Monitoring Net Primary Productivity Dynamics in Java Island Using MODIS Satellite Imagery

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Abstract

Net Primary Productivity (NPP) is the amount of net carbon accumulated in plant biomass per unit space and time. Temporal and spatial dynamics of NPP have significant impacts for ecosystems, since NPP provides energy for most biological processes. Java Island is the world's most populated island in which vast area of natural vegetation have long been converted into croplands as well as settlements to meet the human's need for food and housing. This research aimed (1) to study the trend in NPP over the Java Island during 2011-2011, and (2) to investigate the roles of climate and land-cover changes in affecting the dynamics of NPP. This study is expected to give us more understanding on carbon cycle and various ecological processes, especially in tropical region with high anthropogenic influence. The NPP data was based on Moderate Resolution Imaging Spectroradiometer (MODIS) annual NPP product (MOD17A3). The data on land-cover, vegetation and climate were acquired from NASA Reverb/ ECHO. The result shows that during 2001-2011, the annual NPP ranged from 0 to 1885 g $C.m^{-2}.yr^{-1}$ with an average of 937 g $C.m^{-2}.yr^{-1}$. NPP had negative trend over the study period with some anomalies during the year of 2004 and 2010. Statistical analysis shows a strong correlation between NPP and climatic parameters, but not between NPP and land-cover related parameters. This suggests that the dynamics of NPP in Java are affected more by climate rather than land-cover change. Analysis on the distribution of NPP across various land-cover types in the most recent data (2011) shows that almost 70% of NPP for the Java island were generated by the evergreen-broadleaf forest and cropland/natural vegetation mosaic.

Key words: Net Primary Productivity (NPP), spatio-temporal analysis, MODIS, remote sensing, Java.

1. Introduction

Primary production is the rate of solar energy converted to plant biomass through photosynthesis. Total of the converted energy is gross primary productivity (GPP). Net primary productivity (NPP) is the difference between GPP and energy lost during plant respiration (Campbell, 1990). NPP is also regarded as the net carbon stored since ultimately solar energy is fixed in the form of carbon-carbon bonds (Barbour, *et al*., 1999).

Primary productivity is the entrance of energy into ecosystem in the primary trophic level and represents the potential energy available for the higher trophic level (Barbour, *et al*., 1999). NPP measurements are becoming important because when energy flow in ecosystem can be measured, we are able to describe the state of ecosystem and predict the response of changes or disturbances (Whitten, *et al*., 1996). NPP also receives more attention today because it is the key process in carbon cycle and directly measures the quantity of goods provided from the ecosystem (Zhao and Running, 2008).

Human activities have generated great impact on earth. In order to accommodate our needs, we modified land-cover over various ecosystems, altering the nutrient cycle, the hydrological processes, the chemistry of atmosphere, and

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further the climate systems. Our understanding of in the response of the terrestrial NPP and its relationship with the carbon cycle is crucial for predicting and mitigating the impacts of future environmental change.

Remote sensing technology provides vegetation-related data that can be used to study the dynamics of terrestrial NPP over regional or global scale. Most of primary productivity estimation based on remote sensing data applied the principle of light use efficiency (LUE) that was firstly introduced by Monteith (1972). The principle states that ecosystem productivity is a function of the maximum efficiency of photosynthesis, active absorbed solar radiation (APAR), and environmental variables as the limiting factor of photosynthesis (Tan, *et al*., 2012).

Moderate Resolution Imaging Spectroradiometer (MODIS) is one of the main instruments of global monitoring of the Earth Observing Satellite (EOS) Terra and Aqua. MOD17 is data product of global GPP and NPP based on MODIS instrument images. MOD17 algorithm is a result of the development of a general ecosystem model of Biome-BGC based on LUE logic (Zhao, *et al*., 2005).

Java Island is located in the southern of South-East Asia. Warm tropical climate, numerous volcanoes, and fertile soil are the reasons for Java becoming the world's most populous island and one of the most-densely populated island. Java is the economic, social, political, and cultural hub of Indonesia (Whitten, *et al*., 1996). Java is becoming more interesting since it is located in highly productive region and has experienced high anthropogenic disturbances due to high population density.

This research aimed (1) to study the trend in NPP over the Java Island during 2011-2011, and (2) to investigate the roles of climate and land-cover changes in affecting the dynamics of NPP. This study is expected to give us more understanding on carbon cycle and various ecological processes, especially in tropical region with high anthropogenic influence.

2. Materials and Methods

2.1 Study area

Java Island (05°55"S - 08°43'5"S, 105°06"E 114°32"E) is the most populated island on earth, has a total area of 130.000 km^2 (Whitten, *et al*., 1996). Administratively, Java is divided into six provinces: Banten, DKI Jakarta, West Java, Central Java, DI Yogyakarta, and East Java. In the north of East Java province there is Madura Island (5260 km^2) which is also administratively part of Java Island. The region examined in this work includes Java Island itself, Madura Island, and small islands around Java (Figure 1).

The original vegetation of Java was large tracts of tropical rainforest. Naturally Java Island has various ecosystems from mangrove in north coast, rocky shoreline in the east, low-land tropical rainforest and tropical montane forest in the mountain slopes. The area of natural vegetation have long been converted into croplands as well as settlements to meet the human's need for food and housing. The island is characterized by warm tropical climate. There is a climate gradient in which the west part of Java tends to have more precipitation rather than the east part. The mean annual temperature is 28 ^{o}C and the mean annual humidity is 80%. Mean annual precipitation is 2550 mm (BIG, 2012).

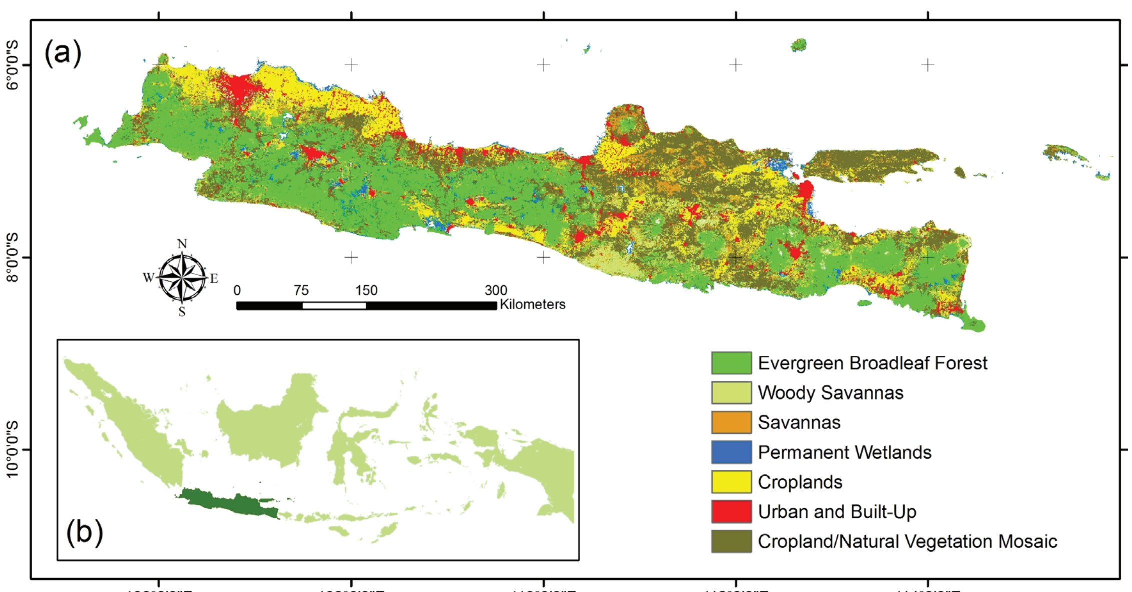

Figure 1. Location of study area: (a) major land-cover distribution type in 2011 based on MCD12Q1 data with IGBP land-cover class, (b) location of Java Island in Indonesia.

2.2 Collecting data

Most datasets required in this study are the remote sensing data product from NASA's TERRA MODIS and AQUA MODIS instrument. The following are brief descriptions of datasets used.

2.3 Net Primary Production (NPP) data

We used MODIS Annual NPP (MOD17A3) provided by Numerical Terradynamics Simulation Group (http://www.ntsg.umt.edu/) with 1-km spatial resolution. These data is calculated with MOD17 Algorithm, developed from BIOME-BGC general ecosystem model (Zhao, *et al*., 2000) based on the Light Use Efficiency (LUE) Logic (Monteith 1972). The LUE logic assumed that ecosystem productivity is the function from solar radiation, maximum efficiency of photosynthesis, and environmental constraints (Tan *et al*., 2012). MOD17 algorithm has three inputs for the estimation of NPP: MODIS land-cover products (MOD12), LAI/fPAR (MOD15) and daily meteorological data from the Global Modeling and Assimilation Office (GMAO). The Algorithm for Annual NPP values were derived from 8-days periods summation. We downloaded the available data from 2001 to 2011 and produced a mosaic of two MODIS tiles to cover the entire Java Island.

2.4 Land-cover data

Latest available data of land-cover (2011) was provided by Land Cover and Surface Climate Group at the Boston University. MCD12Q1 data downloaded from NASA Echo/Reverb has 500-m spatial resolution. The dataset used were the improved version with the overall accuracy of about 75%. International Geosphere-Biosphere Program (IGBP) land cover classification was adopted as the basis for defining land-cover types. There are 17 land cover classes consisting of 11 natural vegetation classes, three non-vegetation classes, and three human-altered classes.

2.5 Climate variable data

Land surface temperature data was derived from MOD11A2 data product (1km, 8-days composite). Precipitation data was generated from Tropical Rainfall Measuring Mission (TRMM) 3B43 V7 dataset (0.25^{o}, 1 month). Both datasets were downloaded from NASA Echo/Reverb. MOD16A3 (1-km, annual) data product was used for generating actual evaporation, provided by NTSG, the same source as NPP data.

2.6 Vegetation variable data

Fraction of Photosynthetic Active Radiation (FPAR) and Leaf Area Index (LAI) data were obtained from MOD15A2 data product. This data set was produced at 1-km spatial resolution and 8-days composite. MOD15A2 was based on lookup table (LUT) inversion approach algorithm. LUT from various biomes produced from three dimensional radiative transfer model. LAI/fPAR is one of key upstream inputs for MOD17 Algorithm for simulating various physical and biological process in primary production.

2.7 Data processing

All MODIS tiles datasets were processed in MODIS Reprojection Tool (MRT) for mosaicking and reprojection (UTM 49S). Spatial analysis was done using ArcGIS 10 and the statistical analysis was performed using SPSS.

2.8 Evaluation of the NPP map

The NPP data from MOD17A3 and land-cover data from MCD12Q1 were compared with the actual land-cover and vegetation properties. This is to evaluate whether the values of NPP in a given land-cover class and their variation across different land-cover classes are realistic. We used latest data (2011) as the reference. Actual land-cover was observed by ground truth visit in June 2013 and literature review from BIG (2012). We have selected 29 plots and assumed that in the validation spots there were no land cover changes within the study period.

3. Results and Discussion

3.1 Land Cover and NPP Relationship

The relationship between land cover and satellite derived NPP and land-cover over the study domain relationship are summarized in Table 1. Based on MCD12Q1 with IGBP land cover classification scheme in 2011, the top 5 land cover types in Java were cropland/natural vegetation mosaic, evergreen broadleaf forest, cropland, woody savanna, and urban built-up. The evaluation showed that the result of classification were generally match with the actual land cover. However, some misclassification were identified. Misclassification commonly occurs in the similar land cover types, e.g. broadleaf evergreen forest (EBF) and cropland/natural vegetation mosaic (CVNM). Discrepancy was easily found in the pixels bordering different land cover types, therefore misclassification tend to occur in heterogeneous landscape (Garcia-Mora, *et al*., 2012). Compared to the actual land-cover, representation of diverse land-cover types at coarse resolution (1-km or greater) satellite data have not been able to represent the complex pattern of mixed non-forest within the predominant land use (Potter, *et al*., 2012).

Overlayed data on land-cover and NPP of the same year suggests a variation of NPP values across various land cover types and climate variables. For evergreen broadleaf forest (EBF) land-cover type for instance, the mean annual NPP value of montane forest in Mt. Papandayan was 1.390 g C/m^2.yr. The teak dominated woodlands in Baluran that is characterized with dry climate have lower value of NPP (760 g C/m^2.yr). The lower NPP values for areas having drier climates indicates that the NPP values were able to illustrate

Table 1. Summary of major land cover types and NPP values in Java 2011.

[1]IGBP Class	Area (km^2)	[2]Area (%)	Total NPP (Tg C)	[3]NPP_{av} (g C/m^2.yr)	NPP Contribution (%)
Cropland / natural vegetation mosaic	48869	31.64	40.868	836 (281)	28.87
Evergreen broadleaf forest	47281.25	30.61	58.063	1223 (265)	41.01
Cropland	33458.61	14.93	16.174	701 (283)	11.43
Woody savanna	10424.25	6.75	9.793	939 (307)	6.92
Urban built-up	8322.818	5.39	4.456	535 (353)	3.15
Other land-cover types (<5% Area)	51257.77	10.68	12.216	-	8.63

[1] International Geosphere-Biosphere Program defined land cover classes (Rasool, 1992).
[2] Proportional area represented within the entire study domain (including Madura and other small islands around Java) .
[3] Mean annual NPP (standard deviation in parentheses) in 2011.

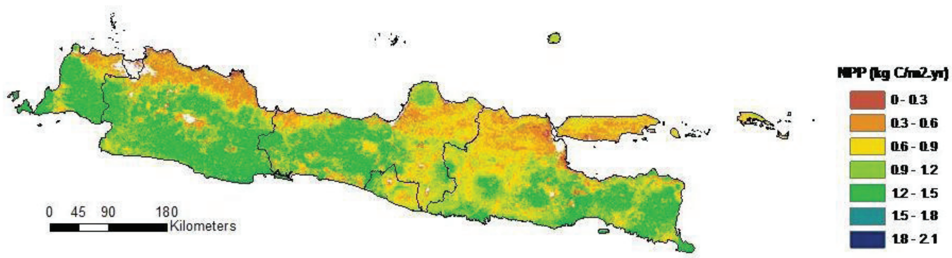

Figure 2. Mean annual NPP of Java between 2001 and 2011.

Table 2. Summary of Provinces in Java and its NPP values.

Province	Area (km^2)	Area (%)	[1]NPP_{av} (kg C/m^2.yr)	NPP Contributions (%)
DKI Jakarta	678	0.51	0.060	0.03
Banten	9349	7.05	1.002	7.78
Jawa Barat	37152	28.01	0.998	30.82
Jawa Tengah	34283	25.85	0.874	24.90
DI. Yogyakarta	3149	2.37	0.878	2.30
Jawa Timur	48019	36.21	0.856	34.17

[1] Mean annual NPP between 2001 and 2011.

the environmental constraints variation.

Cropland/ natural vegetation mosaic (CVNM) was the most extensive land-cover type in Java. This land-cover actually comprises mosaic of cropland, woodlands, and also human settlement. Situ Cisanti in Bandung Regency for example, which was dominated by woodland, shrubs, and cropland has the NPP of 1040 g C/m^2.yr. Other spot like Nagrek, Bandung Regency has much less dense vegetation cover and threfore has lower value of NPP compared with Situ Cisanti, i.e. 590 g C/m^2.yr. Cropland (CL) land cover types were commonly dominated by rice-field. Mean annual NPP of a paddy field in Pamarican, Ciamis was 970 g C/m^2.yr. In contrast, the NPP of a paddy field located in Jatinom, Cirebon that has less precipitation was 360 g C/m^2.yr. Urban built-up land cover type was concentrated in big cities. There were no data in dense urban built-up areas because these non-vegetated areas were excluded in the NPP calculation. However, less dense urban built-up areas mixed with cropland still has NPP values. The mean annual NPP in a spot at Cileen, Bandung for example was 290 g C/m^2.yr.

Table 1 showed that evergreen broadleaf forest (EBF) cover was the most productive land cover class with the mean annual NPP in 2011 amounting at 1288 g $C.m^{-2}.yr^{-1}$. This value is within the rangen reported in oher studies, e.g. Malhi (2012) who reporter that the mean annual NPP in lowland moist tropical forests ranged 730 and 1280 g $C.m^{-2}.yr^{-1}$.

Ground truth results indicate that the vast area of EBF land-cover actually includes all forest-like environments. The actual land-cover of EBF may include 65% of production forest and 35% of protected areas. Most of the forest areas are under Perhutani management (Nawir, *et al*., 2008). EBF encompass 30.61% area Java but contributes 41% of net primary production of Java. The high productivity these land cover type in tropical region almost entirely derived from the absence of dormant period, rather than diversity level or warm temperatures (Malhi, 2012). The ability to sequester and store more carbon than any other terrestrial ecosystem makes forests are important element to slow down climate change (Gibbs, 2012). That is one of several reasons to conserve it. We also note that broadleaf forest (EBF) and cropland/natural vegetation mosaic (CNVM) represents 62.25% area of Java and generated almost 70% of total annual NPP. These numbers means terrestrial carbon sink and the entry of energy at the primary trophic level in Java depends on those two types of biome.

3.2 Distribution of NPP

Total NPP of Java Island between 2001-2011 is 1.551 Tg C or approximately 141 ± 17.14 Tg $C.yr^{-1}$. The annual NPP ranged from 0 to 1885 g $C.m^{-2}.yr^{-1}$ with an average of 937 ± 355 g $C.m^{-2}.yr^{-1}$. The estimated average of NPP in South East Asian tropical region was 847 g $C.m^{-2}.yr^{-1}$ (Potter, *et al*., 2012), therefore it implies that Java may be classified as a strong carbon sequester region. The spatial pattern of NPP in Java was mapped in Figure 2. Various environmental components can affect NPP values, but it seems high NPP regions (>0.9 kg $C.m^{-2}.yr^{-1}$) were distributed in forested land-cover and in relatively higher precipitation (>2500mm.yr^{-1}). Inversely lower NPP regions (<0.9 kg $C.m^{-2}.yr^{-1}$) were distributed in developed and mosaic land-cover and lower precipitation (<2500mm.yr^{-1}).

We further divided Java by provincial administration and examined the NPP values in each province (Table 2). The most extensive province, East Java, contributed 34.17 % of the total NPP. However, the total NPP contribution of West Java and Banten altogether reached 38.6% despite the fact that the total area of those two provinces were smaller than East Java. It confirms the general perception that western part of Java (Banten and West Java) is more vegetated and biologically productive than the eastern part (East Java). High-density urban areas which have large proportions of built-up surface are very low in carbon uptake (Zhao, *et al*., 2012). That was almost entirely reason why DKI Jakarta showed a very small NPP contribution as well as its small area.

3.3 Dynamics of NPP over 2001-2011 period

Figure 3 showed negative trend of NPP from 2001 to 2011 with some apparent anomalies during the year of 2004 and 2010. Total Annual NPP reached maximum values in 2004 and inversely reached its minimum value in 2010. Declining trend was mainly caused by reductions in solar radiation in Asia (Zhao and Running, 2010). Imanda (2010) suggests that there is association between NPP variability and El Nino and La Nina events.

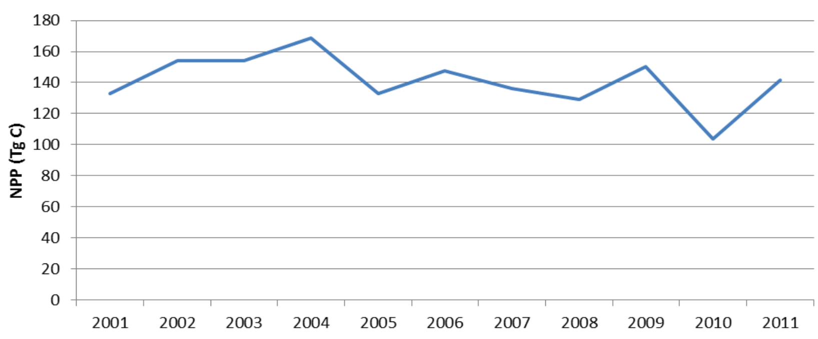

Figure 3. Annual total NPP and trends of NPP between 2001 and 2011.

Table 3. Correlation of NPP with climatic and vegetation variables.

		NPP	LST	PREC	ET	LAI	fPAR
NPP	Pearson Correlation	1	.815**	-.836**	-.704*	.028	-.014
	Sig. (2-tailed)		.002	.001	.016	.935	.968
	N	11	11	11	11	11	11

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.4 Correlation with vegetation and climate variable

Further we examined the relationship between NPP and several variables that may drive the NPP dynamics over the study period with Pearson correlation analysis (Table 3). LAI and FPAR values can express the vegetation densities. The results indicates that NPP has no correlation (P>0.05) with leaf area index (LAI) and fraction of photosynthetically active radiation (FPAR) variables. LAI and FPAR values also showed stable trends between 2001 and 2011 (Figure 4). It implies that there were no major changes in vegetation cover within the study period and land-cover change was not significant factor for NPP dynamics. Temperature and precipitation are closely related factors to NPP (Potter, *et al.*, 2012). In this study, NPP has very strong correlation (P<0.01) with precipitation (PREC) and land surface temperature (LST). NPP also has strong correlation (P<0.05) with evapotranspiration (ET) (Table 3). This suggests that land-cover change was not important factor in determining the dynamics of NPP in Java.

One may expect that the precipitation values are correlated with water availability, afterwards, it increase the vegetation primary production. In Java, annual precipitation always exceeds 2000 $mm.yr^{-1}$, indicating water availability was not the main potential limiting factor in the tropical region. We argued that the high precipitation values followed by severe cloudiness, low radiation penetration into the vegetation, and lead to low photosyntesis activity (Zhao and Running, 2010). Flux studies also reported that moist tropical forests productivity can be light-limited in the wet season (Malhi, 2012). Inversely temperature has positive correlation. Strong La Nina event occurred in 2010 (Buchanan, 2011) represent the highest annual precipitation value between the study period (Figure 4). High precipitation would go together with severe cloudiness, decreasing solar radiation penetration, and 2010 had the lowest NPP (103 Tg C). It explains why in Java precipitation was negatively correlated with NPP.

Temperature increment appears linked to less cloud cover and more radiation penetration, subsequently increasing the photosynthesis activity (Shiba and Apan, 2011). Maximum

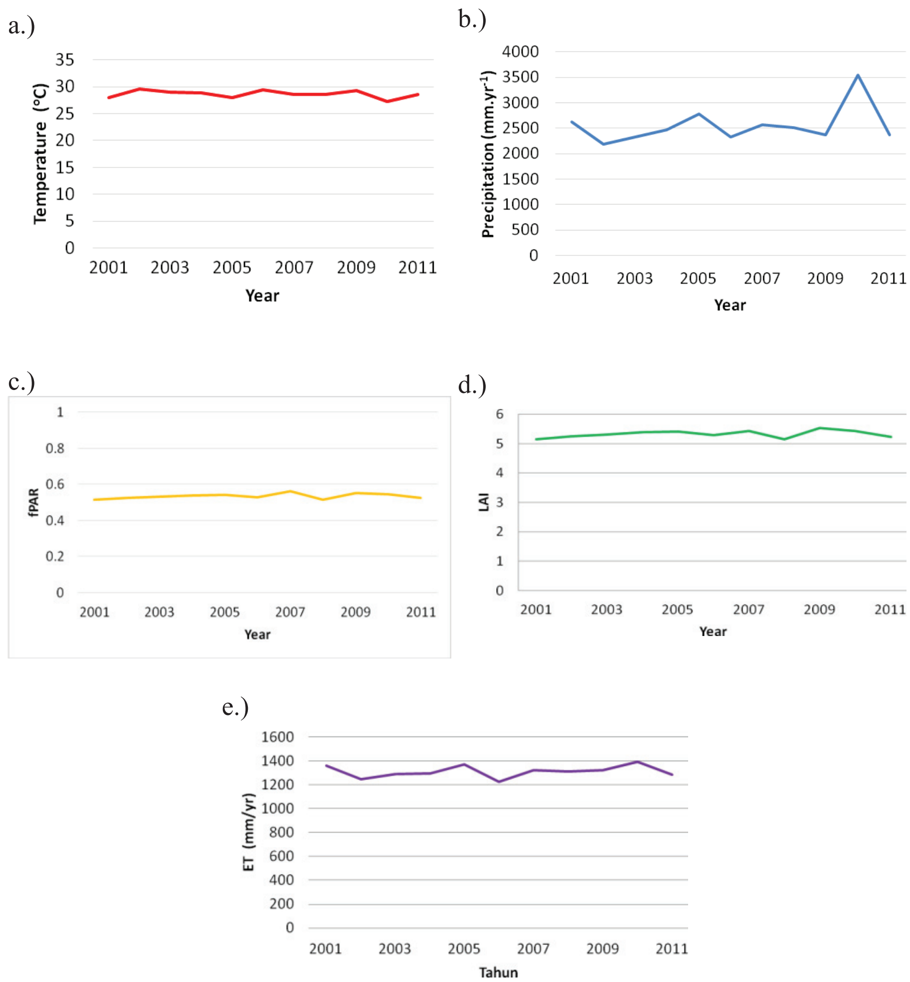

Figure 4. Mean annual of a.) land surface temperature (°C), b.) precipitation ($mm.yr^{-1}$), c.) fPAR, d.) LAI, and e.) Actual Evapotranspiration ($mm.yr^{-1}$).

NPP in 2004 (168 Tg C) was associated with neutral climate pattern in the beginning of the year followed with weak El Nino event in the end of the year (Gillis, 2004). During weak El Nino event, there was abundance of solar radiation, warm temperature in South East Asia. It induced photosynthetic activity increment and also supported with sufficient precipitation.

4. Conclusion

The distribution, dynamics, and trend of NPP were analyzed for Java Island from 2001 to 2011 based on MOD17 data product. Analysis on the distribution of NPP across various land-cover types in the most recent data (2011) shows that almost 70% of NPP for the Java island were generated by the evergreen-broadleaf forest and cropland/natural vegetation mosaic. During 2001-2011, the annual NPP ranged from 0 to 1885 $gC/m^2.yr$ with an average of 937 $g\ C.m^{-2}.yr^{-1}$. NPP had negative trend with some anomalies during the year of 2004 and 2010. Statistical analysis shows a strong correlation between NPP and climatic parameters, but not between NPP and land-cover related parameters. This suggests that the dynamics of NPP in Java are affected more by climate rather than land-cover change.

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