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REMOTE SENSING TREND OF FOREST ECOSYSTEM PRODUCTIVITY IN GUJARAT USING SATELLITE IMAGERY

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ABSTRACT
Forest changes are now being rapid because of the higher rate of climatic variability. Landscape-scale evaluations of forest productivity are important to understand the response of forest species to changing climate. Net primary productivity (NPP) changes over long-term (from the year 1981 through 2006) was studied in the forest ecosystems of Gujarat state, India. The NPP product used in the study is derived from National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer scanner imagery by National Remote Sensing Centre, Indian Space Research Organisation. Trend analysis was done using a linear regression model in different major forest types. There was a positive trend in NPP in all forest types studied. Statistically significant (p-value < 0.05) highest trend was observed in the thorn forest (+ 1.75 g C m^{-2} yr^{-1}). Increase in forest greenness indicates warming. The change in forest productivity is one of the fingerprints of climate variability.

Keywords: *Earth observations, Climate change, Vegetation, Net Primary Productivity, Green reflectance, Ecology*

INTRODUCTION
Productivity or primary productivity is the amount of atmospheric carbon fixed by the photosynthetic organism (primary producers) using light as the source of energy. Net primary productivity (NPP) is the total amount of carbon fixed by the organism (gross primary productivity) minus the carbon used up in the respiration of the organism. This paper is about theNPP by higher plants, specifically in the forest ecosystems. NPP is considered as the capacity of the plant to fix atmospheric carbon using light as the source of energy. There are observations of deviation in the NPP of forest due to the difference in species compositions, light conditions, moisture availability, soil properties, and stresses.
Ecosystem-scale evaluation of the carbon cycle is important to understand the factors controlling the annual storage of forest carbon (Gough et al. 2008). There is an enhancement of plant growthand productivity in the globe due to recent changes in climate (Nemani et al. 2003). Increase in temperature and solar radiation up to the optimum level can provide more energy for the plant increasing the productivity rate. However, excessive temperature and radiation can cause heat andlight stress in plants inhibiting photochemistry.
The total forest cover in Gujarat, India is 14,757 km², that is 7.52% of the total geographic area (State of Forest Report, SFR 2017). NPP studies focussed specifically on the forest cover of Gujarat has rarely been done using satellite imageries. Field-based evaluations at the ecosystem- scale are both costly and time-consuming. Long-term analysis of forest productivity is necessary at the landscape scale for understanding the effect of climatic variability and fingerprints of climatechange. The objective of this research was to evaluate the changes in the NPP in forests of Gujaratat long-term (for 26 years). The whole approach of this study was computational.

MATERIALS AND METHODS
Study area

The study area is the major forest areas of Gujarat (extent: 68.18º E - 74.48º E longitude, and 20.13º N, and 24.71º N latitude). The mean and maximum elevation of the studied area is 144 m and 998 m a.m.s.l., respectively (Digital Elevation Model, DEM; Shuttle Radar Topography Mission; SRTM, 2000; Farr et al., 2007). The climatic mean (the year 1970 through 2000) minimum, average, and maximum temperature of the forest region is 12.08 º C (in January), 26.63
º C, and 38.50 º C (May), respectively. The climatic annual cumulative precipitation of the forestregion is 853.38 mm. The lowest and highest rainfall occurs on April (0.49 mm), and July (333.88mm), respectively. DEM and climate data (version 2.0) are provided by WorldClim (Fick et al., 2017; https://worldclim.org). Gujarat has 378 km^2 of very dense forest, 5,200 km^2 of moderately dense forest, and 9,179 km^2 of open forest cover (SFR 2017).

Data

There are five major forest types in Gujarat, tropical dry deciduous, moist deciduous, littoral and swamp/mangrove, thorn, and semi-evergreen. These forest type areas maps were acquired from *Bhuvan*, Indian Geo-Platform of Indian Space Research Organisation, National Remote Sensing Centre, Hyderabad, India (NRSC; www.bhuvan.nrsc.gov.in; Reddy et al. 2015). The time series of monthly NPP data (Nayak et al. 2016) from the year 1981 to 2006 at 5 km spatial resolution was acquired from *Bhuvan*. This NPP data product is derived by Nayak et al. (2016) using the Carnegie-Ames-Stanford approach (CASA) biosphere model (Potter et al. 1993). The Global Inventory Monitoring and Modeling System (GIMMS) Normalized Difference Vegetation Index (NDVI) derived from National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer scanner imagery (Pinzon and Tucker 2014) is used as vegetation index forthe model. It is a terrestrial ecosystem model of NPP that integrates the concept of light-use efficiency, that is controlled by moisture stress, temperature, and soil properties.

ANALYSIS

All the raster and vector analysis were done using '*raster*', '*sp*', '*rgdal*' and '*ncdf4*' packages in Rprogramming language (R Core Team 2020). All the statistical analysis was done using '*stats*' package in R. The trend analysis was done using '*zyp*' and '*trend*' package in R. The trend test was conducted using Mann-Kendall trend test (Libiseller and Grimvall 2002).

RESULTS AND DISCUSSION

The analysis of NPP data over the forest cover showed an overall increase in NPP from the year 1981 to 2006 (Table 1). The unit of NPP is shown in g C m^{-2} yr^{-1}. This shows the actual amount of carbon the plants in a particular forest type fix in their green surface area. The maps at every four years interval (due to limitation in space) are shown in Figure (1). The forests in the south- eastern part of Gujarat has higher NPP than other areas in the state. The region was mostly dominated by dry and moist deciduous forests.

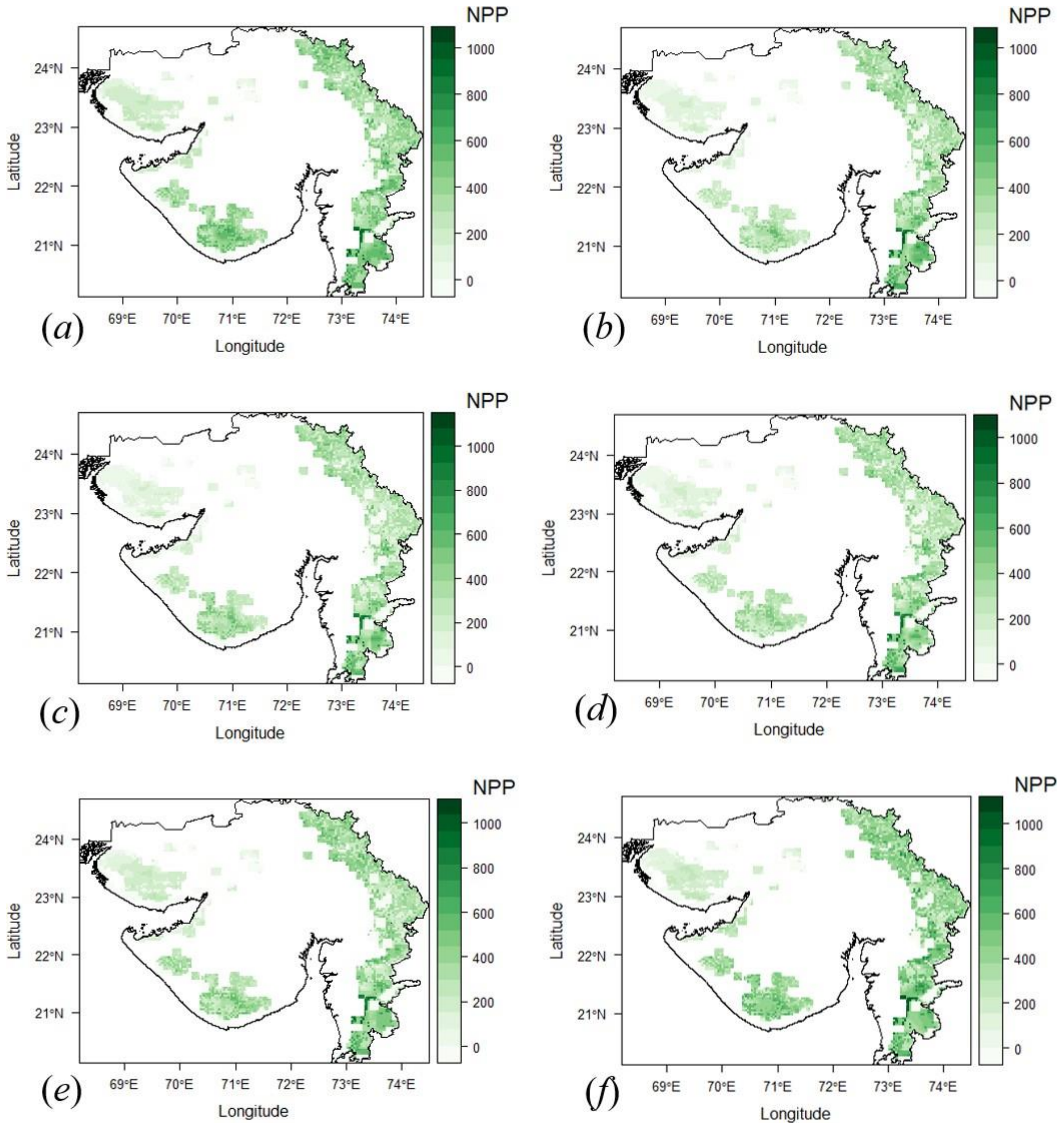

Figure 1 Maps of net primary productivity in the forest vegetation of India in the year, (a) 1981,(b) 1986, (c) 1991, (d) 1996, (e) 2001, and (f) 2006. The unit of NPP is g C m^2 yr^{-1}.

The histogram of the pixel values in the maps (Figure 1) is shown in Figure (2). Most of the valuesof NPP was in the range zero g C m^2 yr^{-1} to *c.* 600 g C m^2 yr^{-1} in the all forest types. The maximum pixel value of NPP in forests of different years varied. The maximum pixel values in the wholeforest area (sum of all forest NPP) was 825.26 g C m^{-2} (1994) to 1178.60 g C m^{-2} (1990).

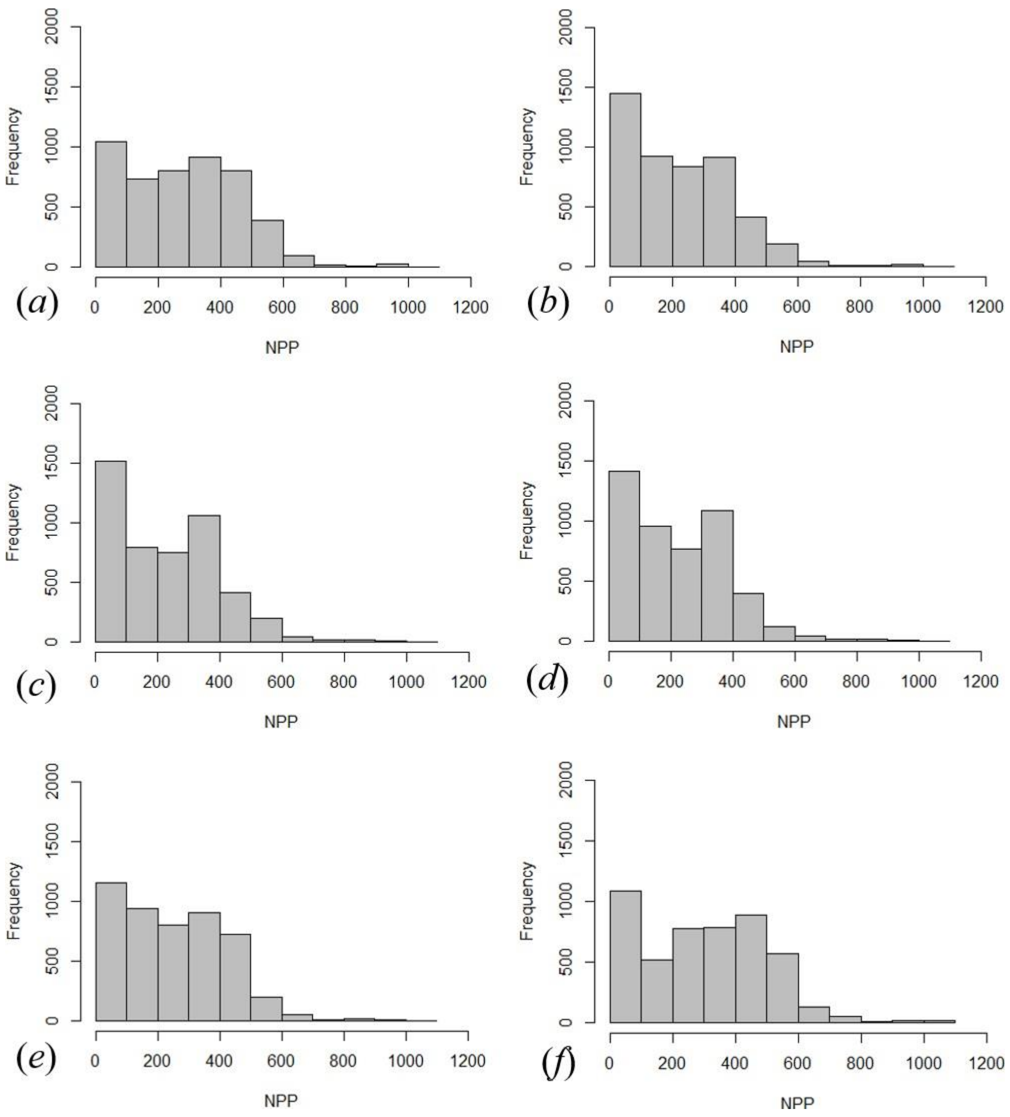

Figure 2 Histogram showing the distribution of net primary productivity data in the year, (a) 1981,(b) 1986, (c) 1991, (d) 1996, (e)2001, and (f) 2006.

In the individual forest type, the lowest (166.25 g C m^{-2}, 1987) and the highest (1178.60 g C m^{-2}, 1990) annual maximum pixel value from 1981 through 2006 was observed in the littoral and swamp / mangrove forest, and moist deciduous forest respectively.

There was an increasing trend in the NPP in all the forest types in Gujarat (Figure 3; Table 1). Thevalues of NPP shown in the Figure (3) is the mean value of all the pixels of a particular forest class.The trend was highest (+2.26 g C m^{-2} yr^{-1}) in dry deciduous forests (p-value = 0.052). Statisticallysignificant (at p-value < 0.05) trend was observed in thorn forest and littoral and swamp/mangroveforests. The increasing trend is least for the moist deciduous forests

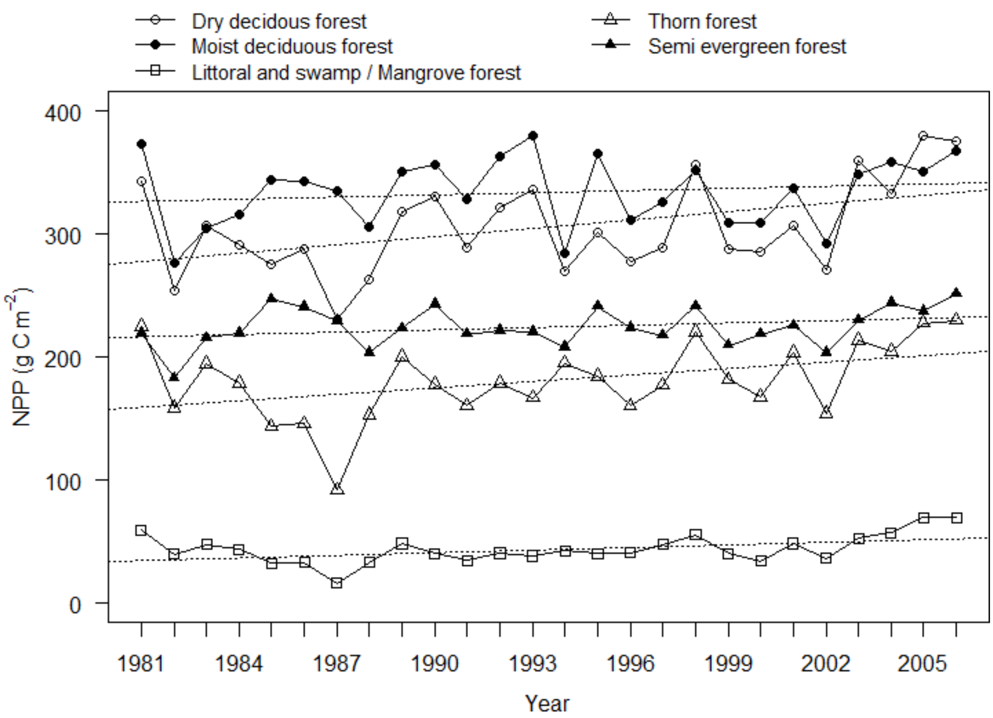

Figure 3 Annual trends of net primary productivity from 1982 to 2006 (26 years) in different foresttypes in Gujarat state, India. The dotted lines for each trend are fitted by the linear regression model.

The results of increasing annual NPP in this studied followed the report of an increase in global NPP (3.4 petagrams carbon) due to increased solar radiation, and temperature from 1982 through1999 by Nemani et al. (2003). There is also a report of decreased global NPP from the year 2000 to 2009 (0.55 petagrams carbon; Zhao and Running 2010) that is in contrast with our results in theforest of Gujarat. This deviation is likely due to local abiotic factors in the forest ecosystems of Gujarat.

In the whole forest areas, the annual NPP ranged from 903.74 g C m^{-2} yr^{-1} (1987) to 1294.66 g C m^{-2} yr^{-1} (2006). There were variations in the NPP in different forest types in different years from 1981 through 2006. In dry deciduous forest, the NPP ranged from 230.99 g C m^{-2} yr^{-1} (1987) to
379.98 g C m^{-2} yr^{-1} (2005). In moist deciduous forest, the values ranged from 276.35 g C m^{-2} yr^{-1} (1982) to 380.51 g C m^{-2} yr^{-1} (1993). NPP values in the littoral and swamp / mangrove forest ranged from 16.10 g C m^{-2} yr^{-1} (1987) to 69.54 g C m^{-2} yr^{-1} (2006). In thorn forest, the values ranged from 92.16 g C m^{-2} yr^{-1} (1987) to 230.10 g C m^{-2} yr^{-1} (2006). In semi evergreen forest, thevalues ranged from 183.05 g C m^{-2} yr^{-1} (1982) to 251.34 g C m^{-2} yr^{-1} (2006). In all forest types, except the moist deciduous forest, the maximum NPP was observed in the year 2006. The years having lowest NPP were 1982 and 1987.
As per the range of NPP values in different forest types, it is clear that plant species in the moist deciduous forest are better carbon fixer than species in other forest types compared. This is becauseof higher leaf surface of the deciduous forest species and availability of more water. Littoral and swamp / mangrove has least capacity to fix carbon compared to other forest types in the region. This is because, the plant species survives in extremely stress conditions like salinity andfluctuations in water availability. They invest more energy in respiration and adaptive mechanismsin the saline environment, like the higher root mass compared to the shoot mass, and water conservation (Hogarth 2007).
Table 1 Trend statistics of the linear regression model for net primary productivity (NPP) in different forest types from 1982 to 2006 in Gujarat state, India. The positive sign indicates an

increase in the values of NPP over the years. The significance of the trends was tested using the Mann-Kendall trend test.

Forest type	NPP (g C m^{-2} yr^{-1})	*p*-value
Dry deciduous	+ 2.26	0.052
Moist deciduous	+ 0.59	0.332
Littoral and swamp /mangrove	+ 0.71	0.019
Thorn	+ 1.75	0.017
Semi evergreen	+ 0.64	0.158
Unstratified	+ 5.95	0.094

On an average, from the year 1981 through 2006, the whole forest productivity was lowest (6.71 g C m^{-2}) and highest (49.14 g C m^{-2}) on May and September, respectively. The month of highest NPP was same for all forest types. The lowest monthly NPP in the dry deciduous forest, moist deciduous forest, and semi evergreen forest was on May. While, in littoral and swamp / mangroveforests and the thorn forest, the monthly lowest NPP was on June. This is observed as the post- monsoon period causes higher water availability than other months of the year. The lowest productivity was observed in the nearest pre-monsoon period.

Climatic variations control the storage of carbon by forests, and that future climate change can reduce the annual storage of carbon (Gough et al. 2008). The increase in the NPP in the forests isspeculated to be due to the increase in warming. Further analysis of NPP from the year 2007 to current time will make the trend observation more robust at climate change perspective. Further research in future will be done on the annual trend in temperature and precipitation in the forest ecosystems of Gujarat to have a clear cause of the increased forest carbon storage. This researchprovides useful evidence of dynamics in the tropical forest ecosystem productivity.

CONCLUSION

Landscape-level forest productivity change measurements are important to understand the effectsof climatic variability on vegetation photosynthesis. From the year 1981 to 2006, there has been an increase in the net primary productivity in the forest ecosystems of Gujarat, India. Moist deciduous forests have the highest productivity in most of the years. The lowest productivity is observed in the littoral and swamp/mangrove forest in all the years studied in this paper. A computational approach is essential for understanding vegetation productivity using large spatial datasets.

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