai has a hot and humid climate. The city is deprived of the annual southwest monsoons being on the leeward side of the western ghats, and obtains its precipitation only from the north-east monsoons, in October–November, when an average of 1,300 mm (51 inches) of rainfall reaches the city (Kumar, 2016). May is the hottest month, with the temperature touching 45°C. December and January are the coolest months with the temperature reaching 24°C. Cyclones are said to be common along the Bay of Bengal, and floods are constant, though less on the west coast (Francis, 2001).

Figure 2 Landsat 8 image of Adyar sub-basin, South Chennai area, January-2018 (see online version for colours)



Source: USGS Earth Explorer, processed by author

2.1.3 Population

Chennai has an estimated population of 4.646 million people according to the 2011 census (Government of India, 2011), which ranks 6th in India. Most people of faith within Chennai follow one of these religions: Hinduism, Buddhism, Islam, Christianity, Jainism, Sikhism and Zoroastrianism. Most residents of Chennai are Tamils. 62% of migrants to the city were from other parts of the state, 34% were from other parts of India, and 4% were from outside of India. Chennai has the fourth-highest population of slum dwellers in India, estimated at 820,000, or 19% of the city's total population.

2.2 Processing

Three Landsat images acquired comprising Landsat 2 data from 14 February 1977, Landsat 5 TM data from 17 February 1998 and Landsat 8 data from 7 January 2018 from USGS Earth Explorer were adopted. 1:50,000 topographic maps and administrative maps of the region were chosen as ancillary data. In QGIS 3.4 software, the semi-automatic classification plugin was used to perform atmospheric correction on the Landsat images, which were geometrically and radiometrically corrected at source.

Table 1 Landsat data with date and source

S. no.	*Date*	*Satellite data type*	*Source*
1	14 February 1977	USGS Landsat 2 data	USGS Earth Explorer
2	17 February 1998	USGS Landsat 5 TM data	USGS Earth Explorer
3	7 January 2018	USGS Landsat 8 data	USGS Earth Explorer

2.3 Calculation of NDBI, NDVI and NDWI

One can map built-up areas by means of NDBI by measuring spectral responses in the MIR / SWIR (1.55–1.75 μm) wavelength range which is greater for built-up areas than in the NIR (0.76–0.9 μm) wavelength range. NDBI can be expressed as

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

where *NIR* indicates near infrared reflectance such as ETM+ (Landsat enhanced thematic mapper plus) band 4, MIR denotes middle infrared reflectance such as ETM+band 5 in Landsat 2 (or equivalent band SWIR as in Landsat 5 or Landsat 8). Typically, NDBI values range from –1 to +1. The greater the NDBI is, the higher is the proportion of built-up land and hence the area has larger construction activity. NDVI is a linear combination of the near infrared band and the red band and this is regarded as the basic index for measuring the 'greenness' of the ground surface, in other words, the health of the vegetation. It is calculated by the following equation for Landsat image:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where *NIR* is the near infrared band, namely Landsat 2 band 6 reflectance, Landsat 5 band 4 reflectance, and Landsat 8 band 5 reflectance. Red represents red band namely, Landsat 2 band 5 reflectance, Landsat 5 band 3 reflectance, and Landsat 8 band 4 reflectance.

NDWI is a linear combination of the green band and the near infrared band, and may be understood as a basic index of the moisture content in the ground surface. It is calculated using the following equation for Landsat image.

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

where *NIR* is the near infrared band, namely Landsat 2 band 6 reflectance, Landsat 5 band 4 reflectance, and Landsat 8 band 5 reflectance. Green represents green band namely Landsat 2 band 4 reflectance, Landsat 5 band 2 reflectance and Landsat 8 band 3 reflectance. NDWI is often compared to changes in the urban setup as presence of moisture, or rather, availability of water can be directly correlated with city level scenarios, for example, the article by Mcfeeters (2013).

NDVI gives a quantitative measure of vegetation by measuring the difference between near-infrared (which is strongly reflected by vegetation) and red light (which is absorbed by vegetation). If the NDVI value is close to +1, it is highly probable that dense green leaves exist, but when NDVI is close to zero, there is no indication of green leaves and it could be water or even be an urbanised area. NDVI is essentially a standardised way to measure healthy vegetation. Hence, it is a relevant index for urban-environmental studies and is often correlated with land use land cover changes, for instance the work by Gandhi et al. (2015).

The NDWI quantity is dimensionless and varies from –1 to +1. High NDWI values imply high plant water content and hence of high plant fraction. Low NDWI values imply low vegetation content and low vegetation cover. During periods of water stress, the NDWI decreases. Thus, positive and negative NDWI values indicate water features and vegetation features, respectively (Singh, 2017).

The NDBI product is also dimensionless and varies from –1 to +1. High NDBI values indicate higher built-up area ratio and lower NDBI values indicate lower ratio of built-up area. As mentioned before, it is a new method and highly advantageous over supervised classification methods and has high accuracy.

3 Results and discussion

As mentioned in the introduction, a vital question is whether cities are worthwhile arenas for ecological research, and a thorough comprehension of the relationships between urban form and human activity within the ecosystem process is necessary to find solutions for the various problems humans encounter. By means of the observations with regards to the study area, from the satellite images and the built-up index, vegetation index and water index maps, the following observations are deduced.

Decrease in moisture content is evident from the disappearance of patches of blue in the maps above, starting from 1977 through 2018, in the areas close to the Chembarambakkam Lake, mouth of Adyar, etc. The major bodies of water have also decreased in size, with many on the western side having disappeared. The minimum values for NDWI for the year 1977, 1998 and 2018 are –0.895, –0.463 and –0.763, respectively, and the maximum values for the same years are 0.907, 0.776 and 0.755, respectively. For NDWI, +1 refers to presence of more water and –1 refers to no water, usually vegetation. Count refers to the total number of units or pixels, which is 322,685 for 1977, 1,290,718 for 1998 and 1,290,718 for 2018 for all three indices, which is resultant from the satellite referred. The sum of all values varies from –20,160.54 to –569,609 in the period 1977 to 2018. Mean or average, referring to the mid-range value around which they are clustered to show increase or decrease, which in this case, varies from –0.063 to –0.441 from 1977 to 2018, indicates a decrease in the average amount of moisture content as per the pixels. But the coefficient of variation, which is the ratio of standard deviation to the mean, shows an increase from –223.81 to –41.95, indicating that the overall dispersion around the mean in terms of moisture content has increased markedly, implying that water areas have disappeared overall. This is also visible in the maps where there are fewer water bodies in 2018 and a change in predominant colour (in the maps) from blue to green from 1977 to 2018.

Table 2 NDWI analysis data

Dates	*Statistical results of NDWI*						
	Minimum	*Maximum*	*Count*	*Sum*	*Mean*	*Std. dev.*	*Coeff. variation (SD / M) × 100*
February 1977	–0.895	0.907	322,685	–20,160.54	–0.063	0.141	–223.81
February 1998	–0.463	0.776	1,290,718	–180,107.92	–0.140	0.228	–162.85
January 2018	–0.763	0.755	1,290,718	–569,609	–0.441	0.185	–41.95

Figure 3 NDWI maps for the study area (see online version for colours)

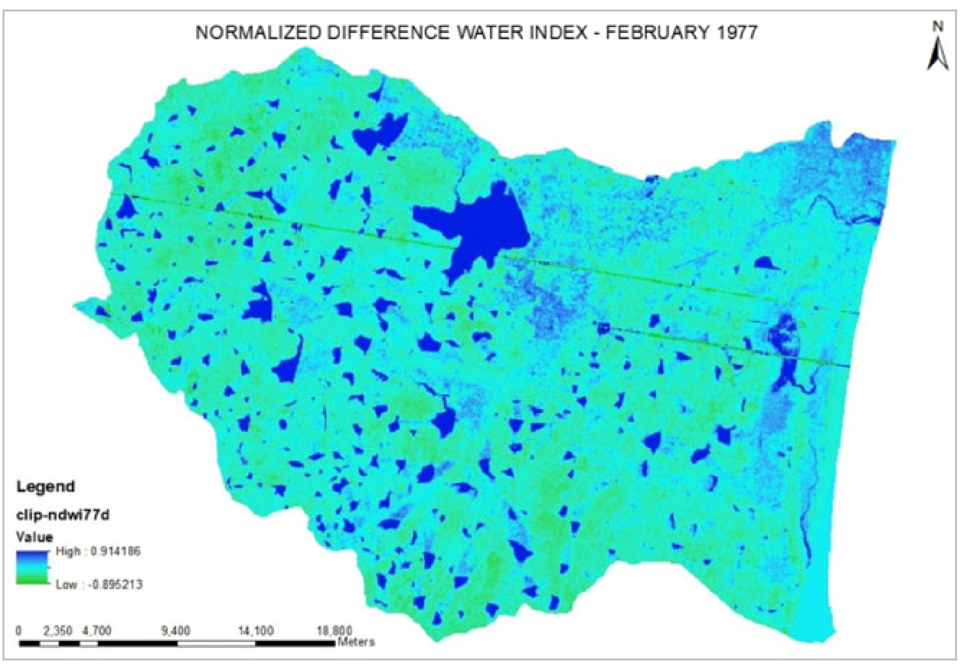
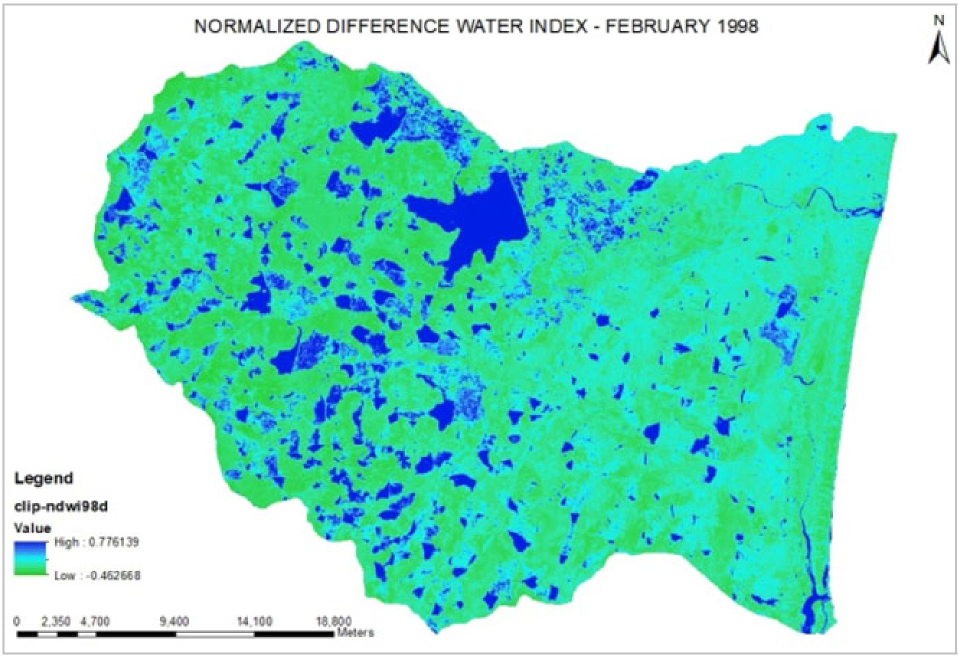
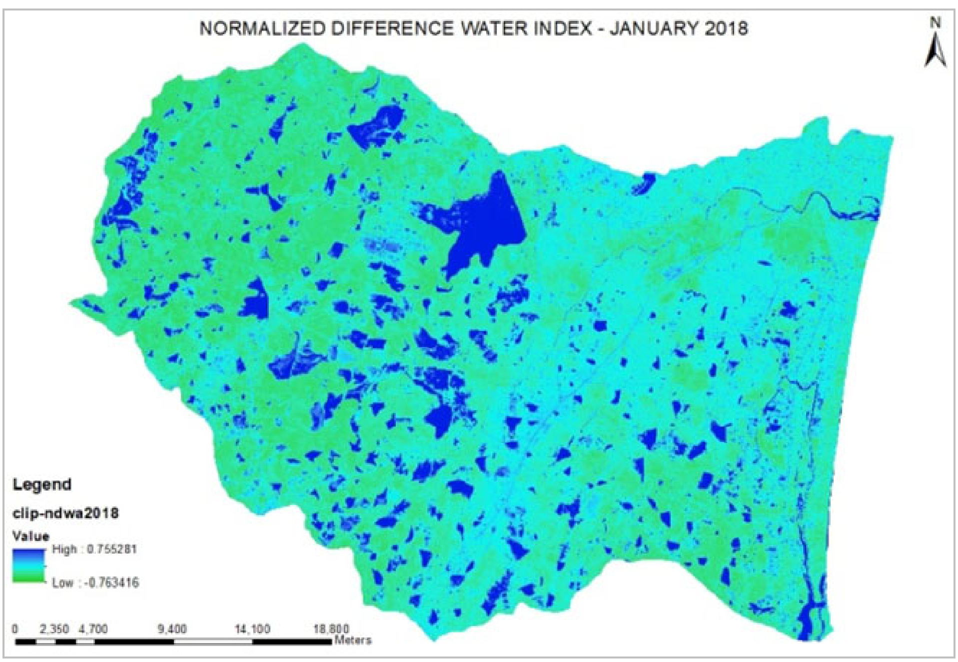


Figure 3 NDWI maps for the study area (continued) (see online version for colours)





In an NDVI map, presence of green indicates healthy vegetation and red indicates no vegetation. The minimum values for NDVI for the 1977, 1998 and 2018 are –0.883, –0.344 and –0.432 respectively and the maximum values for the same years are 0.726, 0.682 and 0.856, respectively. For NDVI, +1 refers to healthy vegetation and –1 refers to no vegetation, indicating water, or even built-up areas. The sum of all values varies from 44,469.14 to 585,882.29 for 1977 to 2018. Mean or average, referring to the mid-range value around which they are clustered is taken to observe increase or decrease, which again shows a trend from 0.138 to 0.454 from 1977 to 2018 indicating a moderate increase in average of pixels showing healthy vegetation. But the coefficient of variation, which is the ratio of standard deviation to mean shows a decrease from 82.61 to 36.78, indicating that the dispersion around mean in terms of health of vegetation has decreased markedly implying a tendency towards homogeneity and less healthy vegetation over time. The colour coding in the maps may also be referred to gain insight into the change in predominance of green to red, where green indicates healthy vegetation and red indicates no vegetation or water. Principle 9 from urban ecology principles states "urban designs and development projects at various scales can be treated as experiments, and used to expose the ecological effects of different design and management strategies" (Pickett and Cadenasso, 2017), which is relevant in this scenario since we observe vegetation indices and ecological impacts of the urban growth and development.

Table 3 NDVI analysis data

Dates	*Statistical results of NDVI*						
	Minimum	*Maximum*	*Count*	*Sum*	*Mean*	*Std. dev.*	*Coeff. variation (SD / M) × 100*
February 1977	–0.883	0.726	322,685	44,469.14	0.138	0.114	82.61
February 1998	–0.344	0.682	1,290,718	365,900.08	0.284	0.135	47.54
January 2018	–0.432	0.856	1,290,718	585,882.29	0.454	0.167	36.78

Figure 4 NDVI maps for the study area (see online version for colours)

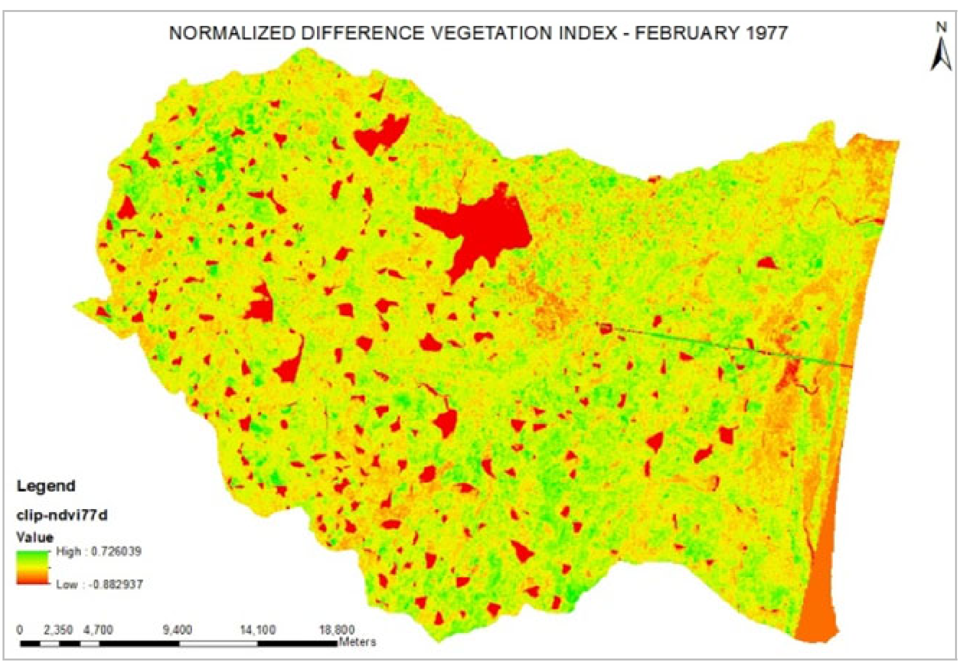
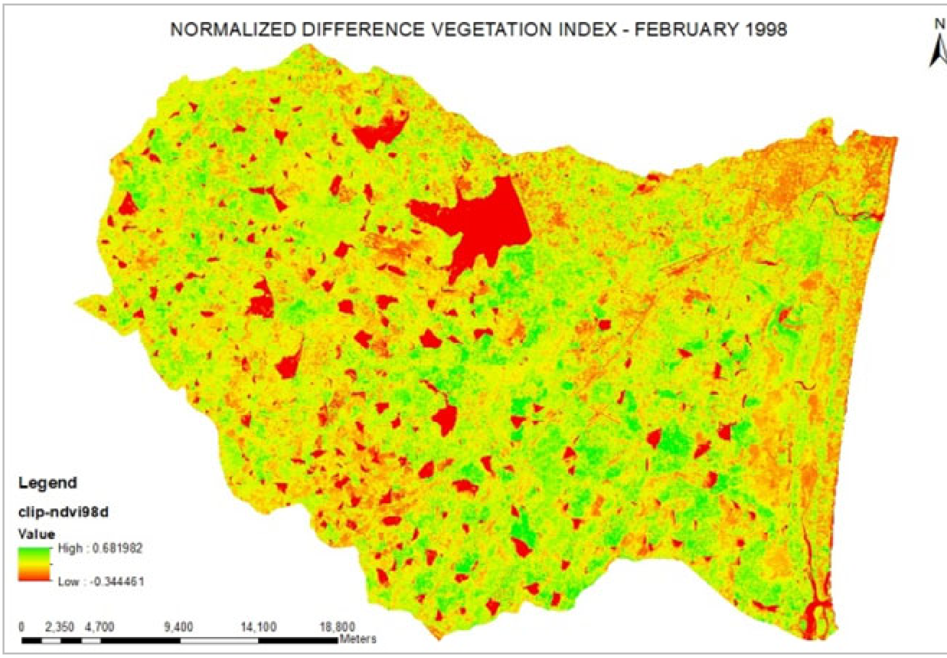
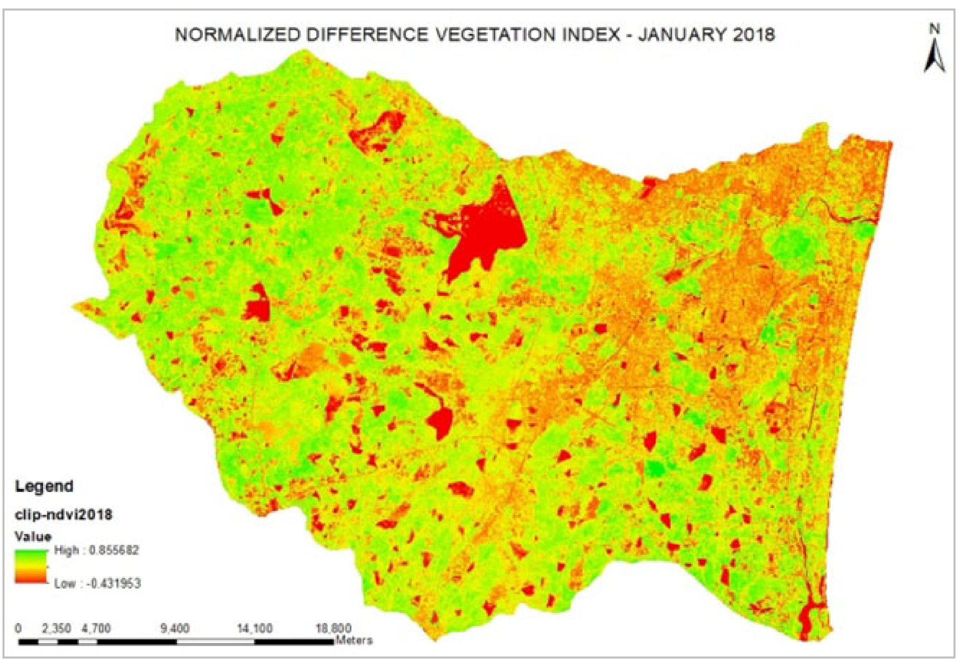


Figure 4 NDVI maps for the study area (continued) (see online version for colours)





As explained before NDBI is an automated mapping method without the interference of an analyst, and it gives an accurate result. The range of colours seen in the map from highest (top) to lowest (bottom) values is shown in the legend. The minimum value of NDBI for 1977, 1998 and 2018 is –0.864, –0.695 and –0.675, respectively, and the maximum for the same years is 0.921, 0.298 and 0.361, respectively. For NDBI, +1 refers to maximum built-up pixels and –1 refers to no built-up pixels. Sum refers to the sum of all values which varies from 2,455.55 to –100,184.97 for 1977 to 2018. Mean or average, referring to the mid-range value around which they are clustered, is taken to observe increase or decrease, which again shows a trend from 0.008 to –0.107 from 1977 to 1998, going up to –0.087 in 2018 indicating marginal change yet overall rise of number of built-up pixels. Marginal changes in mean may be explained by the fact that the boundary chosen is a mixed landscape, comprising of a river basin with agricultural, natural and urban components. Hence, observation of vegetation and water indices will shed light on the nature of processes from an urban ecology perspective. Comparison of coefficient of variation, which is the ratio of standard deviation to mean, for all three years shows that it has decreased from 1977 to 2018 from 1,087.5 to –134.5, indicating a marked decrease in dispersion around mean from 1977 to 1998 and marginal decrease from 1998 to 2018, which implies high level of variation and an overall increase in built-up areas including a tendency towards homogeneity.

Table 4 NDBI analysis data

Dates	*Statistical results of NDBI*						
	Minimum	*Maximum*	*Count*	*Sum*	*Mean*	*Std. dev.*	*Coeff. variation (SD / M) × 100*
February 1977	–0.864	0.921	322,685	2455.55	0.008	0.087	1087.5
February 1998	–0.695	0.298	1,290,718	–137,918.08	–0.107	0.150	–140.2
January 2018	–0.675	0.361	1,290,718	–100184.97	–0.087	0.117	–134.5

Figure 5 NDBI maps for the study area (see online version for colours)

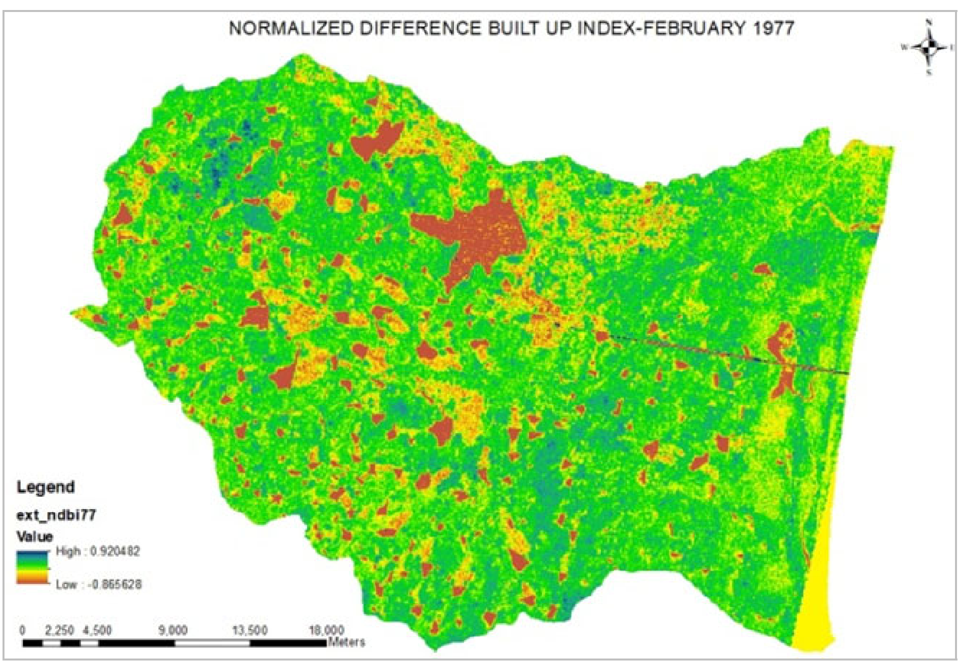
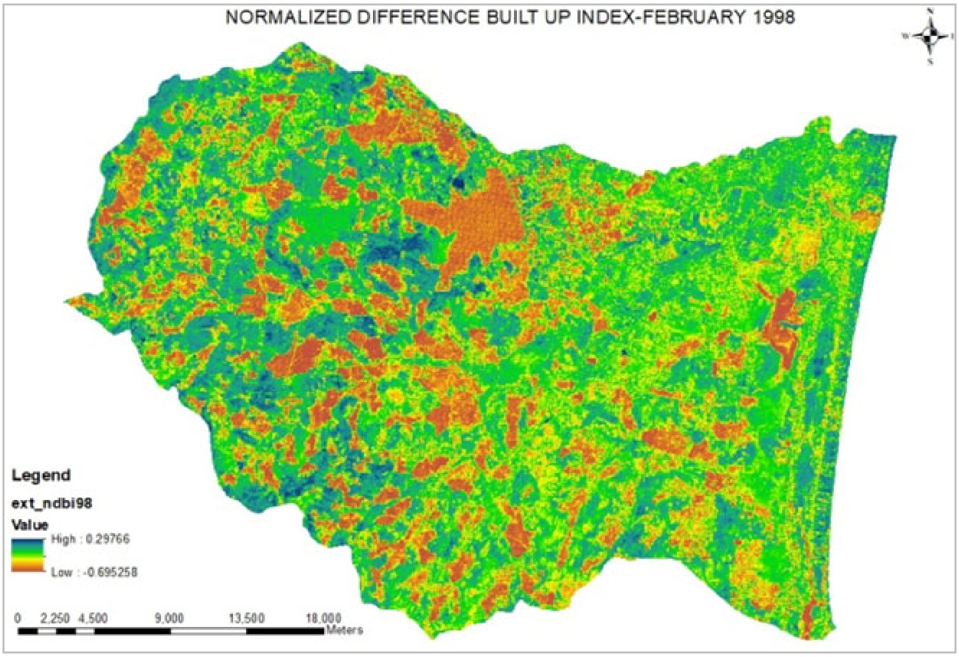


Figure 5 NDBI maps for the study area (continued) (see online version for colours)



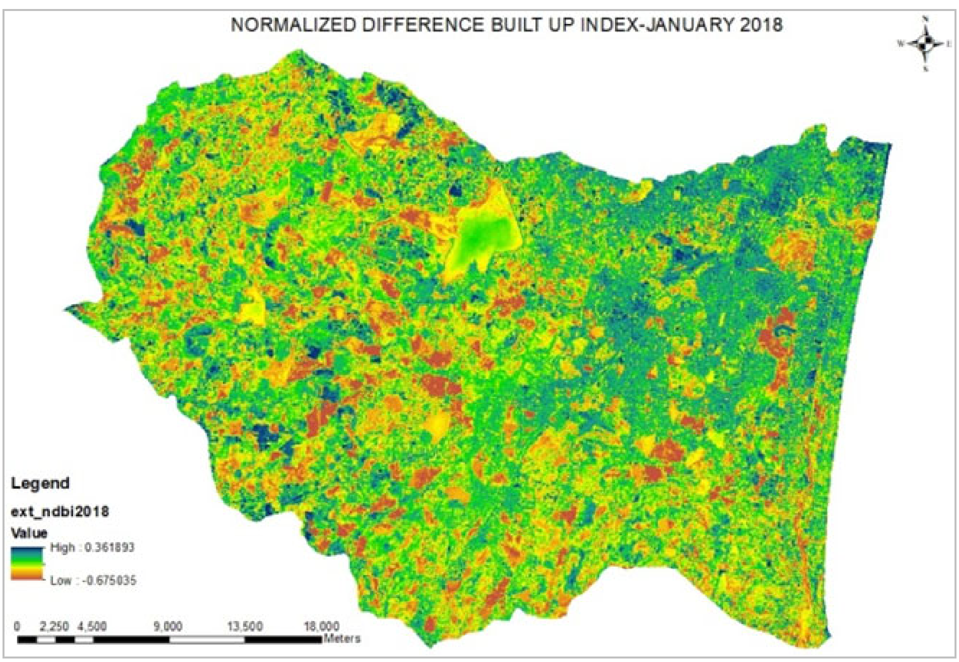


Table 5 T-test for comparison of means

Test	*Degrees of freedom*	*Tailed*	*Level of confidence*	*Mean difference*	*Confidence range*	*Conclusion*
NDBI means (pairs)						
t-test	940,765.2642	Two-tailed	95%	0.115	0.1146–0.1154	Difference of means is statistically significant as it falls within confidence range
t-test	2,581,434	Two-tailed	95%	–0.02	–0.0203—0.0197	Difference of means is statistically significant as it falls within confidence range
t-test	940,765.2642	Two-tailed	95%	–0.095	–0.0954—0.0946	Difference of means is statistically significant as it falls within confidence range
NDVI means (pairs)						
t-test	940,765.2642	Two-tailed	95%	–0.146	–0.1465—0.1455	Difference of means is statistically significant as it falls within confidence range
t-test	2,581,434	Two-tailed	95%	–0.17	–0.1704—0.1696	Difference of means is statistically significant as it falls within confidence range
t-test	940,765.2642	Two-tailed	95%	0.316	0.3155-0.3165	Difference of means is statistically significant as it falls within confidence range
NDWI means (pairs)						
t-test	940,765.2642	Two-tailed	95%	0.077	0.0764–0.0776	Difference of means is statistically significant as it falls within confidence range
t-test	2,581,434	Two-tailed	95%	0.301	0.3005–0.3015	Difference of means is statistically significant as it falls within confidence range
t-test	940,765.2642	Two-tailed	95%	–0.378	–0.3786—0.3774	Difference of means is statistically significant as it falls within confidence range

Table 6 F-test for comparison of standard deviations

Test	*Degrees of freedom*	*Tailed*	*Significance level*	*Ratio*	*Confidence interval*	*Conclusion*
NDBI standard deviations (pairs)						
F-test	n1: 322,684 n2: 1,290,717	Two-tailed	0.05	0.58	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 1,290,717	Two-tailed	0.05	1.28	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 322,684	Two-tailed	0.05	1.34	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
NDVI standard deviations (pairs)						
F-test	n1: 322,684 n2: 1,290,717	Two-tailed	0.05	0.84	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 1,290,717	Two-tailed	0.05	0.81	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 322,684	Two-tailed	0.05	1.46	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
NDWI standard deviations (pairs)						
F-test	n1: 322,684 n2: 1,290,717	Two-tailed	0.05	0.62	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 1,290,717	Two-tailed	0.05	1.23	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant
F-test	n1: 1,290,717 n2: 322,684	Two-tailed	0.05	1.31	95%	The sample standard deviations of the two groups are different and hence the difference between them is considered statistically significant

Principles 12 and 13 from Pickett and Cadenasso (2017) apply quite implicitly in this context. Principle 12 states "urban land covers and land uses extend into and interdigitate with rural or wild land covers and uses", while Principle 13 states, "the flux of water, including both clean water supply, waste, and stormwater management, is of concern to urban and urbanizing areas worldwide, and connects them explicitly to larger regions."

It is desired to ascertain whether the changes in values with time, specifically average values, are significant in their indication of physical changes or modifications. This hypothesis is checked using a recommended statistical tool, the t-test calculator.

Hence, a set of t-tests were conducted to observe the significance of means by comparing pairs of means within the NDBI, NDVI and NDWI. The results indicate that the differences between each pair of means of all three indices is statistically significant, which supports the validity of the data.

It was also desired to ascertain if the changes in standard deviation for each pair of SDs was significant statistically. Hence, a recommended statistical tool, the F-test calculator was applied.

Hence, a set of F-tests were also conducted to observe the significance of standard deviations by comparing pairs of SDs within the NDBI, NDVI and NDWI. The results indicate that the differences between each pair of standard deviations for all three indices are statistically significant.

Kamaraj and Elangovan (2018) have studied the Chennai basin with specific results for Adyar sub-basin to predict land use land cover changes through cellular automata algorithm using slope, land use, exclusion, urban extent, transportation, hillshade (SLEUTH) model. They have given results for the years 2016 and 2036 viz., for Adyar sub-basin, which is of an area of 702.90 sq.km the extent of urban area in 2016 was 343.5 sq.km and in 2036, it is predicted to be 463.0 sq.km. The difference between the two is 119.5 sq.km, and the percentage increase with respect to total area of the basin is 66%, and the percentage increase with respect to 2016 is 34%. The impact of this urban growth on hydrological component parameters like surface run-off in mm amounts to 572.84 mm in 2016 and 874.28 mm in 2036 which is a significant increase; groundwater flow amounts to 52.72 mm in 2016 and 21.01 mm in 2036 which exhibits a significant decrease and evapotranspiration amounts to 948.31 mm in 2016 and 796.39 mm in 2036 which is also a significant decrease. This agrees with the results of our study, which details the effects on water resources corresponding to the built-up and vegetation maps.

In terms of population, the average annual rate of growth considering the three decades from 1971 till 2001 is found to range from 1.85% in Kundrathur to 9.08% in Perungudi town panchayats.[5] Among the panchayat unions, St. Thomas Mount, which comprises of 33 villages and covers an area of 98.39 sq.km, exhibits the highest increase in average annual growth rate of population to the order of 6%. Hence, the magnitude of population increase is found to correlate adversely with urban ecology in the given region. These observations make use of the study on Pontchartrain River Basin by Carstens and Amer (2017) as a reference.

Goldman and Narayan (2019) discuss how the urban transformation of Bangalore from a mid-sized town into a 'Silicon Valley' is coupled with shifts in hydro-social territorial use. Three hydro-social regimes, the catchment-based regime, the hydraulic regime and the speculative urban regime, are used to examine the water infrastructure of Bangalore. Chennai and Bangalore have similarities in their economic growth, as both cities have had an economic up thrust due to the IT industry and the speculative urban hydro-social regime in Bangalore has resulted in private bore wells being sunk and tapped on a vast scale, and the growth of a large-scale private water market with tankers plying all over the city, much like the conditions in Chennai in recent years (Packialakshmi and Ambujam, 2017). The stories reflect similar activity and conditions: solutions need to respond to the geographies, ecologies, and find ways to tackle the resource-loss problems. Tudor et al. (2016) have performed questionnaire surveys and identified by means of behaviour, responses of inhabitants of Chennai, five clusters of residents, namely, non-environmentalist, occasional environmentalist, mainstream environmentalist, committed environmentalist and dedicated environmentalist, which is a demonstration of psycho-social factors in relation to the environment and sustainability. It demonstrates disparate levels of awareness, limitations and also the power of the individual in the situation to mitigate the problems of the community.

4 Conclusions

An analysis by way of comparison of indices indicates the relationship between ecological and land use-related factors in the study area. Areas of diminishing water resources and stressed vegetation and increased built-up area were mapped and analysed in various parts of the study area. These results have been corroborated by other studies as mentioned in the discussion section. Urban ecology principles have also been cited to illustrate the fact that the observed processes fit into models studied previously and can be taken further. The study conducted is a basic comparison of calculated indices for an identified region which is of interest to us. The indices look at different aspects of the problems and provide perspectives which are considered together to arrive at an understanding. It could be extended by considering other indices including soil index, modified normalised difference water index and including them for particular areas which may go into further detail. A study of this nature indicates the need for rethinking the growth policies and the need to take pro-environmental steps, while tackling the demands and the economic agenda. Man, while being a participant in the environmental processes, needs to optimise his interests to suit collective growth interests and objectives while also maintaining the resources and an equilibrium between species.

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Notes

1 Information technology corridor – the highway comprises of multinationals and hence has been named thus.

2 Municipal solid waste refers to MSW dump.

3 Landsat thematic mapper, which refers to a satellite.

4 Short-wave infrared refers to the radiation bands of the satellite imagery.

5 The term panchayat refers to an administrative unit. Formerly in rural areas, it was the local governing body of the village or village council.