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Research Article

CARBON STORAGE ESTIMATION IN HUGLI ESTUARY USING LANDSAT TM5 DATA

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ABSTRACT

Carbon storage quantification and change in tree condition and tree species is vital to understanding the role of vegetation in the environment. At present, this is mostly achieved through ground truth survey. This present study applies a method based on the multi-temporal satellite image for forest carbon storage mapping. Multi-decadal satellite imageries were applied to generate a regression equation to forecast the forest carbon storage from the Normalized Difference Vegetation Index (NDVI) computed from 1989 to 2010 of Landsat TM5 data. It was developed from the 2010 field-based model estimates of carbon storage in Hugli estuary region, India. The total computed carbon storage using NDVI agree closely with the observed data-based model estimates. Changes in total carbon storage by trees in the estuary were estimated using the image from 1989 and 2010. Radiometric correction has been achieved by normalizing the 2010 image to the 1989 image. After the radiometric correction, the carbon storage by trees in Hugli estuary was estimated to be 19.35 million tons and 19.64 million tons of carbon for 1989 and 2010 respectively. The results present the fast and economic capability of change detection in monitoring the change in carbon storage in an estuary.

Keywords: *Ground Truth Survey, Multi-temporal, NDVI, Radiometric Correction, Change Detection*

INTRODUCTION

Trees play an important role in reducing atmospheric CO_2 through assimilation. They can also reduce the use of fossil fuel through various processes.

Quantifying carbon stored by trees in different categories of land should be accompanied by land use change detection because of its more dynamic nature. Field survey and visual interpretation of aerial photographs have been used as conventional methods to obtain the data regarding forest management.

These methods are basically extortionate, labour-oriented and prolonged. Besides, they can monitor only a segment of the area of interest.

Forest area monitoring can be made more rapid and efficient through the help of remote sensing and data interpretation techniques. One common way to monitor biomass at the landscape level is to use spectral indices (Curran, 1981; Franklin and Hiernaux, 1991; Tucker and Sellers, 1986).

For detecting change in carbon storage these spectral indices can be used as the actual amount of stored carbon in a tree indicates the dry-weight biomass of those trees (Forest Products Laboratory, 1952). Normalized Difference Vegetation Index (NDVI) is one of the most commonly used spectral indices which are determined by the brightness values present in red and near-infrared bands of satellite data. The present research used this NDVI using Landsat TM5 data.

In remote sensing the process of change detection is normally used to identify changes in brightness values in corresponding pixels of two or more images of different dates (Singh, 1989).

Radiometric correction methods based on Pseudo Invariant Features (PIFs) show potential for image-to image radiometric normalization (Schott *et al.*, 1988).

Remote sensing techniques can be used in the radiometric normalized imageries to detect changes in carbon storage for different categories of land use.

The primary focus of this study was to develop rapid and worthwhile methods to count the carbon storage of trees and its temporal variation in an estuary using satellite data.

MATERIALS AND METHODS

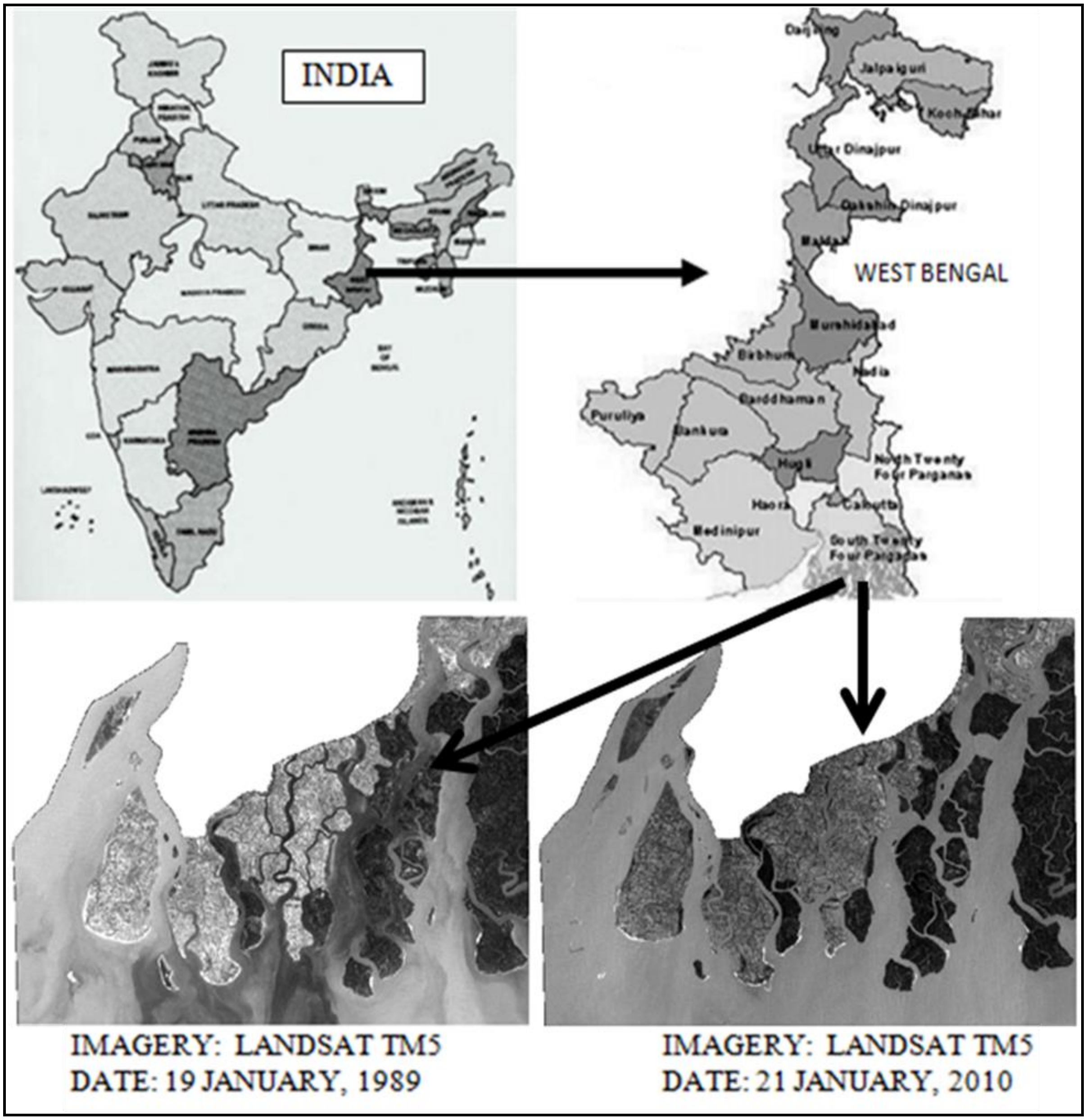

Figure 1: Location of the study area

Study Area and Imagery

A part of Hugli estuary has been considered for study area. It covers an area of 4817.98 km^2. Nayachara, Sagar, Balari and Ghoramara are some significant islands located in this study area. This is a very dynamic and complex landscape due to its tidal action. The area extends from 87^{0}55'01"N to 88^{0}48'04"N latitude and 21^{0}29'02"E to 22^{0}09'00"E longitude, is one of the finest examples of mangrove vegetation. TM5 images from two different dates were used. These selected images were 21 years apart and were taken during the winter season. Here, specific description with respect to minimum/maximum radiance and DN value is needed more for band-3 and band-4 of Landsat TM5 images to get an accurate result in generating normalized difference vegetation index. Apart from the satellite data topographical maps with 1:50,000 scale have also been used for reference purpose.

Table 1: Characteristics of Satellite Images

Data Type	**Acquisition Date**	**Path/Row**	**Sun Azimuth (°)**	**Sun Elevation (°)**	**Resolution (m)**
LANDSAT TM5	19/1/1989	138/45	140.009792	36.905332	30
LANDSAT TM5	21/1/2010	138/45	143.935974	39.7974968	30
	Minimum/Maximum Radiance and DN Value Table				
Date	Band No.	($L\max_\lambda$)	($L\min_\lambda$)	DN (Maximum)	DN (Minimum)
19/1/1989	Band 3	254	-1.17	255	0
19/1/1989	Band 4	221	-1.51	255	0
21/1/2010	Band 3	254	-1.17	255	0
21/1/2010	Band 4	221	-1.51	255	0

Image Processing

Radiometric calibration: Sensor calibration and environmental factors were corrected for multi-temporal images by radiometric correction. The total process has been performed for red and near-infrared bands of Landsat TM5. Digital numbers (DNs) were converted into reflectance values. First, radiance was calculated from DN by:

$$L_l = (DN_l.gain_l) + bias_l \quad (1)$$

Where L is radiance; l is the spectral band; gain is the increase in DN values of spectral band; and bias is the decrease in DN values of spectral band. After that, the signal in each band for pixel has been converted into in-band planetary albedo using the following equation:

$$r_l = p.L_l.Ld^2 / E_{sunl}.cos(u) \quad (2)$$

where r is the unit less planetary reflectance; l is the spectral band; L is radiance; d is the Earth-Sun distance; E_{sun} is the mean solar atmospheric irradiance; and u is solar zenith angle in degree. This correction neutralized the different sun angles for multiple dates of data acquisition.

Image registration for change detection: Pre-processing of satellite images includes geometric, atmospheric and radiometric correction. The 1989 image was geometrically registered to 1:50,000 scale topographic maps; and 2010 image were geometrically registered to the 1989 base image. Root mean square errors of registration have been maintained at less than 1 pixel (<30m) only. After getting the geometrically corrected image the radiometric calibration and image rectification processes were run unless and until the rectified and corrected images were found.

Radiometric normalization and NDVI layer generation: Pseudo Invariant Feature method (PIF) has been used as radiometric normalization technique in this study. Some Polygons were used to select the pixels of PIF, producing a total of 8500 pixels by including the surrounding areas of Hugli estuary. The pixels then were used to develop a linear relationship between the reference image (2010) and the subject images (1989). The coefficients for image normalization were found for band 3 and band 4 (Table 2).

Table 2: The scene normalization coefficients and the correction statistics for 1989 image

1989	**Band 3**	**Band4**
a	0.902	0.824
b	3.382	10.48
r^2	0.885	0.834

To get radiometric normalized image a linear relationship between the reference image and subject image the following equation has been applied:

$$DN_{ref} = aDN_{sub} + b \quad (3)$$

Where *ref* is the reference image (the 2010 image); *sub* is the subject image (the 1989 images); *a* is the slope and *b* is the intercept for the equation of linear relationship. The root mean square error (RMSE) was estimated before and after radiometric normalization (Yuan and Elvidge, 1996). The RMSE is calculated by the following equation:

$RMSE = \{1/n\ S(DN_{ref} - DN_{sub})^2\}^{1/2}$ (4)

Where n is the number of pixels for RMSE computation. Land areas with cloud coverage are directly excluded for the computation. After successful radiometric normalization, a NDVI has been generated for both of the images using the equation:

$NDVI = (NIR - red)/ (NIR + red)$ (5)

where red represents the reflectance values in red band (Landsat TM5 band 3) and NIR represents the reflectance values in near-infrared band (Landsat TM5 band 4).

Forest carbon storage: To quantify carbon storage by trees from the imagery, a regression equation was developed where NDVI have been used as the independent variable and carbon storage (kg C/pixel) for 2010 as the dependent variable. The data were drawn from 200 plots established through a stratified random sampling scheme. This research used a model which is used to determine the value of tree carbon storage for each and every plot through field survey data, such as tree species or tree height. Carbon values on each plot were standardized to kg C/pixel, and registered to the corresponding location in the image. A nonlinear regression Eq. (6) used to give the best result of carbon storage computation for the NDVI data.

$Carbon = ae^{(NDVIb)}$ (6)

Evaluation of eleven random selections of sub data sets divulged that this equation produced results with less variability and with relatively high r^2 values (average $r^2 = 0.66$). The analysis of the sub data sets also showed high statistical significance. Through residual analysis errors were scattered with similar variance. Eq. (6) was developed to determine carbon storage for each pixel, and by summing carbon storage values for all pixels the total carbon storage for the study area has been determined. Carbon storage estimates for 2010 using NDVI were compared with the estimation using model based on field survey for the entire study area.

Table 3: Imagery statistics within Hugli Estuary boundary before and after normalization

		2010	1989
NDVI	Mean	103.850	102.330
	S.D.	61.236	57.683
Band 3	Mean	33.111	30.505
	S.D.	10.030	8.106
Band 4	Mean	37.333	27.425
	S.D.	15.705	16.629

RESULTS AND DISCUSSION

The Effect of Radiometric Correction

Before radiometric normalization image analysis statistics distinguishable significantly from each other (Table 3). But, the RMSE of each band was reduced after normalization. Despite some cloud contamination, after normalization both the images have been characterized with almost same brightness values where no land use change was occurred and made the comparison of changes more reasonable.

The Temporal Change in Total Carbon Storage

From Eq. (6), this research computes the total amount of carbon storage for 2010 is 19.64 million tons. Based on the field based carbon storage data, estimated carbon storage by trees in Hugli estuary is 18.28 million tons. Thus, the NDVI equation for 2010 is further validated since it was within 0.1 percent of the field data estimates. The net change of carbon storage is from 1989 to 2010 was a 1.47 percent increase.

Multi-temporal satellite image potentially enables the carbon storage mapping in an estuary. Compared to aerial photographs, satellite images are more advantageous as it provides steady records. Due to the lack of previously stored information, detection of past carbon storage is only possible through satellite imagery of earlier date. Pseudo invariant features (PIF) approach has been used in the present research work as radiometric normalization method. One earlier study suggested that the biological features might be firmly related to canopy cover and shadow fraction (Li and Strahler, 1985). Moreover, many other studies established a curvilinear relationship between vegetation indices and computed biomass. This study presents a very significant role to estimate the total carbon storage and the change in total carbon storage for the estuary. The estimated value of the tree carbon storage in the estuary for 2010 using satellites is only about 0.2 percent different from the estimated value of field survey of carbon storage. This steadiness suggests that Landsat TM5 data could produce relevant results for the computation of changes in carbon storage over vegetal covered areas.

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