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Spectral Indices for Evaluation of Dominant Species in Orchha Wildlife Sanctuary Using Remote Sensing

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ABSTRACT

Mapping and monitoring of vegetation are essential for conservation planning and restoration efforts and the changes in vegetation have a significant impact on carbon sequestration in soils. Therefore, dominant vegetation in Orchha Wildlife Sanctuary (Madhya Pradesh, Central India) was mapped using LANDSAT satellite data during 1981-2019. The spectral indices derived from the LANDSAT satellite of the year 2019 were used to find the best separation of dominant vegetation species in the sanctuary. Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index were found better than the other three indices (Ratio Vegetation Index, Green Normalized Difference Vegetation Index, and Chlorophyll Vegetation Index) to differentiate *Tectona grandis* and *Anogeissus pendula* (accuracy of 91.6% and 87.4% with NDVI and SAVI, respectively and Kappa coefficient of 0.87 and 0.80 with NDVI and SAVI, respectively). The area under *T. grandis* increased over a period of 38 years. In order to evaluate the effect of major dominant species on soil organic carbon (SOC), surface soil samples were collected and analysed for organic carbon using the standard method. There was a significant ($p<0.005$) positive correlation between SOC and NDVI. The average SOC was higher under *T. grandis* than *A. pendula*. These results suggest that NDVI can be used for mapping and monitoring these species and also finding out the effect of vegetation species on studying the changes in carbon sequestration in soils.

Key words: *Anogeissus pendula*, LANDSAT, Soil Organic Carbon, *Tectona grandis,* Sanctuary

INTRODUCTION

Wildlife sanctuaries hold special significance in the conservation of fragile forests which provide a wide range of ecosystem goods and services to humans (Dudley et al. 2010). In addition to conserving biodiversity that sustains the ecological balance, they also contribute to the vegetation cover which is an important component of the global carbon cycle (Jung et al. 2006). A change in vegetation cover is a source of carbon dioxide to the atmosphere in case of deforestation and a sink in the case of regenerating forests (DeFries et al. 1999).

The plant species present in the protected areas are unique to the soil, climate, and topography of any region. The dominant species affect the structure of the community, ecosystem function and interspecific relationships (Dai et al. 2018). However, the distribution of species is affected by natural or anthropogenic factors (Ciccarelli 2014). Suburban sprawl, timber harvests, and increased fragmentation of natural habitats contribute to human-induced land cover change that poses the biggest threat to the plant species present in the protected areas (Wang et al., 2009). The area dynamics or land cover changes between different species in a forest can give insights into patterns of invasion, regeneration, and deforestation, thereby, helping in the identification of major ecosystem stressors (Lambin et al. 2003). Vegetation mapping, thus, become essential for conservation planning and restoration efforts (Perkl 2016).

Traditional methods like field surveys of studying vegetation cover are time-consuming, date lagged, and expensive (Xie et al. 2008). In order to overcome the disadvantages of conventional methods in vegetation mapping, it becomes important to use cost-effective technologies like remote sensing, but the success of remote sensing in species mapping is largely attributed to the array of spatial and spectral resolution provided by various remote sensing satellites (He et al., 2015). It provides up to date and accurate information, repeated data collection, and also endow with data for inaccessible regions.

Many studies have used the satellite remote sensing to identify and classify the changes in plant species in sanctuaries (Christian and Krishnayya 2009, Islam et al. 2018, Menon and Bawa 1997, Reddy et al. 2007). Generally, satellite images of each year are classified to study the changes in plant species using spectral indices which are used to enhance the vegetation cover signal while minimizing the response of various background materials (Hernandez-Stefanoni and Ponce-Hernandez 2004, Ozyavuz et al. 2015, Peters et al. 1997). Ratio Vegetation Index (RVI) is one of the simplest indices to discriminate vegetation and it shows the contrast between red and infrared bands for vegetated pixels (Rouse Jr et al. 1974). The RVI values of more than one are taken as vegetation, but less than 1.0 is considered as non-vegetation. The major limitation of RVI is the division by zero (pixel value of zero in the red band) which gives the infinite ratio value (Ramachandra 2007). To avoid this, Normalized Difference Vegetation Index (NDVI) was proposed by Rouse et al. (1974). Mapping of vegetation in different parts of the world has been carried out using NDVI. It has been found that NDVI is sensitive to low chlorophyll concentrations (Gitelson et al. 2005). For the vegetation species with high chlorophyll content, green NDVI (GNDVI) is sensitive and accurate for assessing chlorophyll content at the tree crown level (Gitelson et al. 1996). It has been found that darker soil substrates result in higher NDVI values for vegetation. In order to correct the effects of soil brightness resulting from soil colour, moisture, organic carbon etc., soil adjustment factor 'L' was added in the NDVI equation by Huete (1988). The factor 'L' is set to zero for high green and dense vegetation, where it is set to one for low green and very sparse vegetation. In addition to these indices, Chlorophyll Vegetation Index (CVI) developed by Vincini et al. (2008) can be used as the leaf chlorophyll estimator which may give an indication of vegetation health. Canopy chlorophyll determined from leaf area index and leaf chlorophyll content (LCC) (Gitelson et al. 2005, Kooistra and Clevers 2016) can be used for vegetation mapping (Zhang et al. 2019). Alvino et al. (2020) compared NDVI, SAVI, EVI (Enhanced Vegetation Index), GNDVI (Green Normalized Difference Vegetation Index), SR (Simple Ratio), NDWI (Normalized Difference Water Index), and MSI (Moisture Stress Index) for corn monitoring using LANDSAT-8 and they found that SR was sensitive to high corn biomass, whereas GNDVI, NDVI, EVI, and SAVI were sensitive to low values. Polykretis et al. (2020) found that the use of NDVI and albedo were found superior to other indices (soil adjusted vegetation index, tasselled cap greenness, albedo, bare soil index, and tasselled cap brightness) to find the land cover changes (including vegetation) in Greece. These studies show that spectral indices derived from satellite data can be used for vegetation mapping.

The changes in vegetation species have a significant impact on carbon in soils (Shi et al. 2020). Soil organic carbon is a significant long-term reservoir of carbon (C) and plays a significant role in the global C cycle (Swift 2001). The effects of land use on C stocks are generally well studied and have been recognized as an important part of the global carbon cycle. Land-use change has played a significant role in changing the C held in plants and soil. The reduction of SOC levels due to land-use change reduces soil quality and leads to CO_2 emissions to the atmosphere, thereby enhancing climate change (Smith 2008). Land-use change is believed to be the second-highest source of CO_2 emissions to the atmosphere after fossil fuel consumption (Lal 2008). Soil carbon is a balance between inputs (like carbon grain by plants) and losses (like microbial decomposition) (Setia et al. 2013). The pattern of organic carbon in soils is mainly controlled by climate, vegetation and organisms etc. (Wiesmeier et al. 2019). However, it remains unclear whether a change in vegetation species affects carbon storage in soils. There are few studies in which the effect of vegetation species on carbon storage in soils have been assessed, otherwise, it is required to predict the ecological consequences of changes in vegetation species on soil organic carbon. Therefore, a study was carried out to analyse the long-term changes in vegetation species of the Orchha Wildlife Sanctuary present in Madhya Pradesh (India) from the years 1981 to 2019 and its effects on soil organic carbon. The specific objective of the study was to compare various vegetation indices for identifying the major vegetation type in the sanctuary using LANDSAT 3, 5, 7 and 8 over a period of 38 years (1981 to 2019) and the effect of vegetation type on carbon sequestration in soils.

MATERIAL AND METHODS

Study area

Orchha Wildlife Sanctuary is in the Bundelkhand region of Madhya Pradesh (Central India) and is an important protected area on the banks of Betwa River predominated by Teak (*Tectona grandis*) and Kardhai (*Anogeissus pendula*) forests (Fig. 1). It has remained unexplored with no substantial literature available on ecological studies that make use of Remote Sensing. This unique ecosystem presents a major gap in information related to the classification of the plant species present and the area changes occurring amongst them which is vital for management and

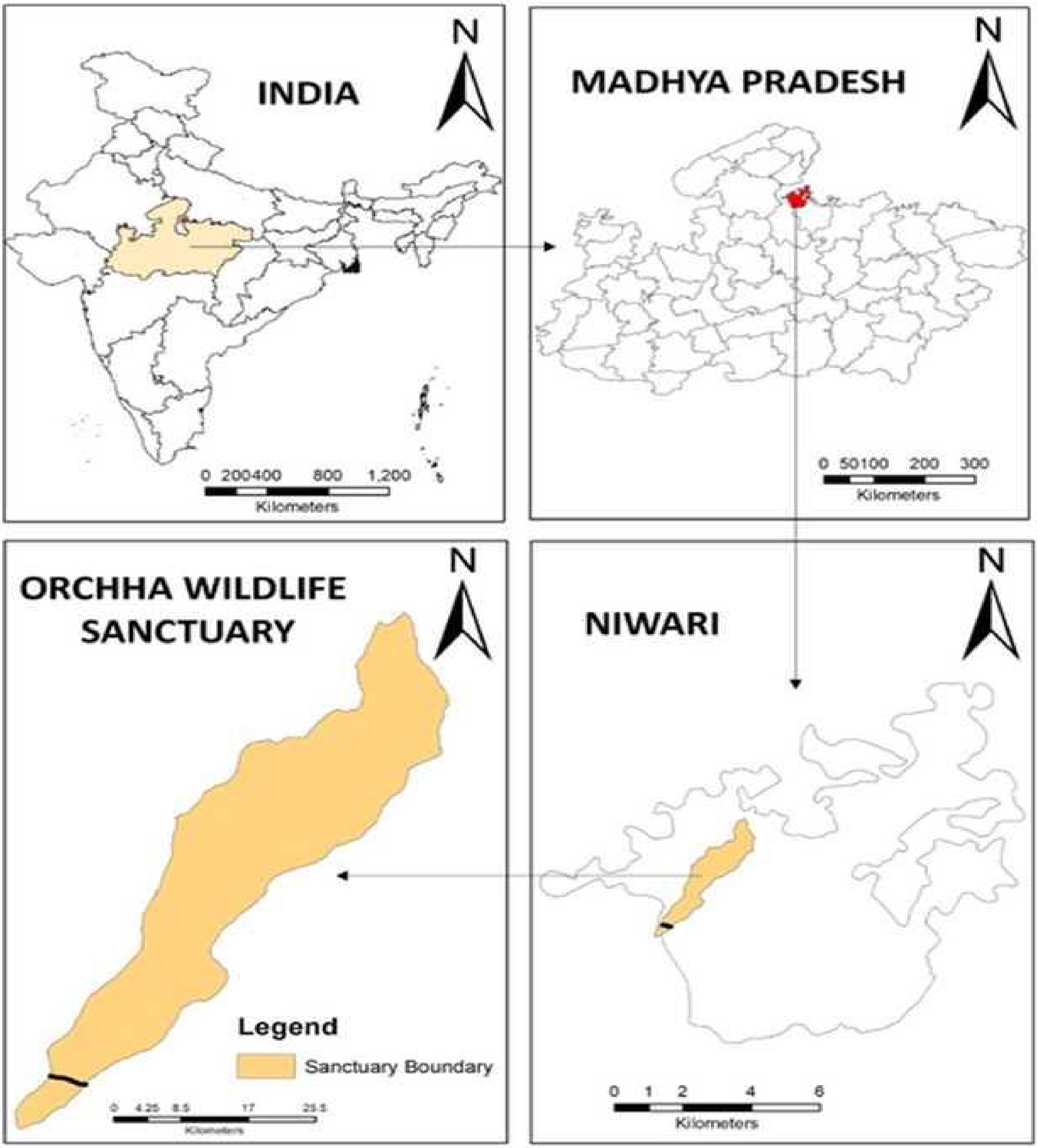

Figure 1. Study area

conservation. The conjunctions and confluence of the Betwa and Jamni rivers delineate the boundary of the Sanctuary. It is geographically located between the latitude 25°13’45’’N to 25°22’30’’N and longitude 78°33’45”E to 78°40’15”E and its altitude varies from 207 to 357 m above mean sea level (Shrivastava et al. 2017). According to Champion and Seth (1968) classification, the forests in Orchha are comprised of Southern Tropical Dry Deciduous Forests. This forest is also locally known as Kardhai forest.

Satellite data

LANDSAT data of the years 1981 (LANDSAT 3), 1991 (LANDSAT 5), 2001 (LANDSAT 7), 2011 (LANDSAT 5) and 2019 (LANDSAT 8) was used to study the temporal changes in vegetation species (Fig. 2). The satellite data of January/February of each year was downloaded from Earth Explorer of the United States Geological Survey (USGS) because these two months mark the onset of the deciduous season which is an ideal time to differentiate the vegetation species. The spatial resolution of visible and NIR bands of LANDSAT 5, 7 and 8 is similar (30 m), but LANDSAT 3 was re-sampled from 80 to 30 m.

Classification of satellite imagery using spectral indices

The following indices were used to classify the vegetation species and other features from LANDSAT 3, 5, 7 and 8 satellite data:

I. Ratio Vegetation Index (RVI) $= \frac{NIR}{Red}$

II. Normalized Difference Vegetation Index (NDVI)

$$= \frac{NIR - Red}{NIR + Red}$$

III. Green Normalized Difference Vegetation Index (GNDVI)

$$= \frac{NIR - Green}{NIR + Green}$$

IV. Soil Adjusted Vegetation Index (SAVI)

$$= \frac{NIR - Green}{NIR + Green + L} x\ (1 + L)$$

V. Chlorophyll Vegetation Index (CVI) $= NIR * \frac{Red}{Green^2}$

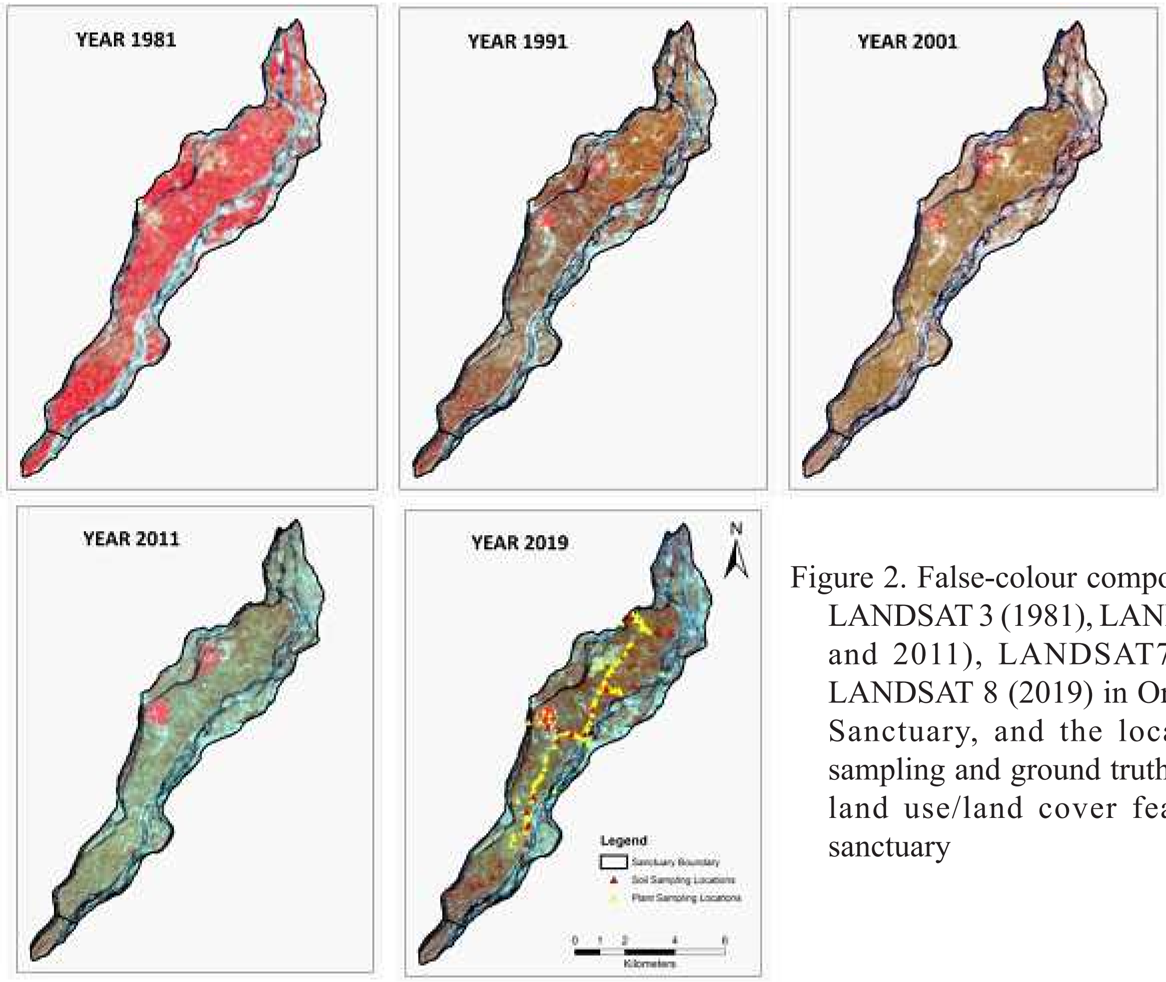

Figure 2. False-colour composite (FCC) of LANDSAT 3 (1981), LANDSAT 5 (1991 and 2011), LANDSAT7 (2001) and LANDSAT 8 (2019) in Orchha Wildlife Sanctuary, and the location of soil sampling and ground truthing points for land use/land cover features in the sanctuary

Where, Green is the green band, Red is red band, NIR is NIR band and L is the soil brightness correction factor. The value of L varies from 0 (in very high vegetation regions) to 1 (in areas with no green vegetation), but L=0.5 works well in most situations and is the default value used.

Ground truth data collection and soil sampling

The classes mapped using spectral indices were verified by collecting 95 ground truth (GT) points during February 2019 (Fig. 2). The overall accuracy was recorded highest (91.58 %) in NDVI followed by SAVI (87.37%), CVI (16.84%), GNDVI (6.32%), and RVI (0.91%). The Kappa coefficient value was highest for NDVI (0.87) followed by SAVI (0.80), GNDVI (0.02), RVI (-0.05), and CVI (-0.09).

In order to evaluate the effect of major dominant species on soil organic carbon (SOC), surface (0-15 cm) soil samples (N=19) were also collected during the GT. The locations of ground truth points and soil sites were recorded using a Global Positioning System (GPS) (Garmin eTrex model). Organic carbon concentration in soils was determined by Walkley and Black's rapid titration method using diphenylamine indicator (Walkley and Black 1934). Soil texture was determined using the Hydrometer method (Gavlack et al. 2005). Bulk density was determined from pedotransfer following Saxton et al. (1986). Organic carbon content (kg ha^{-1}) in soils

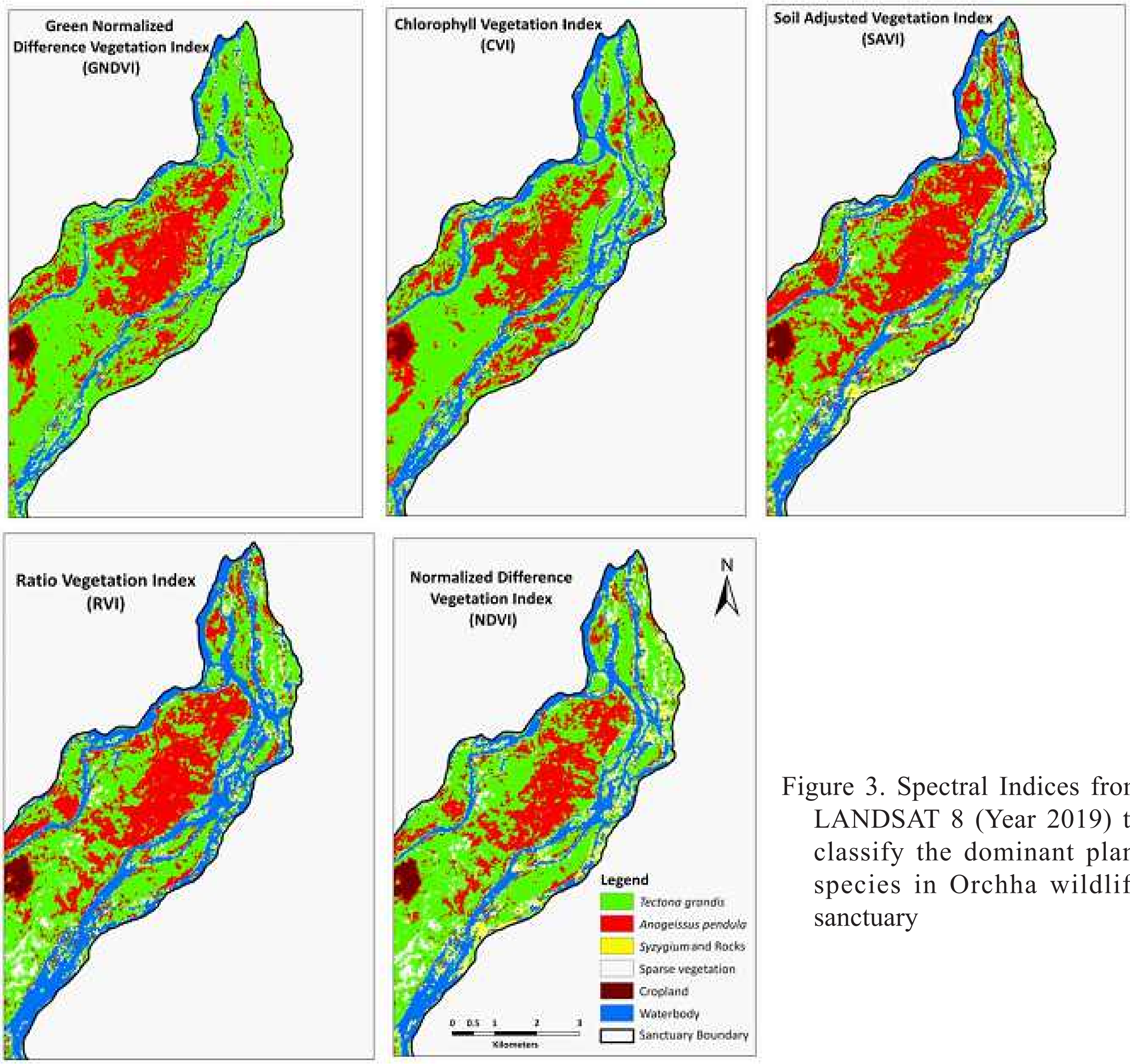

Figure 3. Spectral Indices from LANDSAT 8 (Year 2019) to classify the dominant plant species in Orchha wildlife sanctuary

was determined from organic carbon concentration in soils, bulk density and sampling depth (0-15 cm). The relationship between SOC and spectral indices (2019) was studied using linear regression. The changes in SOC from 1981 to 2019 were estimated with reference to species *T. grandis* and *A. pendula*.

RESULTS AND DISCUSSION

Comparison of spectral indices for vegetation mapping

The LANDSAT based study exhibited the dominance of *Tectona grandis* (47.4% of the area) in majority of the parts of the Orchha wildlife sanctuary followed by *Anogeissus pendula* (17% of the study area) primarily in the northern parts of the area (Fig. 3). An overestimation in *A. pendula* with SAVI and RVI indices was observed during 2019, whereas the same species was underestimated in CVI and GNDVI indices (Fig. 3). Xiao and McPherson (2005) also showed that NDVI is better than the other spectral indices for the areas with homogenous vegetation. The forest in the Orchha wildlife sanctuary can be considered homogenous because it shows the demarcation between *A. pendula* and *T. grandis* forests barring a few patches. The temporal changes in the vegetation are notably used employing NDVI of AVHRR (Wang and Tenhunen 2004, Weiss et al. 2004, Duan et al. 2011) and LANDSAT TM (Ozyavuz et al. 2015) and SAVI with a soil factor of (0.9) has been best suited to map the vegetation using Worldview-II imagery (Almutairi et al. 2013).

Spatio-temporal variations in dominant plant species from 1981 to 2019

The LANDSAT images were classified for the years 1981-2019 using NDVI. During the year 2019, 47.4% of the total area of the sanctuary was occupied by *T. grandis* followed by water bodies (21.1% area). However, *A. pendula*, sparse vegetation, *Syzygium* and rock, and crop occupied 17%, 8.3%, 5.3% and 1% of the total area, respectively during the year 2019 (Fig. 4). Compared with the area under *T. grandis* during the year 1981, there was a consistent increase in area with this species over a period of 38 years. However, the changes in the area with *A. pendula* were not consistent from 1981 to 2019, but there was a decrease (7.89%) in an area under this species during the year 2019 when compared with the year 1981 (Fig. 5). The area occupied by *A. pendula* decreased from 1981 to 2019 which might be attributed to factors like tree felling for human use in the 1980s before the wildlife sanctuary was established in 1994, and/or low regeneration. The germination capacity of the seed is very low, and the seedlings have a tendency to die back probably due to prolonged drought. Therefore, seedling regeneration is not adequate and dependable (Kumar et al. 2018). However, an increase in area under *T. grandis* and a decrease in the area under *A. pendula* in the context of the regeneration potential in the Orchha wildlife sanctuary is currently under study. The area under sparse vegetation, *Syzygium* and Rocks were lesser during the years 1991, 2001, 2011 and 2019 when compared with the year under these features during the year 1981 (Fig. 5). The cropped area has increased over time as two small villages were set up and agriculture was practised since the year 1991. However, one of the villages was later relocated away from the sanctuary and the area was reforested. There was a decrease in sparse vegetation which might have contributed to an increase in an area under *T. grandis*. A decrease in area under water body might be due to changing rainfall patterns, erosion of the river banks and the growth of *Syzygium* species which has shown an overall increase over a period of 38 years.

Relationships between spectral indices and soil organic carbon

The organic carbon varied between 0.53 and 0.70 g m^{-2} in soils under *A. pendula* and it ranged between 0.44 and 1.05 g m^{-2} in soils under *T. grandis*. However, the average soil organic carbon under *A. pendula* and *T. grandis* was 0.62 and 0.76 g m^{-2}, respectively. There was a significant ($p<0.005$) positive correlation between SOC and NDVI (Fig. 6), but SAVI was not significantly related to SOC. Higher SOC of *T. grandis* than *A. pendula* suggest that *T. grandis* in the Orchha wildlife sanctuary is a positive outcome as this increased forest cover would act as a carbon sink in soils. Due to *T.* grandis, there was an accumulation of 1696 g m^{-2} of SOC from the year 1981 to 2019. *T. grandis* plays a vital role in carbon sequestration and the duration of retention of carbon in teak wood products and soils under these species is longer than any other timber species (Jha 2015).

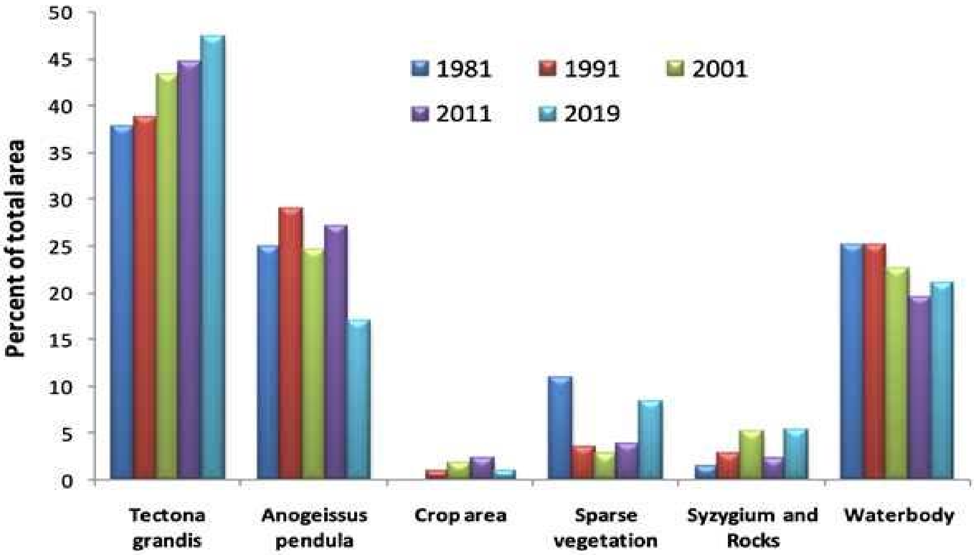

Figure 4. Temporal variations in area under dominant plant species and other land use/ land cover in the Orchha Wildlife Sanctuary during 1981-2019

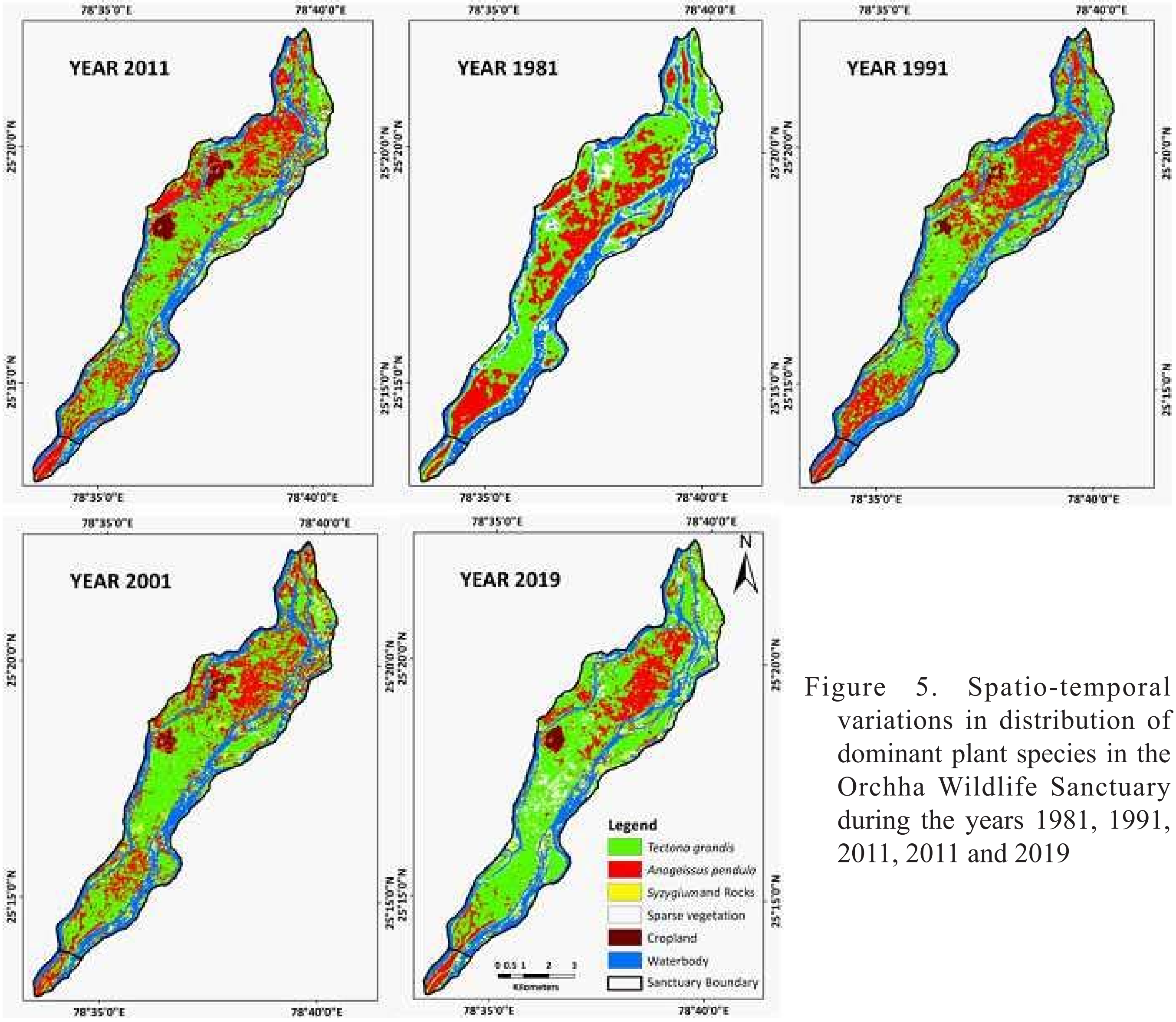

Figure 5. Spatio-temporal variations in distribution of dominant plant species in the Orchha Wildlife Sanctuary during the years 1981, 1991, 2011, 2011 and 2019

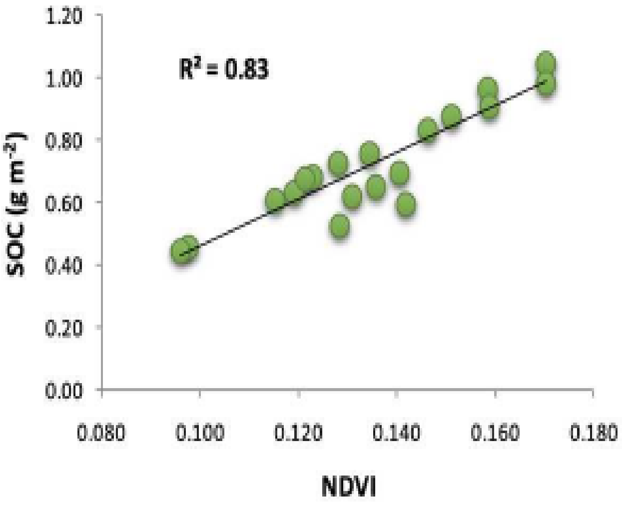

Figure 6. Relationship between NDVI and soil organic carbon

CONCLUSIONS

The results of this study suggest that the best separation of *Tectona grandis* from *Anogeissus pendula* was possible with NDVI in the Orchha wildlife sanctuary. The area under *T. grandis* increased over a period of 38 years in the sanctuary. A decrease in area under *A. pendula* species requires target specific conservation, however afforestation of this species and controlling disturbance due to vehicular movement around the forest can help in better survival of the species. Soil organic carbon was significantly positively correlated with NDVI which suggest that NDVI of both the vegetation species may be used to estimate SOC. An increase in *T. grandis* cover over time suggest that soils under this forest cover would act as a carbon sink. However, the conservation efforts would help sustain the unique ecology of the Orchha wildlife sanctuary, which harbours a number of flora and fauna, aids in carbon sequestration as well as provides a wide range of ecosystem services to people living in this region. An increased cover is also beneficial to the wildlife residing in the sanctuary as it opens up wider niche options and food availability.

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