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Multi-Temporal Analysis and Quantification of the Carbon Stocks in the Urban Forests of Chennai Metropolitan Area Using Geoinformatics Techniques to Identify Their Role in Climate Change Mitigation

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Abstract

The rapid urbanisation that has been happening over the years has led to the total disturbance in the ecological balance of the environment. Various developmental activities have led to the continuous depletion of the vegetation cover. Monitoring the loss of vegetation cover is a challenging task now a days due to the changing trends of urban sprawl and heterogeneous nature of the urban vegetation cover. From various reviews, it is known that the most common methods used for carbon storage studies are the field based studies that are more destructive in nature. Hence in the current research effort has been taken to carry out to study the carbon storage potential of the urban green spaces using the non-destructive methods that is, using satellite images. In the current study the carbon storage was taken as a function of the vegetation indices. The carbon storage was found to be a function of the Vegetation Indices. Hence a regression equation was developed to quantify the carbon storage of the urban trees using NDVI as the independent variable and the carbon storage (in Mg/pixel) for five different years (1980, 1991, 2001, 2011, and 2016) as the dependent variable. The data was drawn from 500 plots established through stratified random sampling scheme, based on the land use type, built up, vegetation and barren lands and further residential and commercial areas within city. From the regression equation the carbon storage potential of the urban green space was derived for 5 different years. Hence the gradual change in the above carbon biomass for 5 years was calculated from which the total biomass and subsequently the carbon stored were calculated.

Keywords

Ecological balance; Urban vegetation; Carbon storage ; Geoinformatics and Urban green space

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Introduction

The planned development of Chennai city should present a clean and green space with trees, plants, lakes and parks and towns in Chennai. The city seems to be growing at a faster pace towards north, west and southern directions. This may be attributed to the development of IT corridors, special economic zones and smart cities. Chennai has shown tremendous growth during last decade. But these developments have created a greater threat to the existing greens. Tree canopies shows moderate temperature, provide shade to buildings, sidewalks, streets and also reduce pollution [1]. Urban areas harbors a large variety of green spaces, such as parks/gardens, green space near institutions, Green spaces play a major role in urban areas through their environmental, aesthetic, social and economic contributions to residents' health and wellbeing [2].

Study Area

Chennai formerly known as Madras, with a total population of 4,646,732 (Census, 2011), is ranked as fourth largest urban agglomeration in India and also capital of Tamil Nadu. It is situated on Bay of Bengal in Eastern India. Chennai city has grown laterally with municipality and its peri-urban fringe, including Thiruvallur and Kancheepuram districts. The urban agglomerate covers a total area of 1189 sq. km including the city's 176 sq. km. The green cover of Chennai city is 6.25%, which includes 5 sq. km of moderately dense forest and 4 sq. km of open forest (Forest Survey of India, 2009). In Earlier days, plantation of tree has been done by the Forest department, Public Works Department and Corporation of Madras. Also many G.Os indicate the nature of trees to be planted in avenues and as fuel trees in Madras. The city is rapidly losing its tree cover because of various infrastructure development projects. The commencement of metro rail work in many areas of the city has resulted in the closure of parks like May Day Park at Chintadripet, Nehru Park on Poonamallee High Road and Thiru-vi-ka Park at Shenoy Nagar. Many rare trees for Chennai like Barringtonia acutangula and Berrya cordifolia inside Thiru-vi-kapark and Cassia javanica subsp. nodosa, in Nehru Park have been axed. The continuous loss of green cover due to these development activities has caused tremendous changes in the environment of Chennai (Figure 1).

Urban Green Space Analysis Using NDVI

The satellite images were acquired to monitor the vegetation conditions in the study area. The images were acquired in the same months preferably in the month of April and May so that the vegetation conditions may remain the same. To avoid errors or any false changes in the images radiometric corrections need to be carried out. Quantitative analysis to study the vegetation status of CMA was done using NDVI (Normalised Differential Vegetation Index). Health of the vegetation can be studied by the amount of reflectance received from the vegetation cover. The healthy vegetation cover absorbs most of the red light and reflects huge portion of light in the Infra-red region. NDVI is found by ratio of the intensities in red (R) and near Infra-red spectral bands.

$$\text{NDVI} = \frac{NIR - R}{NIR + R}$$

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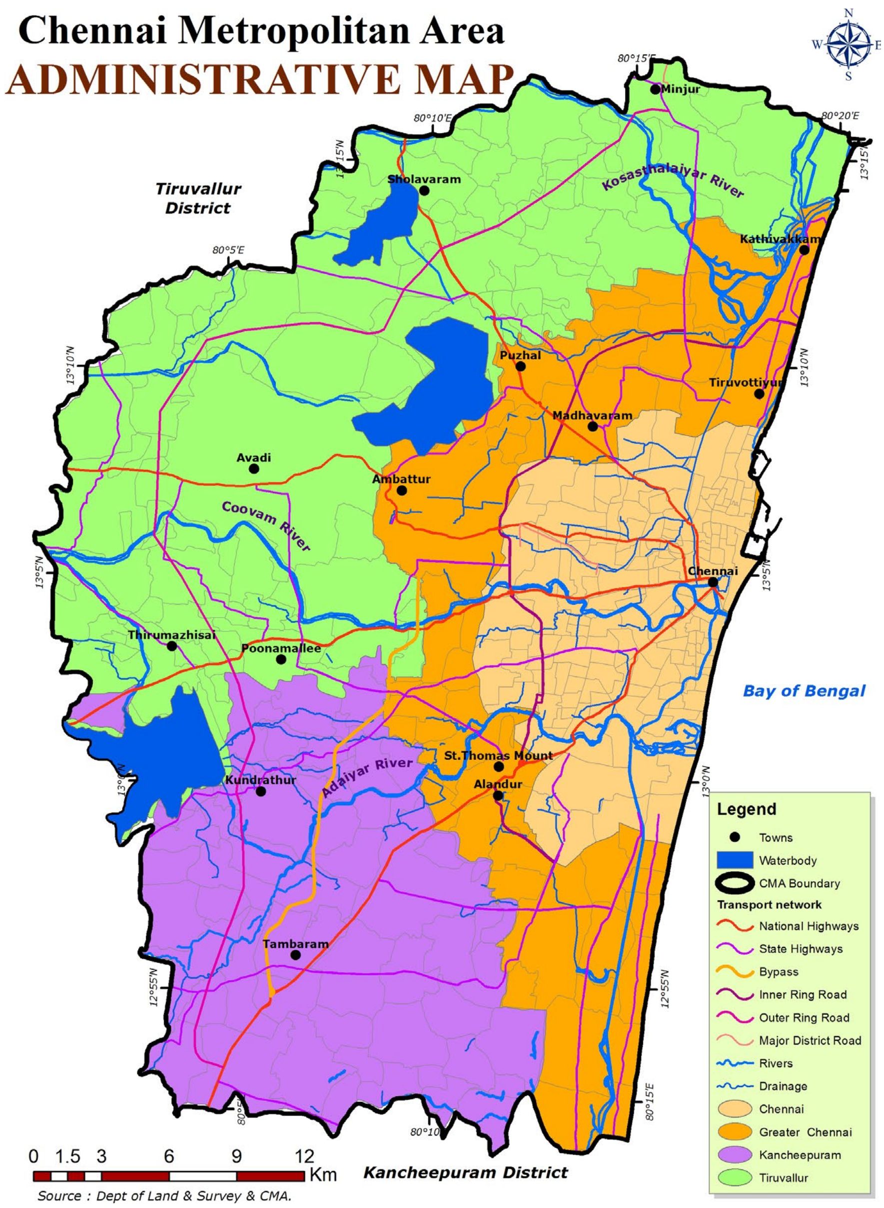

Figure 1: Chennai metropolitan area.

NDVI for TM, ETM+ and OLI images were computed by using the above formula. Resulting index value ranging from -1 to +1 indicates the sensitivity to presence of vegetation on the land surface of earth, can be used to address issues of vegetation type, amount and condition. NDVI is found to be a major tool for analysing the change. It is best suitable for change detection as they are less affected by atmospheric conditions [3].

Carbon Sequestration Potential of the Urban Green Space Using Satellite Image

The significance of the urban trees and forests are slowly gaining importance but the awareness among the general public is very less. The urban trees play a major role by acting as the lung spaces by absorbing the atmospheric carbon dioxide in the air and fixing it by photosynthesis and converting them into biomass. Hence there needs to be a balance between the amount of the emissions and the urban trees that act as a natural sink. These keep on fluctuating due to the continuous change in the urban infrastructure and the land use. These changes are primarily due to human influences. But once the trees grow old and decay the carbon stored in these trees will be further released into the atmosphere which in turn adds on to the carbon dioxide level in the atmosphere. Hence this shows clean evidence on how the urban greeneries influence the air temperature and energy use in the buildings and consequently alter carbon emissions from numerous urban sources (e.g., power plants). This shows the direct relationship between the urban trees and the local climate, climate change, energy use and mineral cycles [4,5].

Generally these vegetation data for studying the carbon storage and sequestration potential are acquired by the field based studies or by using the visual interpretation of the aerial photos. But for the remote sensing methods for this purpose solve lot of problems. They are useful in acquiring the vegetation dynamics for a large scale area and also is helpful in monitoring the temporal data. As the field based studies are hectic and labour intensive the remote sensing based approach are found to be more effective in terms of the speed , acquiring the data for previous years and also helpful in covering a larger area. Using spectral indices like NDVI to monitor the biomass is found to be effective recently [6]. Biomass can be estimated with the help of spectral indices as the NDVI captures the vegetation health. From the biomass the carbon dynamics can be studied as it occupies half the dry weight of the biomass.

By observing objects or the process in different time periods, the changes in objects or phenomenon can be observed. This is termed as change detection [7]. The changes in land use and land cover are constantly studied. The radiance values of the satellite data is found to change constantly with the change in the land cover [8]. The sensor calibrations are found to differ in different images. These calibrations should be minimised [9,10]. Satellite imagery collected in different acquisition dates should be corrected for differences between satellite calibrations and environmentally introduced radiometric effects. Radiometric corrections using Pseudo Invariant Feature (PIFs) show immense potential for imagery to imagery radiometric normalization [11,12]. After radiometric normalisation the changes in the carbon storage for different years are found out to assess the damage from natural and manmade events. The PIF method involves the analysis of features like roads, rooftops and parking lots where the reflectance characteristics are invariant over time. Instead of using threshold values, invariant features (e.g. roads. rooftops, quarries and deep water) collocated from multiple years were manually selected. Although it was a labour intensive task, this improves statistical consistency because the selected pixels are located at same location on every image, thereby limiting the possibility of using statistical outliers such as dramatic land cover change.

Radiometric Normalization Using PIF (*Pseudo Invariant Feature*) Method

Radiometric normalization using PIF was developed by Salvaggio and Schott et al. [11,12]. The objects that have reflectance that doesn't change in different scenes from the same area. These objects don't show variation in the reflectance in different seasons or biological seasons. The PIF were selected from the imageries were distributed equally in the concrete structures and other manmade objects that doesn't change over a period of time. These were taken with reference to the literatures [13-15].

PIF set={(band 4 / band 3)<1 and band 4>180}

The normalization coefficients (a_i, b_i) were obtained on the basis of the PIF selected from the subject and reference images, applying the following formula:

$$a_i = \frac{s\,ri}{s\,si}$$

$$b_i = m_{ri} - ai * m_{si}$$

(where: s_{ri}-Standard deviation of PIF set in the reference image for band(i); s_{si}-Standard deviation of the PIF set in the subject image for band(i); m_{ri}-The average value in the reference image for band(i); m_{si}-The average value in the subject image for band(i).

Urban Forest Carbon Storage

The carbon storage was found to be function of Vegetation Indices. Hence a regression equation was developed to quantify the carbon storage of urban trees using NDVI as the independent variable and the carbon storage (in Mg/pixel) for different years (1980, 1991, 2001, 2011, 2016) as dependent variable. The data was drawn from 500 plots established through stratified random sampling scheme, based on the land use type, built up, vegetation and barren lands and further residential and commercial areas within the city (Table 1). Of the 500 plots, 125 plots were treeless. From the derived NDVI data, the coefficients a and b were determined. The nonlinear regression equation was derived from this to estimate the total carbon storage in the urban forest setting (Figure 2) [16].

$$\text{Carbon} = a*e^{(NDVI*b)}$$

Urban forest carbon storage equation

The plot of stored Carbon (Mg /C pixel) vs. scaled NDVI was taken for 500 plots. The final regression equation of the carbon storage and the vegetation index is

Carbon = $0.25*e^{(NDVI*0.233)}$ for the year 1980

Carbon = $0.46875*e^{(NDVI*0.14197)}$ for the year 1991

Carbon = $0.11538*e^{(NDVI*0.23811)}$ for the year 2001

Carbon = $1.15385*e^{(NDVI*-0.0056)}$ for the year 2009

Carbon = $1.17838*e^{(NDVI*-0.0032)}$ for the year 2016

Where Carbon is the total Carbon Storage (Mg C/pixel) and NDVI is the Landsat NDVI value.

The value was then calculated for hectare. The Above ground biomass was found out using ERDAS Imagine 2014. The Below Ground Biomass was 26% of the Above Ground Biomass. From the AGB the BGB was calculated. From these the Total Biomass was calculated by adding the AGB and BGB. The biomass value was converted into carbon stock by using the conversion factor with the equation [17]. Biomass values were multiplied by 0.475 to get carbon storage values of the urban trees [18] (Figure 3).

Results

Temporal change in the total carbon storage

From the above equations, the research estimates the total amount of carbon storage for 5 years (Table 2).

The carbon stock estimation for 5 different years has been

Table 1: The Correlation coefficients derived from Imagery statistics for five different years.

Correlation Coefficients					
Year	1980	1991	2001	2011	2016
Coefficient a	0.25	0.46875	0.11538	1.15385	1.17838
Coefficient b	0.23337	0.14197	0.23811	-0.0056	-0.0032
Mean	-0.05674	0.164728	-0.16403	0.194827	0.219185
Standard Deviation	6.67E-06	3.56E-06	1.44E-05	1.44E-06	1.67E-06

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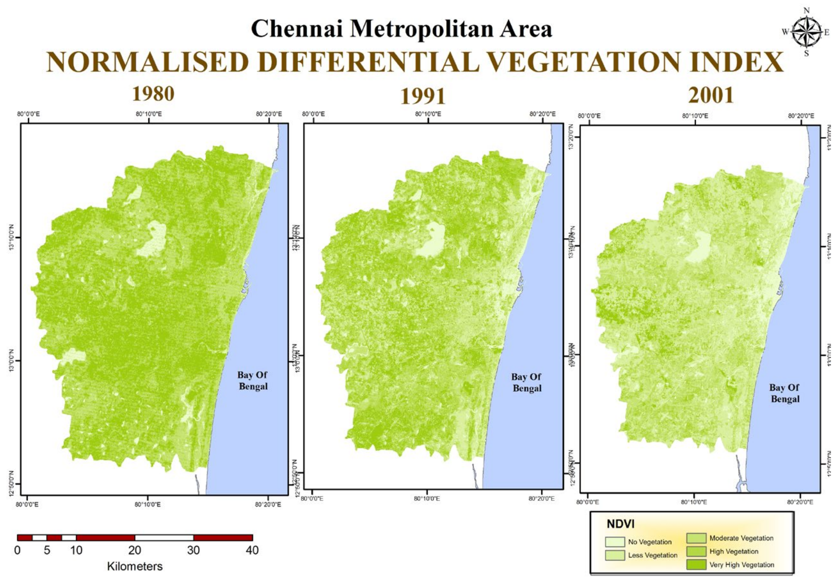

Figure 2: Normalized differential vegetation index – 1980, 1991 & 2001.

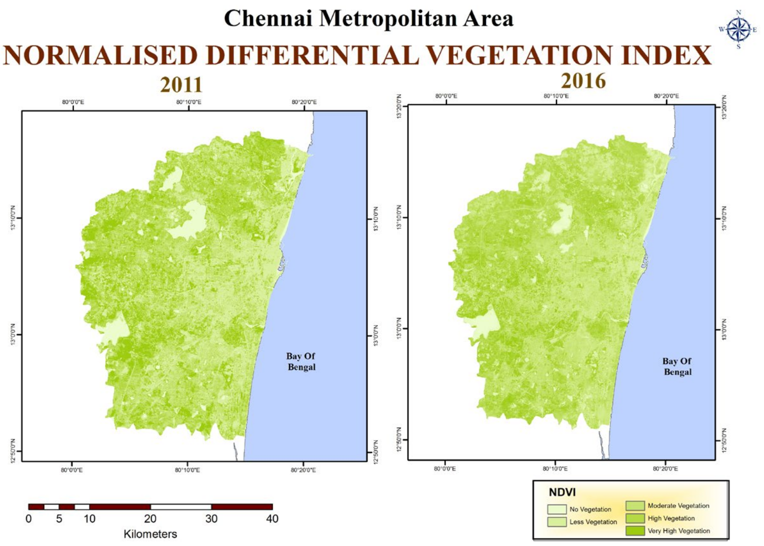

Figure 3: Normalized Differential Vegetation Index – 2011 & 2016.

Table 2: Carbon stock estimation of Chennai Metropolitan Area for 5 different time periods.

Year	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TGB (Mg ha^{-1})	CS (Mg ha^{-1})
1980	540560.9	140545.8	681106.7	306498.04
1991	290558.2	75545.13	366103.3	164746.50
2001	133615.1	34739.93	168355	75759.76
2011	99563.15	25886.42	125449.6	56452.30
2016	78536.24	20419.42	98955.66	44530.05

estimated and has been found to be in a decreasing manner. The green spaces have reduced gradually over the years due t drastic expansion of the city limits, The area of Chennai has expanded from 174 sq.km to 426 sq.km in 2011. Now the Chennai Metropolitan Area extends up to 1189 sq. km. The population has been expanding very rapidly towards south and north western direction. This may be attributed towards the upcoming industrial and commercial establishments in these regions and a lot of open spaces, green spaces and water bodies have been lost in these regions, The loss of these green spaces have in turn reduced the capability to store carbon. Hence there has been a decreasing trend. Thus the total carbon storage of the CMA has reduced from 306498.04 Mg ha^{-1} to 44530.05 Mg ha^{-1} thereby showing almost 85% reductions in the carbon storage.

Conclusion

The satellite image data was found to be very useful for mapping carbon on a large scale. Using multi-temporal satellite image data potentially enables mapping of the urban forest carbon storage regionally, rather than limiting to ground measurements. Detecting the carbon storage by urban vegetation in past was a challenge. Hence

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remote sensing data has been used to find out the carbon storage of the earlier years. Forests, especially the urban forests, are heterogeneous surfaces where complicated interactions among features can be obtained in the spectral response. Mixed pixels in conjunction with the inherent variability of regression estimation equations lead to over and under estimation of carbon storage throughout the city. Considering that the urban areas have considerable mixed pixel effects, the results of carbon storage estimation in this study are satisfactory.

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