Research Article

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MODIS satellite based net primary productivity of natural rubber in traditional growing region of India

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Abstract

Net primary productivity (NPP), an indicator of ecosystem productivity is being assessed by field sampling technique or by gas exchange technique but are not ideal for regional level assessment/monitoring with spatial and temporal dimension. In this regard, satellite based NPP data are becoming the handier tool in monitoring and assessment of ecosystem performance spatially and temporally at regional and global level in non-destructive and cost effective manner. This paper aims at understanding the variation in the productivity of rubber ecosystem by MODIS satellite based NPP data across the traditional belt of India and their relation with topography, soil and climatic factors of present as well as projected future climate. MODIS satellite based average annual NPP of rubber plantation was estimated as 10 tons C ha^{-1} $year^{-1}$. Rubber NPP showed geographical variation across the traditional rubber belt showing significant negative correlation with latitude (r = -0.54) and positive correlation with longitude (r = 0.327). Mean diurnal temperature range, T_{max} of warmest month, annual temperature range and annual precipitation showed significant negative correlation with rubber NPP. Soil management unit as well as moisture adequacy index showed significant effect on rubber NPP. Soil with high OC, less gravel and more depth showed better NPP. Rubber NPP showed a significant positive relation with soil moisture. Regression based model predicted declining trend of rubber NPP in southern region and increasing trend in central region under future climatic condition.The present study indicated significant influence of climate, topography and soil on rubber ecosystem.

Keywords: Climate change, natural rubber, net primary productivity, MODIS

Introduction

Natural Rubber (NR) plantation is a man-made ecosystem which has twin advantages of supplying raw material for natural rubber industries as well as enhancing the carbon sequestration of terrestrial biosphere through atmospheric CO_2 fixation, thus helping in reducing greenhouse gas (GHG) level of earth's atmosphere. Rubber has a carbon sequestration potential of 36 to 43 tonnes Cha^{-1} $year^{-1}$ which is comparable with forest species. Productivity of any ecosystem is largely influenced by climate and edaphic factors and their interaction. In India, Kerala state and Kanyakumari district of Tamil Nadu are the traditional belt of NR cultivation together accounting 84 and 94 per cent of area and production, respectively. Geographically, traditional belt of NR cultivation lies between 72^0E to 76^0E longitude and 8^0N to 12^0N latitude with varied soil and climatic conditions. Study on economic yield performance of *Hevea* clones in estate sector across traditional belt has indicated a declining trend from south to north (Chandy and Sreelakshmi, 2008). This study did not account the small holdings which constitute more than 90 per cent of rubber area and no attempt was made to analyse the reason for the variation. Nair *et al.* (2010) grouped the traditional rubber growing area into five regions and related the regional soil and climate variability with sample survey based regional yield statistics reported by Rubber Board. They concluded that well distributed rainfall of around 1500 mm is adequate for the good rubber yield. All these studies did not

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account spatial and temporal variability of rubber yield. Moreover, rubber is chemically a long chain isoprene synthesised in latex vessels and is extracted by regular tapping of bark. Rubber yield is highly influenced by harvesting technique and management practices. So rubber yield do not fully account for the productivity of rubber ecosystem as a whole. Net primary productivity (NPP), an indicator of ecosystem productivity, is being assessed by field sampling technique or by gas exchange technique. However, these methods are ideal for field level assessment and are not ideal for regional level assessment/monitoring with spatial and temporal dimension. In this regard, satellite based NPP data are becoming a handier tool in monitoring and assessment of ecosystem performance spatially and temporally at regional and global level. Satellite based data has the advantage of rapid coverage of large area, detection of inter annual variation, non-destructive and cost effective. The present study was aimed at understanding the variation in productivity of rubber ecosystem across the traditional belt of India, which accounts for more than 80 per cent of India's rubber area.

Materials and methods

For the present study, MODIS (Moderate Imaging Spectroradiometer) annual NPP data covering the Indian subcontinent were downloaded for the period from 2000 to 2014 and were subjected to pre-processing and quality check. Using the administrative boundary of Kerala state and Kanyakumari district of Tamil Nadu, NPP data were clipped and used for further analysis. Temporal NPP data was overlaid with rubber distribution map under the GIS environment and extracted point NPP data with rubber area covering >75 per cent of NPP pixel area only. Mean bioclimatic variables data (1950-2000) covering the Indian subcontinent were downloaded from WorldClim website (www.worldclim.org) and extracted data for the study area. Overlaid NPP data over bioclimatic data and extracted corresponding pixels for all 19 bioclimatic variables. Traditional rubbers growing area was divided into five geographical regions: south, south central, central, central north and northern region. The mean values of rubber NPP (2000-2012) was correlated with different bioclimatic variables as well as topographic parameters like latitude and longitude. Point NPP data were subjected to spatial analysis to know the spatial clustering using GeoDa v 1.6.7 software. Factor analysis was done for each identified clusters to ascertain the important bioclimatic parameters influencing the productivity of rubber ecosystem. Soils of rubber growing region in traditional region have been grouped into seven soil management units (SMU) with increasing order of limitation of depth, gravel content and soil OC (Naidu *et al*., 2008). Earlier study reported that climate of Kanyakumari is more suitable for rubber cultivation compared to other regions in traditional region (Rao *et al*., 1993), and in another study soil and climatic factors were identified as underlying factors determining the performance of rubber in Kanyakumari district compared to Kasargod district in northern Kerala (Meti, 2013). Hence, to ascertain the effect of the soil and climate on rubber productivity, Kanyakumari district of Tamil Nadu was selected and rubber NPP points within the Kanyakumari district were grouped according to Soil Management Unit (SMU) and Moisture Adequacy Index (MAI) by overlaying over SMU and MAI map individually in GIS and were analysed to know the effect of SMU and climate on NPP. Data were subjected to statistical analysis using SPSS software.

Results and discussion

Rubber NPP

Natural rubber annual NPP showed fluctuation during 2000-2014 (Fig. 1). Mean NPP of natural rubber was 0.93 kg C m^{-2} $year^{-1}$ which was comparable with earlier reports based on biomass inventory method as well as Eddy covariance technique. Annamalainathan *et al*. (2011) measured the rubber ecosystem net CO_2 exchange in a four to five year old rubber plantation using eddy covariance technique and reported as 1.08 kg C m^{-2} $year^{-1}$. Following the biomass inventory method, Jacob and Mathew (2004) estimated the total carbon sequestered by 21 year old plantation under Kerala condition as 67 t C $acre^{-1}$ which works out to 0.8 kg C m^{-2} $year^{-1}$. Similarly Wauters *et al*. (2008) reported carbon stock of 76 t ha^{-1} in above ground biomass of 14 year old rubber plantation which works out as

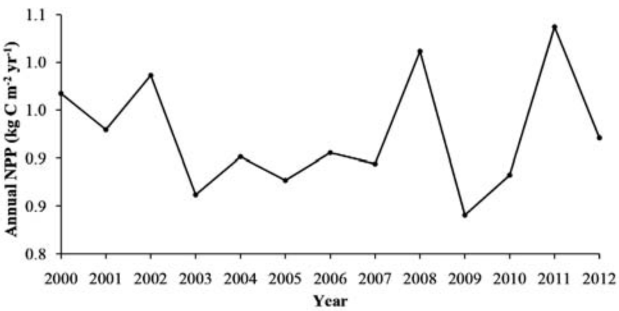

Fig. 1. Annual NPP of natural rubber

0.54 kg C $m^{-2}year^{-1}$. Considering the cost, repeatability, easiness and spatial information, satellite based NPP data scores over the Eddy covariance as well as biomass sampling method.

Spatial advantge of satellite based NPP is evident from Figure 2. Natural rubber ecosystem productivity was comparatively higher (1.1 to 1.2 kg C m^{-2} $year^{-1}$) in southern region and least (<0.76 kg C m^{-2} $year^{-1}$) in northern central part of traditional rubber growing area. Liu *et al.* (2013) also reportd a decreasing gradient of NPP in China from south to north. Rubber ecosystem productivity showed declining trend from south to central north and again showed increasing trend in northern region of traditional rubber growing region (Fig. 2 and 3). However, earlier reports reported decline of rubber yield continuously from south to north of traditional rubber growing region (Pushpadas and Karthikakuttyamma, 1980; Chandy and Sreelakshmi, 2008). This difference may be because only estate sector yield was considered in the earlier studies. Major rubber rubber area is under small holdings compared to estate sector and estate area is less in northern region compared to south and central region. However, there are no earlier reports of better productivity in northern region compared to central region.

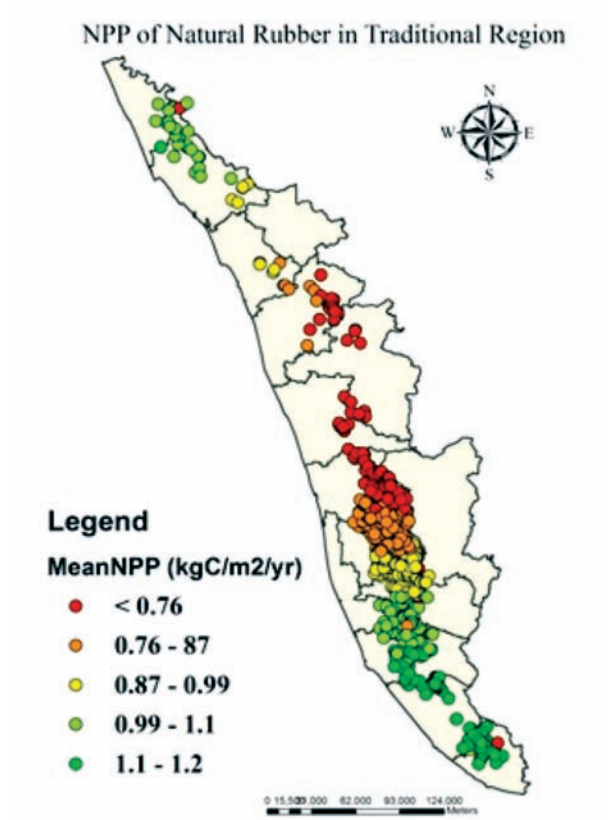

Fig. 2. Spatial distribution of mean rubber NPP

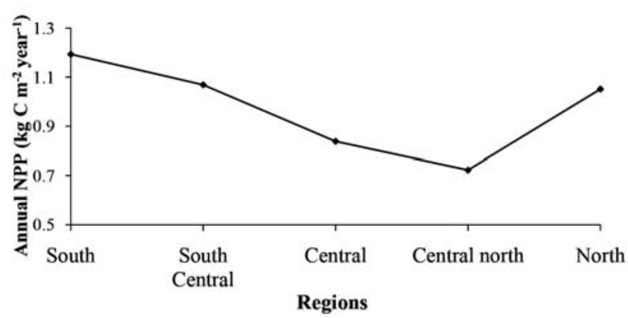

Fig. 3. Annual NPP of rubber at different regions

Climate-Topography-NPP relationship

Climate is an important ecological factor as the soil characters to great extent are dictated by climate in which they occurs. The most important elements of climate which influences the rubber cultivation are rainfall, temperature and wind. Correlation of natural rubber NPP with 19 bioclimatic variables is presented in Table 1. Rubber NPP of entire traditional region as a whole showed significant higher negative correlation with mean diurnal range (BIO2) (r = -0.88), maximum temperature of warmest month (BIO5) (r = -0.81), temperature annual range (BIO7) (r = -0.77), mean temperature of warmest quarter (r = -0.63), annual precipitation (BIO12) (r = -0.66) and precipitation of wettest quarter (BIO16) (r = -0.61). Traditional region as a whole showed strong correlation with temperature than rainfall. Regional analysis showed that southern region did not show strong correlation with neither temperature nor rainfall bioclimatic variables indicating the prevalence of ideal climate for rubber

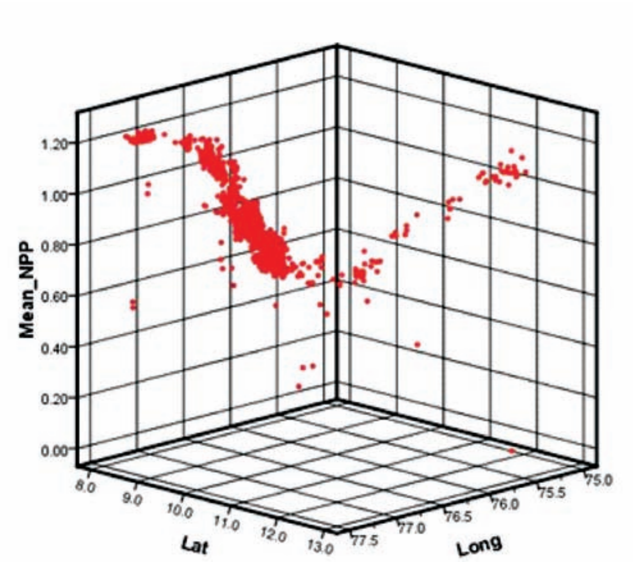

Fig. 4. A3D scatter plot of rubber NPP, latitude and longitude

growth. On the other hand northern Kerala showed strong correlation with temperature and rainfall bioclimatic variables indicating strong influence of temperature and rainfall on rubber NPP. Similarly Wang *et al*. (2014) also reported regional variation with temperature as more important in central and eastern region while precipitation in northern part of China. Temperature and rainfall are identified as most critical climatic factor for successful growth of rubber (Omont, 1982; Ortolani *et al*., 1982; Monteny *et al*., 1985; Zongdao and Yanqing, 1992). Classifying the climate of rubber growing areas using thermal and moisture index, Rao *et al*. (1993) categorized the southern part of traditional rubber growing area comprising Kanyakumari, Trivandrum, Kollam districts as climatically suitable whereas northern part comprising Palakkad, Kasargod and Kozhikode districts as moderate zone for rubber cultivation. The orographical featuresof Kerala profoundly influence the meteorology of state, affecting the rainfall distribution and temperature which has influenced the regional variation in rubber NPP. Rainfall progressively increases from south to north with southern part receiving low and

Table 1. Correlation of natural rubber NPP with bioclimatic parameters

Bioclimatic parameters	Entire	South region	South central	Central	North central	North
BIO1 = Annual mean temperature	-0.47**	-0.08	-0.39**	-0.42**	0.18	-0.40*
BIO2 = Mean diurnal range (Mean of monthly (max temp - min temp)	**-0.88****	-0.31*	**-0.75****	**-0.80****	-0.25	**-0.92****
BIO3 = Isothermality (BIO2/BIO7) (* 100)	0.19**	0.04	-0.19**	0.64**	0.42**	-0.06
BIO4 = Temperature sasonality (standard deviation *100)	-0.39**	-0.29*	0.02	**-0.84****	-0.37**	**-0.81****
BIO5 = Max temperature of warmest month	**-0.81****	-0.16	**-0.66****	**-0.80****	-0.27	**-0.77****
BIO6 = Min temperature of coldest month	0.11**	0.03	0.11	-0.10*	0.10	-0.09
BIO7 = Temperature annual range (BIO5-BIO6)	**-0.77****	-0.31*	**-0.72****	**-0.82****	-0.32*	**-0.88****
BIO8 = Mean temperature of wettest quarter	0.17**	0.19	0.22**	-0.04	0.30*	-0.41*
BIO9 = Mean temperature of driest quarter	-0.57**	-0.03	-0.06	**-0.71****	0.29*	-0.47**
BIO10 = Mean temperature of warmest quarter	**-0.63****	-0.08	-0.41**	-0.57**	0.13	-0.55**
BIO11 = Mean temperature of coldest quarter	-0.47**	-0.14	-0.43**	-0.25**	0.30*	-0.43*
BIO12 = Annual precipitation	**-0.66****	0.28*	-0.61**	**-0.81****	0.26	0.45**
BIO13 = Precipitation of wettest month	-0.52**	0.27*	-0.49**	**-0.87****	0.39**	0.43*
BIO14 = Precipitation of driest month	0.14**	-0.03	-0.09	0.46**	-0.10	-0.62**
BIO15 = Precipitation seasonality (coefficient of variation)	-0.51**	-0.15	-0.51**	**-0.85****	0.39**	**0.84****
BIO16 = Precipitation of wettest quarter	**-0.61****	0.23	-0.62**	**-0.85****	0.31*	0.57**
BIO17 = Precipitation of driest quarter	-0.04	0.02	-0.37**	0.36**	-0.35*	**-0.85****
BIO18 = Precipitation of warmest quarter	-0.52**	0.27*	-0.45**	-0.63**	-0.06	**-0.71****
BIO19 = Precipitation of coldest quarter	-0.52**	-0.09	0.03	-0.54**	0.22	0.41*
Latitude	-0.54**					
Longitude	0.33 **					

* significant at p=0.05
** significant at p=0.01

well distributed rainfall from both southwest and northeast monsoon but northern region receives more and uneven distributed rain mainly from southwest monsoon (Simon and Mohankumar, 2004; Meti, 2013). Because of this reason rainfall showed positive correlation with rubber NPP in north but it was negative in other parts. Greater NPP value does not always correspond to higher precipitation (Wang *et al*., 2014). Central Kerala showed strong negative correlation between rainfall and NPP because of high rainfall and frequent water surplus observed in this region lead to problem of water logging, nutrient loss (Rao and Vijayakumar, 1992). On the other hand southern region comprising mainly Kanyakumari receives rainfall which is optimum with equitable distribution and less amount than central and hence showed positive relation with rubber NPP.

In order to understand the regional variation of vegetation NPP, it is important to analyse the relationship between NPP, climate and topography. Three dimensional scatter plot of rubber NPP, latitude and longitude (Fig. 4) clearly shows declining trend of rubber NPP between 9^0N and 10.25^0N latitudes. Highest NPP was seen between 8^0 and 9^0 latitudes. Similarly rubber NPP also showed declining trend between 75^0E to 76.4^0E longitudes and showed increasing trend up to 77^0 and then stagnated. Highest NPP was seen between 77^0E and 77.6^0E longitudes. In general rubber NPP showed significant negative correlation with latitude (r = -0.54) and positive correlation with longitude (r = 0.33) (Table 1). Ideal climate for rubber distribution is mainly concentrated around equator. Productivity of any vegetation is primarily determined by the temperature and rainfall (Zhengchao *et al*., 2011) and so with rubber also (Omont, 1982; Ortolani *et al*., 1982; Monteny *et al*., 1985; Zongdao and Yanqing, 1992). Longitude and latitude are proxy for precipitation and temperature, respectively (Gonzalo *et al*., 2011) and rubber showed strong negative relation with temperature and rainfall (Table 1), hence rubber NPP showed a declining trend with increasing latitude and varying response along longitude. Zhengchao *et al*. (2011) reported positive influence of longitude and negative influence of latitude on vegetation NPP from a study on spatio-temporal distribution pattern of vegetation NPP in Buryatiya Republic, Russia. Similarly, Zhang *et al*. (2009) reported decrease in global NPP/GPP ratio along latitude from 30^0 to 10^0N.

Soil-Rubber NPP relationship

Apart from climate, soil type also has been reported to have strong influence on the NPP of forest (Whittaker,1970; Woodward *et al*., 2004; Holdridge, 1964; Pan *et al*., 2013), savanna (Zhu and Southworth, 2013; Schuur, 2003) and grassland (Scholes and Hall, 1996; Xia *et al*., 2014) and wetland (Birkett, 1998). Rubber NPP was also significantly influenced by soil type (Fig. 5). Soil management unit having more soil OC, less gravel content, deep soil (SMU 1 & 2) showed higher NPP and it showed declining trend with soils which are shallow, gravely and poor in soil OC.

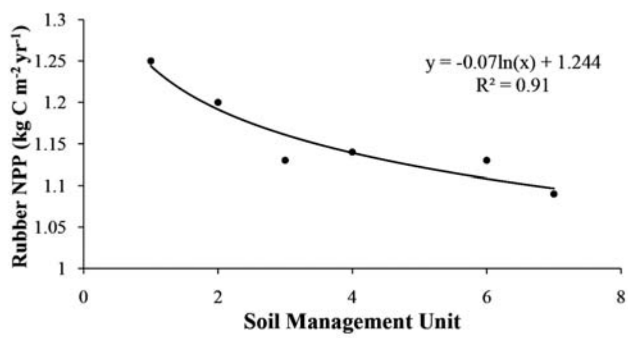

Fig. 5. Relationship between rubber NPP and soil management units

Water holding capacity of soil and potential evapo-transpiration of climate together influence the water balance of an ecosystem, ultimately determining the moisture adequacy for the vegetation. Soil and climate interact each other and the nature of this interaction determine the resource availability mainly water and nutrient to the plant which ultimately determine the productivity. Moisture adequacy index (MAI) is one such index based on actual evapo-transpiration (AET) and PET indicates the adequacy of moisture of a locality for the vegetation. Rubber NPP showed a significant positive relation with MAI (Fig. 6) and according to Raich *et al*. (1991) soil moisture is the dominant factor controlling vegetation NPP, compared to annual rainfall.

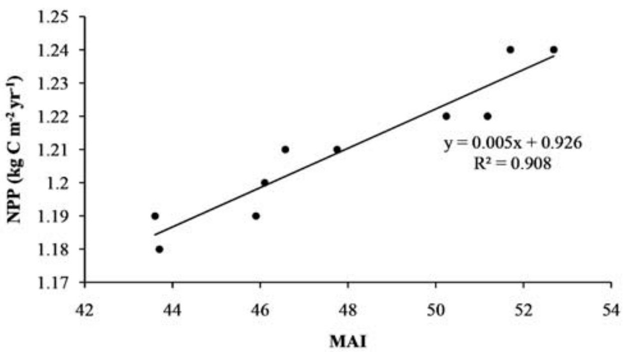

Fig. 6. Rubber NPP as influenced by moisture adequacy index

Spatial distribution of NPP

Rubber NPP showed significant spatial clustering with Moran Index of 0.85 (Fig. 7). Local Moran scatter plot of standardized mean NPP against standardized lagged mean NPP showed significant clustering of high values surrounded with high values (upper right quadrant) and low values surrounded with low (lower left quadrant) NPP values (Fig. 7).

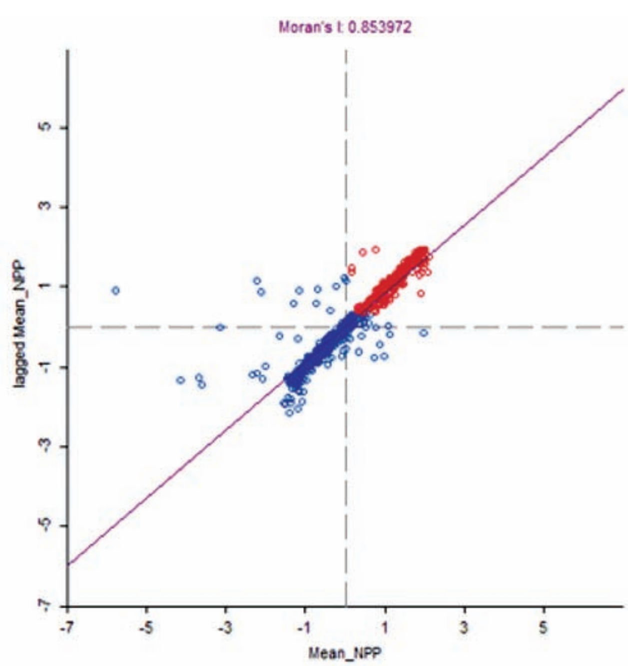

Fig. 7. Local Moran Scatter plot of rubber mean NPP

Statistical significance of spatial distribution of rubber NPP cluster is represented in Fig. 6.Out of 959 rubber NPP points, 249 were in high group, 241 in low group and 459 points did not show significant spatial clustering. Rest of the points (10 points) were outliers. High NPP points were clustered in Kanyakumari district of TN, Trivandrum, Kollam, parts of Pathnamthitta, Kannur and Kasargod district of Kerala (Fig. 8). Low NPP points were clustered in Ernakulam, Idukki, Thrisur, Palakkad, Malappuram and Kozhikode district of Kerala. It is interesting to note that rubber NPP points in central Kerala *i.e.*, Kottayam and parts of Pathnamthitta district did not show significant clustering into low or high group. Non-significant clustering indicates significant variation in NPP locally. In central Kerala rubber is being grown in undulating terrain with elevation ranging from below sea level to >500 m. This creates local variation in climate and soil condition which influences rubber performance locally and hence showed non-significant clustering.

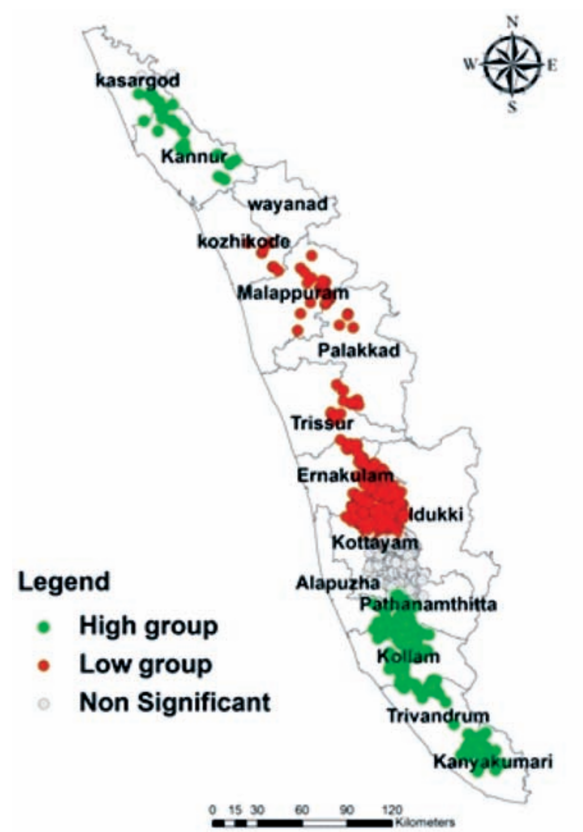

Fig. 8. Spatial clustering of high and low rubber mean NPP values

Rubber NPP and Future climate

Present and future bioclimatic variables extracted using high and low NPP cluster points is presented in Table 2. Temperature based bioclimatic variables showed increase in future in both high and low NPP areas. On the other hand rainfall based bioclimatic variables in high NPP areas do not show much change in future whereas in low areas they showed declining trend in future compared to present.

Table 2. Present and future bioclimatic variables for rubber growing areas

Bioclimatic variables	High NPP area		Low NPP area	
	Present	Future	Present	Future
Biome1	27.0	29.3	27.3	29.8
Biome2	6.9	6.8	7.8	7.5
Biome3	6.6	6.5	6.5	6.4
Biome4	97.5	98.3	107.2	103.3
Biome5	32.4	34.7	33.8	36.0
Biome6	21.9	24.3	21.9	24.4
Biome7	10.5	10.4	11.9	11.6
Biome8	26.5	29.3	26.4	29.1
Biome9	26.5	28.9	27.3	30.1
Biome10	28.5	30.8	29.0	31.4
Biome11	25.9	28.2	26.4	28.9
Biome12	2352.8	2359.9	3372.6	3233.1
Biome13	483.8	408.3	742.3	573.5
Biome14	18.7	14.2	18.0	13.3
Biome15	69.7	66.5	84.7	72.6
Biome16	1169.1	1049.2	1903.0	1492.4
Biome17	97.7	105.6	103.7	104.6
Biome18	417.3	472.4	528.5	581.4
Biome19	521.5	568.0	1437.6	1076.5

Regression based rubber NPP prediction model developed with present four temperature based bioclimatic variables namely Biome 1, 2, 5 and 8 and six rainfall based bioclimatic variables like 13, 14, 15, 16, 17 and 18 were significant (Table 3&4). Among the variables biome 2, 5, 8, 14, 15, 16 and 18 contributed negatively and the rest, positively. Future NPP predicted using regression model with future bioclimatic (2070) was deducted from present NPP to know the change in future rubber NPP is presented in map and it shows spatial variation (Fig. 9).

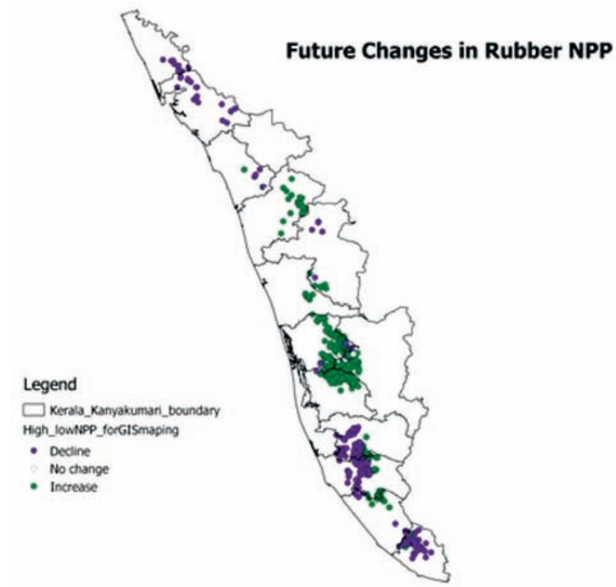

Fig. 9. Future changes in rubber NPP over traditional region

Future NPP of Kanyakumari district of TN, Kollam, Pathanamthitta and Kasargod district of Kerala showed decline whereas that of central Kerala showed increasing trend (Fig. 7). This may be due to the fact that rainfall having negative relation with NPP in central Kerala showed declining rainfall trend in future (Table 4) and hence future NPP increased. On the other hand future NPP of north and south showed decline due to increase of temperature bioclimatic variables in future.

Table 4. Coefficients of regression model for rubber NPP using bioclimatic variables

Variable	Coefficients	t	Significance
(Constant)	2.7926	13.277	0.000
BIOME1	0.0160	8.196	0.000
BIOME2	-0.0095	-4.423	0.000
BIOME5	-0.0113	-7.730	0.000
BIOME8	-0.0033	-2.369	0.018
BIOME13	0.0021	12.913	0.000
BIOME14	-0.0101	-6.564	0.000
BIOME15	-0.0112	-9.401	0.000
BIOME16	-0.0007	-9.475	0.000
BIOME17	0.0030	4.953	0.000
BIOME18	-0.0009	-7.903	0.000

Table 3. ANOVA of rubber regression model

Model	DF	Sum of squares	Mean sum of squares	F	Significance	R^2
Regression	10	20.768	2.077	1021.766	0.000	0.95
Residual	586	1.191	0.002			
Total	596	21.959				

Conclusion

Rubber ecosystem productivity based on satellite data showed inter-annual as well as spatial variation. Geographically it showed declining trend from south to central north and again showed increasing trend in northern region of traditional rubber growing region. Regarding climate, rubber NPP showed strong correlation with temperature than rainfall. However, regional variation was observed with northern region showing strong correlation with temperature and rainfall bioclimatic variables but not in southern region. Natural rubber ecosystem showed declining trend between 9^0N to 10.25^0N latitudes and 75^0E to 76.4^0E longitudes. Highest NPP was seen between 8^0N to 9^0N latitudes and 77^0E to 77.6^0E longitudes. In general, rubber NPP showed significant negative correlation with latitude and positive correlation with longitude. Soil also showed significant effect on rubber ecosystem productivity with soil management unit 1 and 2 showing higher productivity compared to others. Rubber ecosystem productivity under future climate showed spatial variation with southern and northern region showing decline whereas increasing trend in central region of traditional rubber growing area of India. The only limitation with satellite based NPP data is that it has coarse spatial resolution (1km) and it is difficult to get the effect of age of plantation on C sequestration. Compared to eddy covariance method, satellite based NPP will not give hourly or daily data.

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