Evaluating the Impact of Different Vegetation Types on NEE: A Case Study of Banni Grasslands, India

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Abstract

Estimation of NEE of Grasslands ecosystems becomes mandatory as these grasslands with their wide spread (almost 40% of land of the earth) and high plant diversity play a major role in global carbon balances and NEE at both local and global scale. The present study has been focused on understanding the role of different plant species responsible for variation in NEE of the Banni Grasslands of India. These grasslands form a belt of arid grassland having low growing forbs, graminoids and scattered tree cover. Due to its wide spread and inaccessibility of Banni, this study utilized spatial approach for evaluating carbon emissions and NEE. Landsat data was utilized for vegetation type classification and SMAP data for extraction of NEE values proved their potential for categorising vegetation type and generating NEE values precisely. Three major plant types were identified from the study area *viz.*, Grasslands, Land with *Acacia* and Land with *Prosopis*. Grasses were dominant covering 77% and the rest of the area was occupied by the other two classes, *i.e. Acacia* and *Prosopis*. The NEE values were higher for the grasses when compared to the other two plant species proving to be the active sinks when compared to other plants. The differential contribution of NEE by species has been depicted in the present work.

Keywords

Normalized Difference Vegetation Index (NDVI), Fractional Vegetation Coverage (FVC), CO_2 Flux, *Prosopis*, Grasses, *Acacia*

1. Introduction

Regional and interannual patterns of the terrestrial carbon dynamics are changing enormously due to increasing atmospheric CO_2 and climate change which makes it imperative to understand the phenomenon at ecosystem level [1] [2] [3]. Estimation of Net Ecosystem (CO_2) Exchange (NEE) is an important parameter to understand the carbon dynamics of terrestrial ecosystems as it outlines the net exchange of Carbon (C) occurring between an ecosystem and the atmosphere (per unit ground area) [4] [5] [6] [7]. It is crucial in determining the role of these ecosystems in regional and global C balances. Grasslands are one of the important terrestrial ecosystems which play a significant role in NEE of CO_2 at both local and global scale owing to their wide coverage and high plant diversity [8]. These ecosystems are highly sensitive to precipitation variability and thus show varied patterns of interannual variations in net primary productivity which shows a direct impact on NEE [9] [10] [11]. Not only that, but NEE is very sensitive to on-going shifts in the plant species composition [12] [13]. Even short-term changes in plant species alter the ecosystem carbon budgets through increased inter and intra-annual variations in NEE by biophysical and biogeochemical pathways [14]. Plant species type is important parameter to be considered while analysing the variations in NEE of the grasslands [15]. It is therefore important to evaluate interactions and feedbacks within the carbon cycle with different plant species [16]. The role of grasslands in NEE has not been adequately quantified specifically in India though it has potential importance and contribution. Therefore, this study has been taken up for the Banni Grasslands located in Kutch, Gujarat, India. These grasslands are one of the largest grasslands of its kind in Asia with high plant diversity which highly influences the global and regional climate. Due to its wide spread and inaccessibility of Banni, this study utilized a spatial approach for evaluating carbon emissions and NEE. As the satellite-based methods have high spatial-temporal resolution even at landscape level, their utilization in measurement of NEE becomes imperative.

Satellite remote sensing continuously measures the carbon fluxes with high temporal and spatial coverage and provides an attractive and powerful tool for upscaling the fluxes. Many ecosystem carbon exchange models have been developed which utilizes remote sensing data to understand the carbon dynamics at the ecosystem level or beyond [17]. Combining NEE data with remote sensing is the most feasible method for mapping carbon sources and sinks for grasslands [18]. Satellite data provides consistent and systematic observations of vegetation and ecosystems, and plays an important role in estimation of NEE [19]. Using remote sensing for NEE measurements avoids problems associated with small-scale flux sampling while determining areas of sink. In earlier years, biomass inventory and soil carbon quantity were utilized to measure an ecosystem NEE over a specific period [20]. In today's time, two main techniques have been developed for measuring NEE fluxes: the Eddy Covariance (EC) technique and the chamber technique. EC technique provides measure the fluxes continuously at ecosystem scales for many seasons and years along with quantifying the impact of various environmental factors on the fluxes [21] [22] [23]. However, this technique provides measurements over tower footprints with relatively smaller areas that depend upon the tower height, canopy physical characteristics and wind velocity [24]. This has unveiled the limitations of this technique despite its high temporal resolution [25]. Chamber technique is important for point measurements of NEE, but prone to a variety of potential errors and consumes plenty of time [26] [27] [28]. In addition, it is not possible to scale up net CO_2 exchange over the ecosystem level using EC and Chamber techniques [29] [30] [31]. Application of spatial approach can overcome this problem. Spatial approach also aids in understanding the distribution of different plant species of grasslands which helps in precise understanding.

Distribution of different grasses, their association and net primary production of these ecosystems play crucial role in global carbon budget and influence regional climate by modulating the evapotranspiration flux [13]. In this context, distribution and quantification of vegetation become imperative for understanding to encompass the changes in carbon flux. Satellite-based Normalized Differential Vegetation Index (NDVI) helps in comprehensive monitoring and quantification of vegetation [32] [33] [34]. Fractional Vegetation Cover (FVC) which is derived from NDVI using empirical relations is the vegetation-covered fraction of ground [35]. FVC is the ratio of the vertical projection area of vegetation (including leaves, stalks, and branches) on the ground to the total vegetation area which is directly detectable by the sensor from any view direction [36] [37]. FVC measured using spatial approach provides basic data for characterizing ecosystems which plays an extremely crucial role in the study of regional ecosystems [38] [39] [40] [41] [42]. Most importantly, FVC helps in understanding the seasonal changes occurring in the exchange of CO_2 between the land surfaces and the atmospheric boundary level [43].

Considering above facts, this study has been taken up to analyse the role of different plant species in variations of NEE to understand the carbon dynamics of Banni grasslands. These ecosystems are very sensitive to future changes in climate, and understanding how these systems have responded to climatic changes in the past can provide us with insights into their potential responses to future global change.

2. Study Area

Banni grasslands form a belt of arid grassland ecosystem covering almost 2675 km^2 on the outer southern edge of the desert of the marshy salt flats of Rann of Kutch in Kutch District, Gujarat State, India (**Figure 1**). Similar to other grasslands, vegetation in Banni is sparse and highly dependent on seasonal variations in monsoon. Growing season for grasses starts from the month of June (Onset of monsoon) and lasts up to December month. Banni is dominated by low-growing forbs and graminoids, many of which are halophiles (salt tolerant), as well as scattered tree cover and scrub. The tree cover is consists of Salvadora spp. and the invasive *Prosopis juliflora* while *Cressa cretica*, *Cyperus* spp., *Sporobolus*, *Dichanthium*, and *Aristida* are the dominant species found in the area.

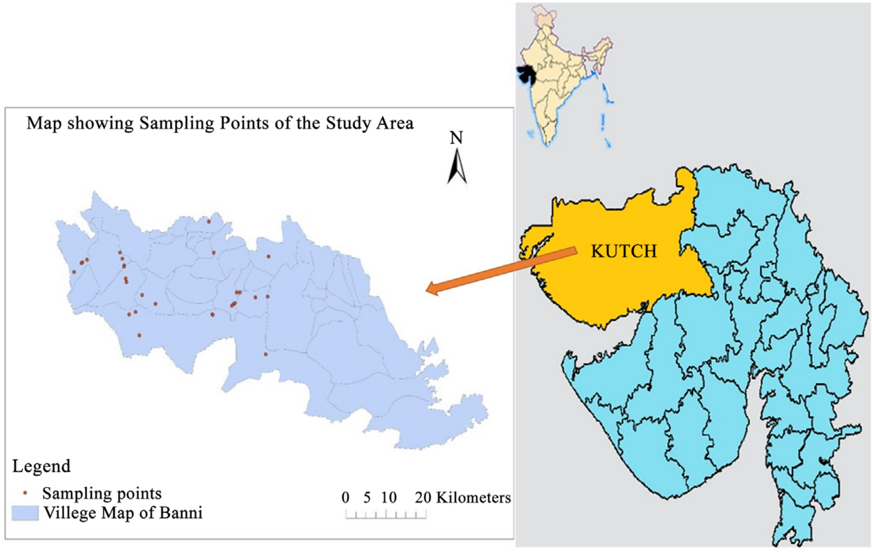

Figure 1. Map showing the sampling points of the study area.

Traditionally, the Banni was declared as a Rakhal (reserve grassland) where only milch cattle were allowed to graze, and sheep and goats were not allowed to reduce the pressure on the grasslands. People were not allowed to reside in the Banni. Later, sheep and goats were also allowed to graze in the area but grazing was regulated by imposing fee at various rates for different categories of livestock. However, this traditional resource management system which had helped in the maintenance of equilibrium between environmental system and human activity since several centuries was no more functional [44]. The grazing regulations slowly disappeared, and all kinds of livestock from every part of the state and neighbouring states were allowed into the area. Large numbers of livestock used to immigrate for grazing during 3 - 4 months of monsoon [45] [46]. Recent interventions such as introduction of *P. juliflora*, introduction of additional livestock have led to reduction in carrying capacity of these grasslands.

3. Materials and Methods

3.1. Pre-Processing the Datasets

Cloud-free Landsat ETM+ satellite data of Nov. 2017 was acquired from USGS website. The data was geographically corrected and was having geographical projection with WGS 84 datum. The study area was included in two different scenes. These two scenes were stacked separately and then mosaicked together to get the study area. The dataset was having the spatial resolution of 30 m × 30 m.

Daily Soil Moisture Active Passive (SMAP) version 4.0 NEE data from the month of January to December 2017 *i.e.* for 365 days was acquired from the website (https://nsidc.org/data/smap/data_versions). This data set was having the spatial resolution of 9 km × 9 km. The dataset was having geographical projection with WGS 84 datum. This data was subset for the study area and then stacked month wise for further processing.

3.2. Methodology

The study area was visited frequently for identifying the areas with different plant species. Landsat Enhanced Thematic Mapper Plus (Landsat ETM+) data of Nov. 2017 was utilized for vegetation classification. Normalized difference vegetation index (NDVI) and Fractional Vegetation Cover (FVC) of the study area were generated for November month of the years 2015, 2016 and 2017. Ground Control Points (GCPs) were collected for accurate identification of various species based on which the supervised classification was carried out. Supervised classification was carried out using the maximum likelihood algorithm of Earth Resources Data Analysis System (ERDAS) Imagine 9.1. Three different classes identified using the satellite data which were Land with *Prosopis*, Land with *Acacia* and Grasslands. Accuracy assessment of classified out was carried out by validating random points by field visits.

Daily NEE values corresponding to the GCPs corresponding to the different plant species derived by classification (*i.e.* classes like Grasslands, Land with *Prosopis* and Land with *Acacia*) were extracted from the datasets. Extracted values were averaged out monthly in order to understand the seasonal variation in NEE. Cumulative NEE of different classes was also calculated. Maps for different outputs were generated using ArcGIS 10.4 software.

NDVI of the study area was derived from Landsat ETM+ data of Nov. 2017. The study area was classified in the four classes, *i.e.*, No vegetation (values lower than 0), Low vegetation (values between 0.1 and 0.3), Medium Vegetation (values between 0.3 and 0.5) and High vegetation (values above 0.5), based on the NDVI values. NDVI was derived using the following formula:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \quad (1)$$

where NIR denotes the near infrared band and Red denotes the red band.

FVC of the study area was derived using NDVI image using the following formula:

$$\text{FVC} = \frac{\text{NDVI} - \text{NDVIsoil}}{\text{NDVIveg} - \text{NDVIsoil}} \times 100\% \quad (2)$$

where NDVI denotes the NDVI value of the pixel, NDVIveg is the NDVI value of a pure green vegetation pixel, and NDVIsoil is the NDVI value of bare soil.

The study area was classified in following 4 different classes based on the fractional vegetation coverage, *i.e.* Low (lower than 0% to 25%), Medium (25% to 50%), Medium high (50% to 75%) and high (higher than 75%) [47].

4. Results and Discussion

Grasslands are amongst the important ecosystems that sequester and store large amounts of soil carbon, which is highly dependent on the factors like herbivory and precipitation. Studies have been attempted to understand effects of different factors on carbon cycling in different regions and how much do they contribute to the NEE. The present study focussed on recognising the patterns of net CO_2 exchange in the Banni Grassland, the largest native grassland ecosystem in of Kutch region. The study conducted during three contrasting precipitation years (dry vs. wet summer), has allowed to investigate on vegetation types existing in this area and their impact on net CO_2 exchange.

Based on Landsat 2017 satellite data classification, three categories classes were identified, *viz*. Grasslands, land with *Acacia* and land with *Prosopis*. Out of three classes generated, Grasslands occupied almost 77% of the study area and were found to be distributed evenly. The grassland class was occupied by grass species like *Dichanthium annulatum* (Jinjvo), *Cenchrus ciliaris* (Dhaman), *Sporobolus fertilis* (Khevai) and *Chloris barbata* (Siyarpuchha) and undershrubs like *Suaeda maritimum* (Lano), *Suaeda fruticosa* (Untmorar), *Suaedanudi flora* (Lano), and *Tamarix aphylla* (Lai). *Acacia* and *Prosopis* species occupied 19% and 4% of the area respectively, with *Acacia* occupying the middle part of the study region while *Prosopis* at the southwestern side (**Figure 2** and **Figure 3**). Classified output showed the accuracy of 85% with the kappa coefficient of 84.83. This indicated that the grasslands are still a dominant vegetation type of the study area which can contribute significantly in carbon dynamics. However, woody species like *Prosopis* and *Acacia* are slowly encroaching the area under grasslands, further altering the carbon dynamics (49).

Further investigation of vegetation carried out using NDVI and FVC for the three consecutive years confirmed the vegetation categorisation with NDVI and FVC values highest for Grassland followed by *Acacia* and *Prosopis* (**Figures 4-9**). Most of the study area was covered by low vegetation indicating the presence of grasses which showed the FVC value of 60% - 70%. Higher area occupied

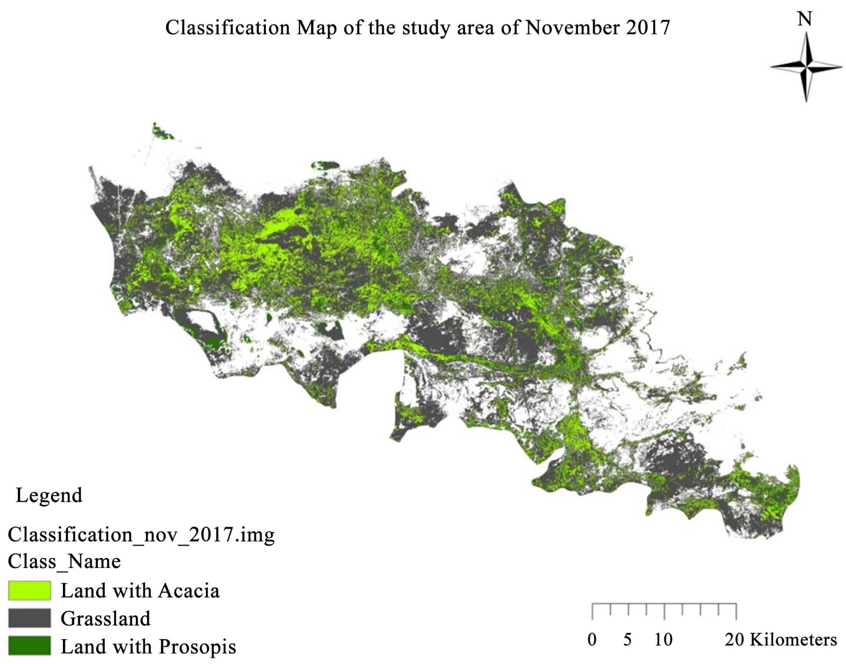

Figure 2. Map showing plant species map of the study area.

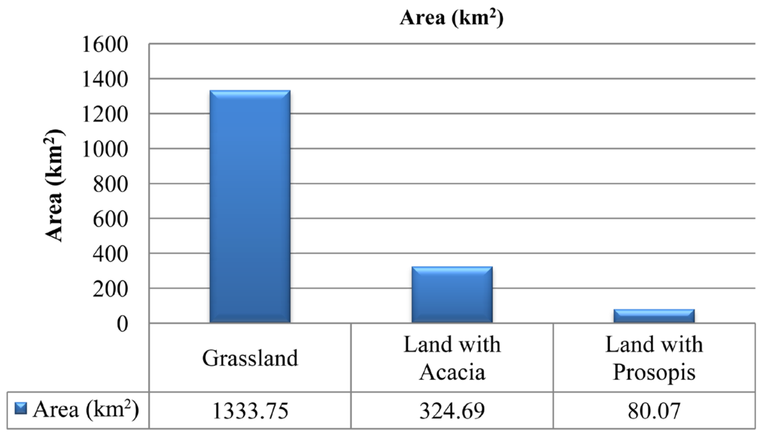

Figure 3. Chart showing the area statistics of Banni grasslands.

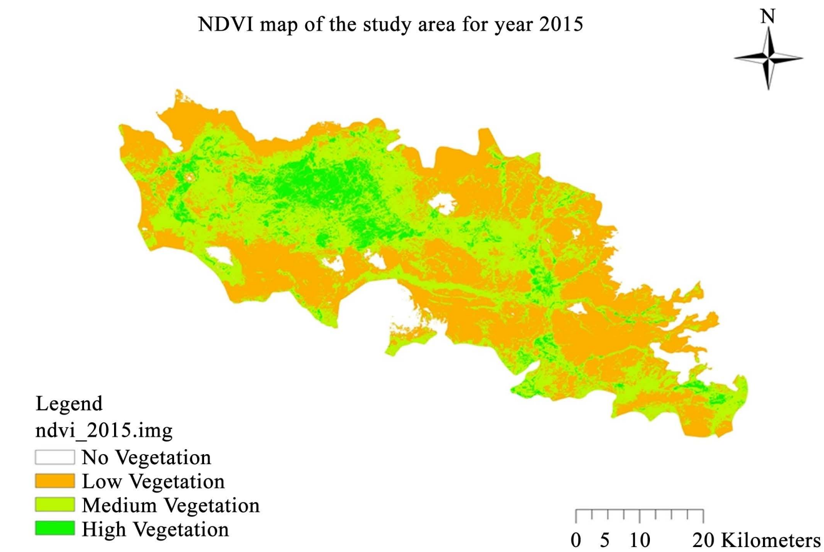

Figure 4. NDVI map of the study area for year 2015.

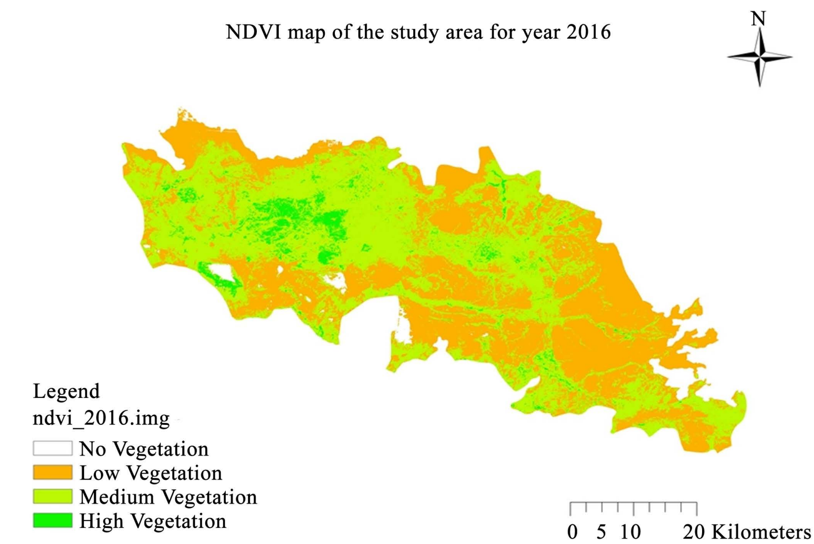

Figure 5. NDVI map of the study area for year 2016.

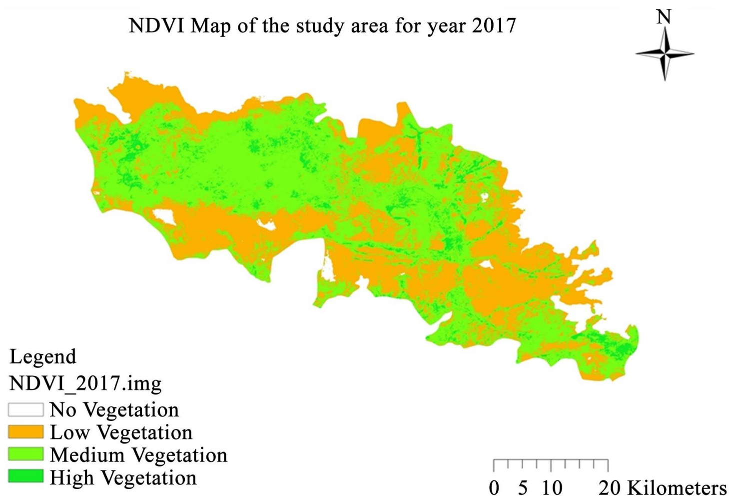

Figure 6. NDVI map of the study area for year 2017.

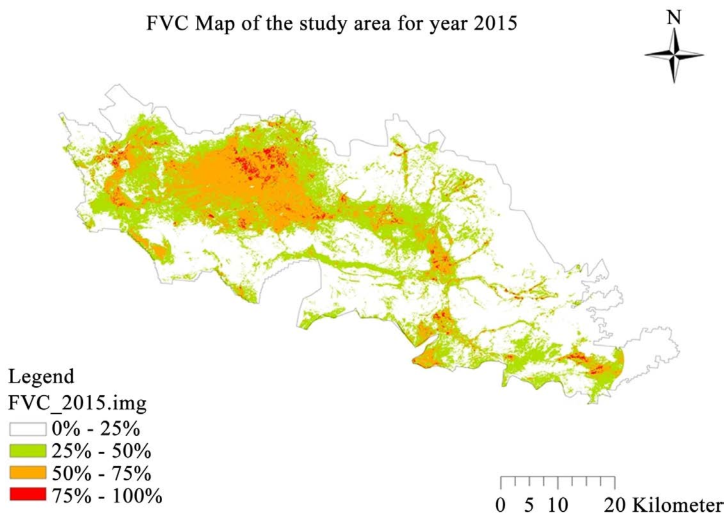

Figure 7. FVC map of the study area for year 2015.

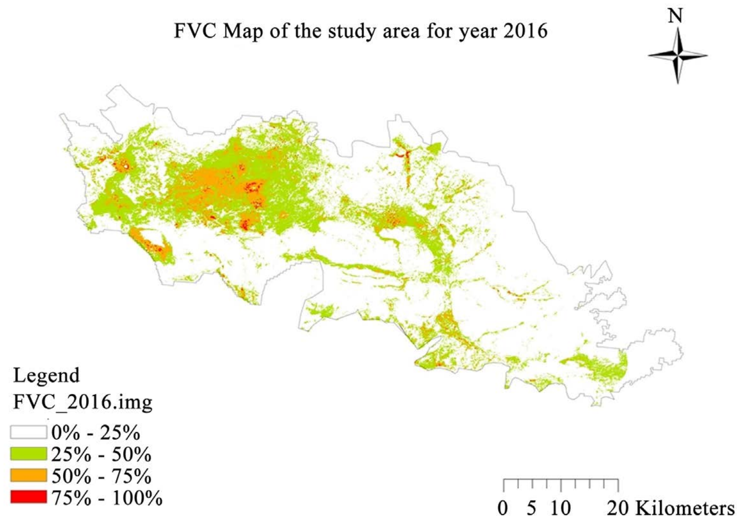

Figure 8. FVC map of the study area for year 2016.

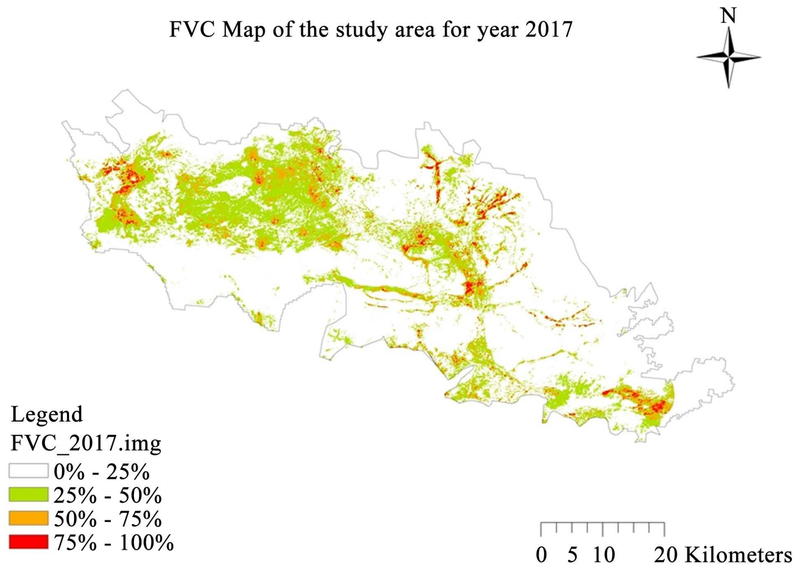

Figure 9. FVC map of the study area for year 2017.

by low vegetation, *i.e.* sparse grassland revealed the fact that the grasslands are under pressure and getting degraded at a faster rate. NDVI values also revealed the health status of vegetation of the study area because these values were closely related to biomass [48] [49], biomass moisture [50], leaf area index [51] [52], absorption of photosynthetically active radiation [53], trends of photosynthesis and transpiration [54] [55] [56], respiration [57] and CO_2 uptake [56] [57].

Clear seasonal variation in NEE was observed, *i.e.* negative values during the growing period (from Aug. to Nov.) of the grasslands and positive values rest of the year (during Dec. to July) (**Figures 10(a)-(c)**) [58]. NEE increased steadily with the progress of the growing season and decreased after the peak in the growing season. Seasonal changes in NEE reflected the vegetation phenological development (in monsoon) and seasonal changes in environmental driving forces [59] [60]. The values ranged from −1.66 $\mu g/m^2$ to 0.66 $\mu g/m^2$ for grasses while it varied from −1.41 $\mu g/m^2$ to 0.64 $\mu g/m^2$ for *Acacia*. A negative value of NEE means a net carbon gain by the ecosystem, *i.e.*, positive net ecosystem productivity (NEP), as it may be assumed NEP to equal-NEE [61]. Positive values of the NEE indicated that the ecosystem was acting as a source during these months [62] [63]. The reason being in summer, water deficits caused leaf senescence (herbs) and therefore less assimilation of carbon leading to decrease in Gross Primary Production (GPP) and thus positive NEE. Periods of negative NEE (indicating net ecosystem uptake) were smaller in magnitude and spanned a shorter duration and coincided with the growing period of the grasses (monsoon). *Acacia* ecosystem varied from a net sink to a carbon source depending on the time of year, with a lower/higher magnitude during the warm/cold season [64].

Yearly comparison of the NDVI, FVC and NEE showed that the NDVI and FVC were higher in the years 2015 and 2016 while the values were lower in the year 2017 (**Figures 11-16**). However, NEE values were found to be higher in the

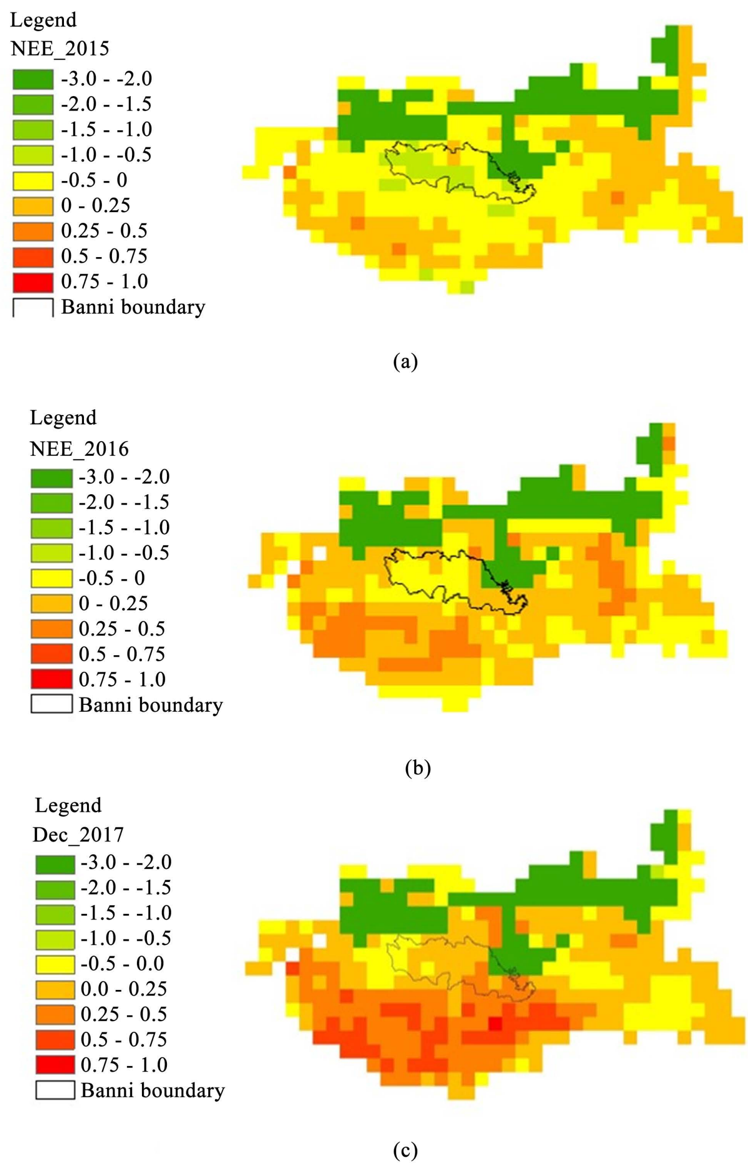

Figure 10. (a)-(c) Variation observed in NEE between years 2015 to 2017. (a) Map showing NEE of December 2015; (b) Map showing NEE of December 2016; (c) Map showing NEE of December 2017.

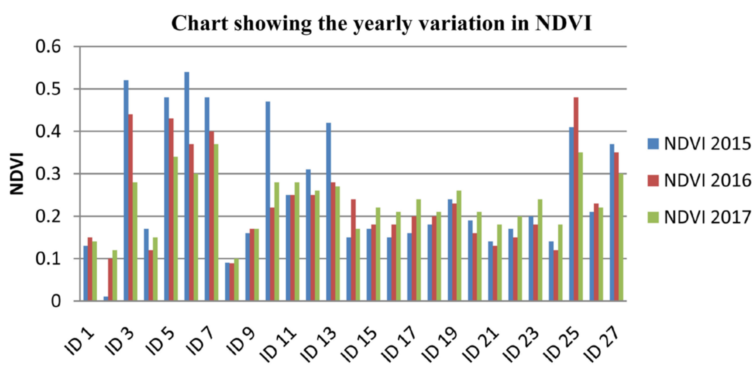

Figure 11. Chart showing the yearly variation in NDVI.

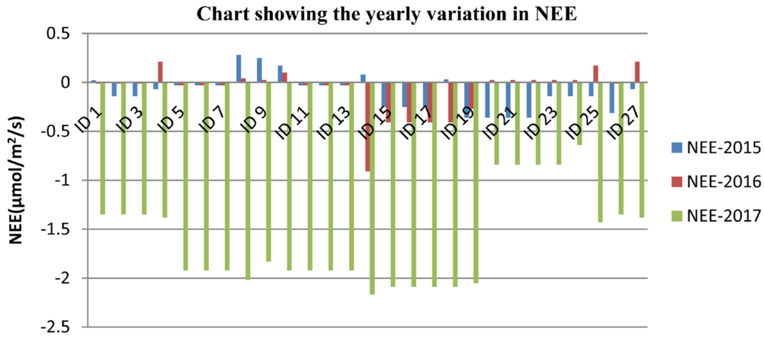

Figure 12. Chart showing the yearly variation in NEE.

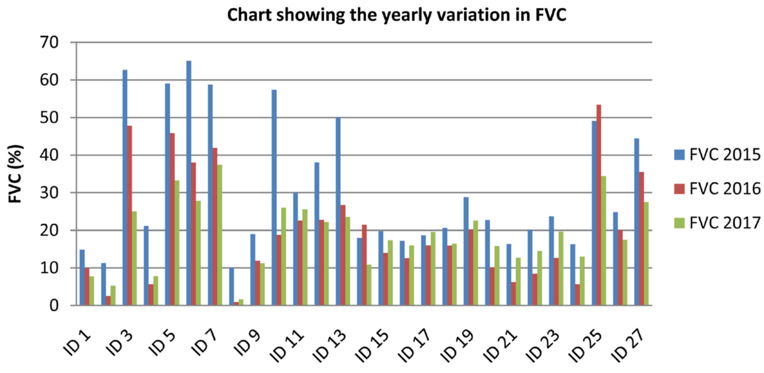

Figure 13. Chart showing the yearly variation in FVC.

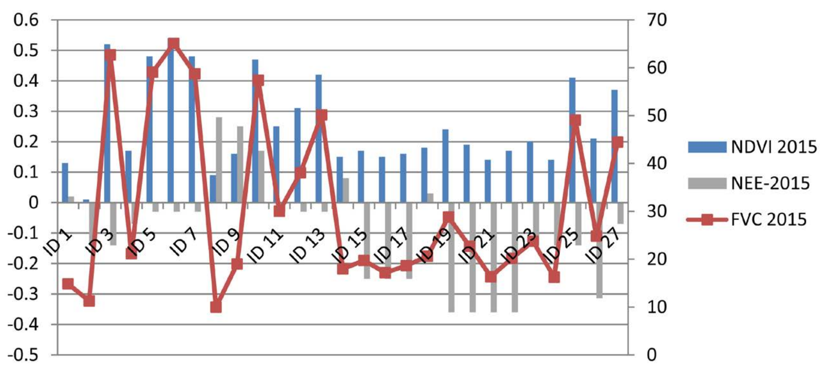

Figure 14. Chart showing comparative account of NDVI, FVC and NEE for year 2015.

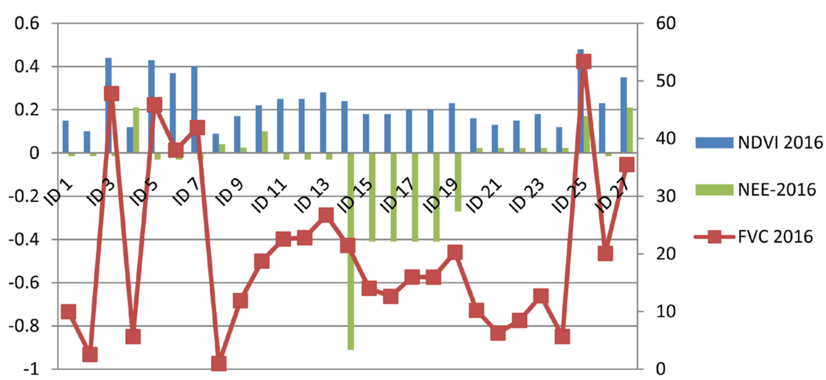

Figure 15. Chart showing comparative account of NDVI, FVC and NEE for year 2016.

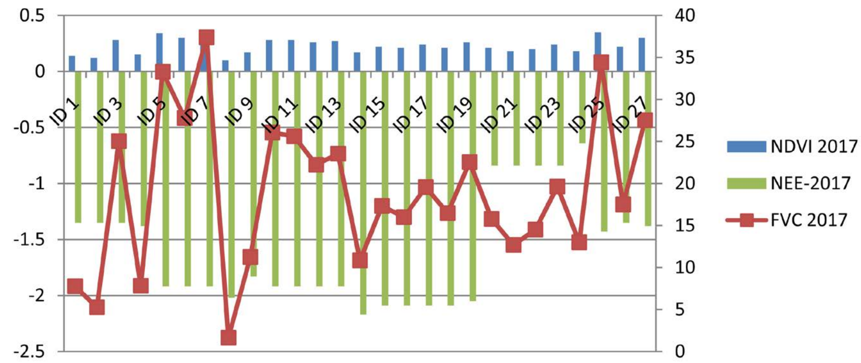

Figure 16. Chart showing comparative account of NDVI, FVC and NEE for year 2017.

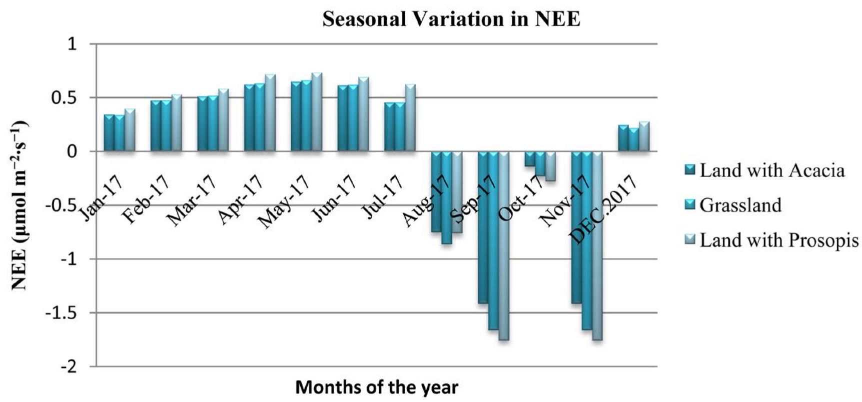

Figure 17. Chart showing seasonal variations in NEE.

year 2017 as compared to the years 2015 and 2016. This indicated that the Ecosystem CO_2 exchange rates were strongly influenced by the type of vegetation which was also evident from the NEE values obtained for these categories. NDVI of the Banni grasslands was found to be higher than a threshold of about 0.3 which indicated that grasses were strong enough to drive a substantial portion of the NEE flux and provided improved NEE in comparison to the *Prosopis* and *Acacia*. For each category a steady increase with the growing season with a distinct decrease after the peak season was noted. With respect to the NEE values for different vegetational categories, not much difference was observed. Though *Prosopis* showed extreme higher and lower values ranging from −1.75 μg/m^2 to 0.73 μg/m^2 the cumulative values for NEE was highest for Grasses *i.e.* −0.5 followed by *Acacia* and *Prosopis*; 0.18 and 0.0, respectively proving grasslands to be an effective sink of carbon dioxide sequestration and no contribution of *Prosopis* for the same (**Figure 17**). *Prosopis* showed more negative values of NEE as compared to *Acacia* during the growth period while it showed more positive values during the summers. This indicated that though *Prosopis* absorbed a high amount of carbon and acted as a sink during growth period but at the same time released a high amount of carbon and acted as the source of the carbon. This may lead to a decreased capacity of carbon uptake and conversion of this ecosystem into the source of the carbon.

5. Conclusion

This study proved that NEE varies with different plant species and in this study, grasses were found to be the most active sink of the carbon dioxide while *Prosopis* and *Acacia* acted as weaker sinks. The ecosystem of Banni acted as the source of C for almost an entire year in the absence of grasses (*i.e.* during January to June) while as a sink during the growth period of grasses (*i.e.* during July to December). Furthermore, application of spatial approach provided consistent and systematic observations for monitoring plant species of Banni grasslands and NEE data at fine temporal resolutions which helped in comprehensive understanding.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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