

Environmental Risk Analysis of Turkey under Climate Change Scenarios using Spatial Modelling: Application of Net Primary Productivity

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Abstract

The aim of this study is to estimate the response of NPP to regional climate changes in Turkey using a biogeochemical modelling approach. The CASA model was utilized to predict annual regional fluxes in terrestrial net primary production for present (2000-2010) and future (2060-2080) climate conditions. A comprehensive data set including percentage of tree cover, land cover map, soil texture, NDVI (Normalized Difference Vegetation Index) and climate variables were used to constitute the model. The multi-temporal metrics were produced using 16 days MODIS composites with 250 m spatial resolution. The future climate projections were based on a RCP (Representative Concentration Pathways) scenario that was defined in 5th Assessment Report of IPCC. In this context, the future NPP modelling was performed with prescribed CO₂ concentrations up to 421 ppm and temperature increasing 1.1°C to 2.0°C.

The model results indicated that the NPP in Turkey averages 1232 gCm²y⁻¹. Terrestrial NPP ranges from 9.61 to 316.1 gCm²y⁻¹ for the baseline period (2000-2010). Modeled total NPP averages 1320.8 gCm²y⁻¹ per year in the period 2060-2080. Total carbon budget of NPP was estimated as 104.78 MT (million tons) per year. The model results showed that the terrestrial NPP was sensitive to changes in temperature and precipitation. Addressing the model results, the CASA provided a great potential to predict present and future productivity on regional basis. Thus, this study will provide a scientific foundation to understand and assess ecological and economic implications and consequences of climate change on the productivity in Turkey.

Keywords: NPP, Modelling, Climate change, Turkey, MODIS, IPCC, RCPs

İklim Değişikliği Senaryoları Altında Konumsal Modelleme Kullanarak Türkiye'nin Çevresel Risk Analizi: Net Birincil Üretim Örneği

Öz

Çalışmanın amacı, Türkiye'de bölgesel iklim değişikliğinin Net Birincil Üretim (NPP)'e etkilerinin biyokimyasal modelleme yaklaşımı ile tahmin edilmesidir. Güncel (2000-2010) ve gelecek (2060-2080) iklim koşullarında karasal NPP'in yıllık bölgesel döngülerinin tahmininde CASA modeli kullanılmıştır.

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Modelin oluşturulmasında ağaç kapallılık yüzdesi, arazi örtüsü, toprak tekstürü, Normalleştirilmiş Fark Vejetasyon İndeksi (NDVI) ve iklim değişkenlerinden oluşan geniş bir veri seti kullanılmıştır. Çoklu zamansal metrikler 250 m çözünürlü MODIS verileri kullanılarak üretilmiştir. Gelecek tahmini için IPCC'nin 5. Değerlendirme Raporunda tanımlanan RCP (Representative Concentration Pathways) senaryoları baz alınmıştır. Bu kapsamda, 1,1°C ile 2,0°C arasında sıcaklık ve 421 ppm'e kadar CO₂ artışı limit alınmıştır.

Model sonuçları, Türkiye için ortalama NPP değerinin 1232 gCm²y⁻¹ olduğunu göstermiştir. Karasal NPP güncel durum için 9,61 to 316,1 gCm²y⁻¹ değişmektedir. Modellenen yıllık toplam NPP ise 2060-2080 yılları için 1320,8 gCm²y⁻¹ dir. Toplam karbon bütçesi yıllık 104,78 milyon ton tahmin edilmiştir. Model sonuçları karasal NPP'nin sıcaklık ve yağış değişimlerine hassas olduğunu göstermiştir. CASA modeli, güncel ve gelecek NPP değerlerinin hesaplanmasında bölgesel temelde başarılı sonuçlar vermiştir. Bu çalışma, Türkiye'de iklim değişikliği altında ekolojik ve ekonomik sonuçların ortaya konması yardımcı veriler üretilmesi bakımından önem taşımaktadır.

Anahtar Kelimeler: NPP, Modelleme, İklim değişimi, Türkiye, MODIS, IPCC, RCP

1. INTRODUCTION

Net primary productivity (NPP) is a key component of the global carbon cycle. Accurate estimation of terrestrial NPP and its sensitivity to regional temperature and precipitation changes are important for understanding the fluxes and amount of total carbon resulting from climate variations. Estimating temporal variations in NPP has significant importance that contributes to improve the understanding of terrestrial carbon cycle and to cope with potential future changes in climate. In this regard, policy makers need information to project the spatial and temporal responses of NPP to various future climate scenarios. Such predictions are necessary to not only measuring the regional carbon stocks but also to enlist the natural systems in mitigating greenhouse gas emissions particularly in heterogenous ecosystems [1]. This is especially true for Turkey where anthropogenically driven climate change can impact the ecosystem productivity within its rich vegetation biodiversity and diverse topography.

The aims of this study were to i) estimate the terrestrial NPP for Turkey using a biogeochemical model CASA (Carnegie Ames Stanford Approach), ii) modelling the future changes in the terrestrial NPP and its response to climate change based on the RCP 2.6 scenario of the IPCC. This study is important to strenghten the understanding

of the quantitative relationship between climate change and NPP on regional basis.

In respect to increases of greenhouse emissions due to anthropogenic effects, The Intergovernmental Panel on Climate Change (IPCC) has developed different climate scenarios within its 5th Assessment Report. These scenarios are called 'Representative Concentration Pathways' (RCPs) because they were developed to be 'representative' of possible future emissions and concentration scenarios published in the existing literature. The RCPs focus on the 'concentrations' of greenhouse gases that lead directly to a changed climate, and include a pathway the trajectory of greenhouse gas concentrations over time to reach a particular radiative forcing at 2100 [2].

RCPs 2.6 scenario was selected with prescribed CO₂ concentrations reaching 421 ppm by the year 2100 to utilize in the CASA model to estimate future NPP changes in response to climate change. A well-evaluated biogeochemical ecosystem model was used to simulate the spatial and temporal changes in NPP in response to the projected climate changes. The main objective was to quantify the ecosystem NPP in Turkey between present situation and 2100 within different IPCC scenarios. In this context, the interannual and seasonal characterization of NPP and climate variables were mapped using an ecosystem model

that globally optimized by the parameter of PAR (Photosynthetic Active Radiation), FPAR (Fraction of Photosynthetic Active Radiation) and LUE (Light Use Efficiency).

1.1. Study Area

Turkey is located in the northern hemisphere between the 36°-42° northern parallel and the 26°-45° eastern meridian (Figure 1). It covers approximately 788000 km². The country is situated on a landscape where Europe meets Asia, creating a link between these two continents. Half the land is above 1000 m and 10% is over 2000 m. Turkey has a mountainous and hilly landscape. The average altitude is approximately 1250 m, and in 62.5% of the total land average slope is more than 15% [3]. The country has diversity and prosperity

of topography, climate and vegetation cover. Turkey, as a result of her geographical and topographical position, has many climate types ranging from arid to humid [4]. The land cover types of the region comprise evergreen needleleaf, broadleaf and mixed forests including needleleaf and broadleaf forests, grasslands and bare grounds.

Turkey is situated in the extensive Mediterranean region where climatic conditions are generally quite temperate, the diverse nature of the landscape and particularly the mountains that run parallel to the coastline, result in significant differences in climatic conditions from one geographical region to the other. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall [3].

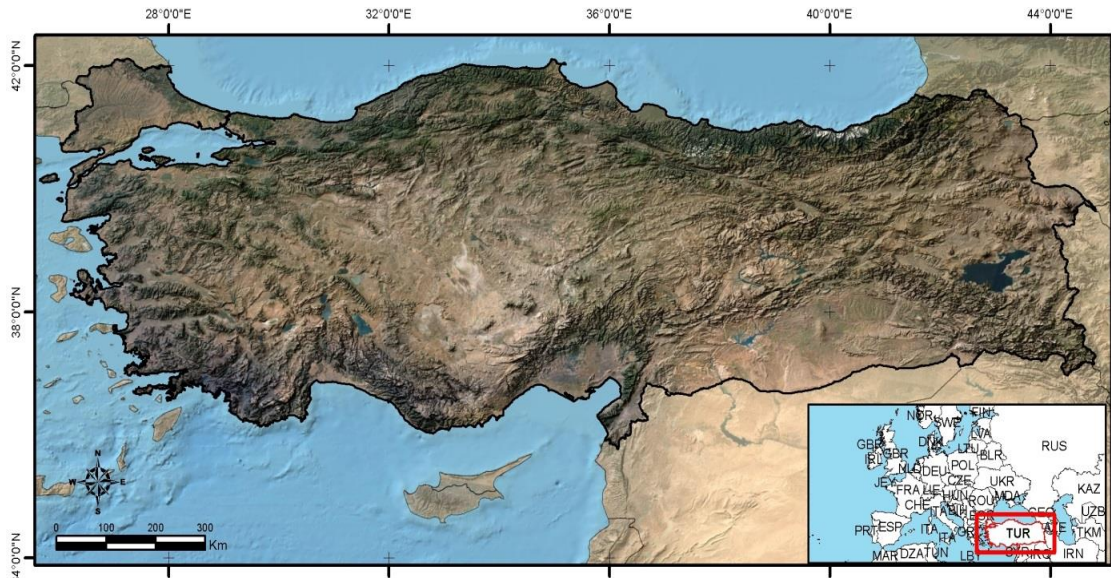


Figure 1. Location of the study region

1.1.2. Data Processing

The main meteorological data used in modelling process were obtained from State Meteorological Works in Turkey including precipitation, solar radiation and air temperature. Those datasets were collected from 300 meteorological stations on daily basis and generalized to monthly basis. Future climate maps were obtained from World

Clim research group with 1-km spatial resolution which were based on climate projections from global climate models (GCMs) for the RCP 2.6. which was one of the most recent GCM climate projections defined in the IPCC Fifth Assessment report. The GCM output was downscaled and calibrated (bias corrected) as baseline 'current' climate [5].

Remote sensing data used in this study were derived from The Moderate Resolution Imaging Spectroradiometer (MODIS). The sensor has the Terra and Aqua satellites on board with 36 spectral bands; spectral bands are primarily designed for study of vegetation and land surface: blue (459–479 nm), green (545–565 nm), red (620–670 nm), near infrared (841–875 nm and 1230–1250 nm), and shortwave infrared (1628–1652 nm and 2105–2155 nm) [1,7]. MODIS 16-day composite data at 250-m spatial resolution were obtained from the National Aeronautics and Space Administration (NASA). These images were geometrically corrected according to WGS 84 Datum and ED 1950 coordinate system.

2. METHODOLOGY

The CASA model was used in this study to estimate present and future NPP in Turkey. The model computes the monthly NPP flux as net fixation of CO₂ by vegetation on the basis of light-use efficiency. Thus, calculates NPP is calculated as a function of the driving energy for photosynthesis, the absorbed photosynthetically active (400 to 700 nm) solar radiation (APAR), and an average light utilization efficiency (ϵ) [8]. The fundamental relation in the CASA model is

$$\text{NPP} = \text{APAR} \times \epsilon \quad (1)$$

$$\text{NPP} = f(\text{NDVI}) \times \text{PAR} \times \epsilon \times g(\text{T}) \times h(\text{W}) \quad (2)$$

where APAR (in megajoules per square meter per month) is a function of NDVI and downwelling photosynthetically active solar radiation (PAR) and ϵ (in grams of C per megajoule) is a function of the maximum achievable light utilization efficiency ϵ adjusted by functions that account for effects of temperature $g(\text{T})$ and water $h(\text{W})$ stress. Whereas previous versions of the CASA model [9,10] used a normalized difference vegetation index (NDVI) to estimate FPAR, the current model version instead relies upon canopy radiative transfer algorithms [11], which are designed to generate improved FPAR products as inputs to

carbon flux calculations. The model was utilized to predict annual regional fluxes in terrestrial net primary production at variable degrees of C, depending on the yearly conditions, with terrestrial net production. Several diverse datasets were used in this research.

Calculation of annual terrestrial NPP is based on the concept of light-use efficiency, modified by temperature, rainfall values and solar radiation scalars. In addition, percentage of tree cover, land cover map of the region, soil texture and NDVI (normalized difference vegetation index) will be used to constitute this model.

Climate Data: Monthly precipitation, air temperature and solar radiation were used as the climate data sets. These variables were based on 10 years (2000-2010) records from the meteorological stations in Turkey. Climate variables were spatially-interpolated together with Digital Elevation Model (DEM) using co-kriging method and mapped on monthly basis and included into modelling process.

Land Cover Map: The MODIS land cover product was used to classify the vegetation types with CORINE land cover scheme. The output comprised 82 land cover classes with 250 m spatial resolution initially. Accuracy analysis was carried out by comparing the classification map and ground truth data obtained from many field campaigns.

Soil Texture Map: The soil texture data file is based on FAO soil texture classification which has 5 classes. The dominant soil type in a soil unit, the designation "coarse", "medium", "fine", "very fine" or a combination of these based on the relative amounts of clay, silt, and sand present in the top 30 cm of soil. These classes were derived from the Pedotransfer rules and expert opinions. The regional soil maps in 25.000 scale was utilized for this study and soil texture classes were assigned on the basis of estimated clay content according to FAO [8].

NDVI: The MODIS/Terra NDVI images produced 16-day intervals, L3 Global and at 250 m spatial resolution were used in modelling process as one of the main inputs. These images comprised transformations of the red (620-670 nm), nearinfrared (841-876 nm), and blue (459-479nm) bands designed to enhance the vegetation signal and allow for precise inter-comparisons of spatial and temporal variations in terrestrial photosynthetic activity [12].

Percent Tree Cover Map: Regression Tree (RT) algorithm was used to predict Percent Tree Cover of Turkey as one of the main inputs in NPP modelling process. The regression tree algorithm

produces a rule-based model for predicting a single continuous response variable from one or more explanatory variables. RT is a piecewise constant or piecewise linear estimate of a regression function, constructed by recursively partitioning the data [13].

The methodology for deriving percent tree cover with RT consisted of five steps for this study Dönmez et al., [14]: i) generate reference percentage tree cover data, ii) derive metrics from MODIS data, iii) select predictor variables, iv) fit RT models, v) undertake accuracy assessment and produce final model and map (Figure 2).

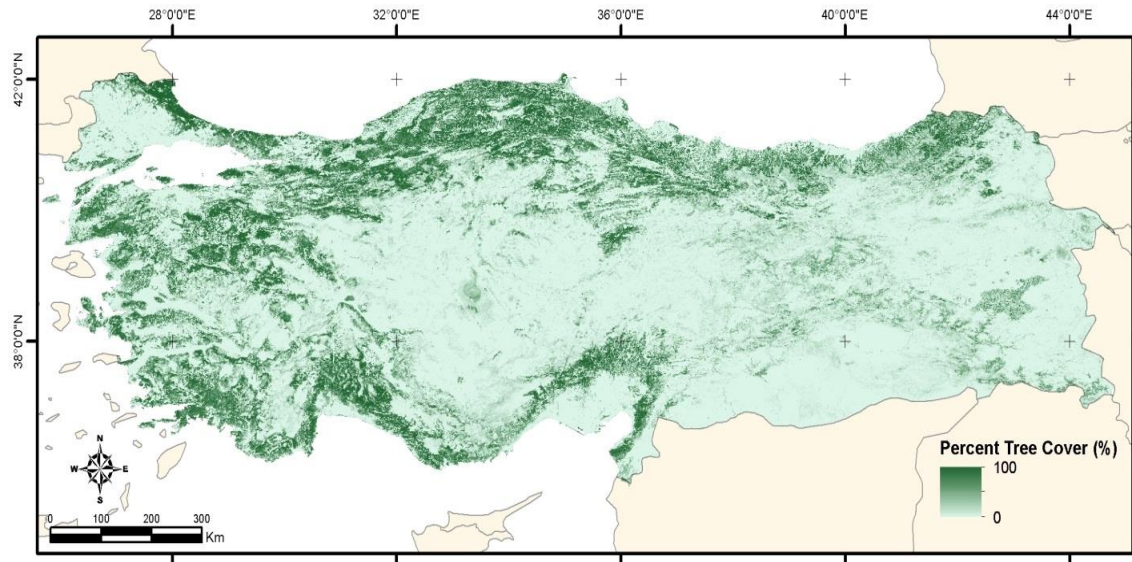


Figure 2. Percent tree cover map of Turkey

Accuracy of the percent tree cover map was defined with correlation coefficient. The CC of the percent tree cover for Turkey is 0.83. It is showed that the percent tree cover map of Turkey was derived by means of RT technique with a reasonable accuracy.

3. RESULTS AND DISCUSSION

The aim of this study is to estimate the response of NPP to regional climate changes in Turkey using a biogeochemical modelling approach. Present and

future projections of NPP were estimated in Turkey in respect the climate change effects. Total NPP carbon budget for the whole region and each land cover class were calculated and the changes were defined.

The 11-yr datasets of MODIS and climatic parameters were used to estimate the patterns of monthly variability of NPP in relation to climate change in Turkey. The NASA-CASA model was run over Turkey for 10-year simulation with respect to FPAR and LUE.

Modelling results showed that the forest NPP in the baseline (2000–2010) condition varied spatially and temporally across the study region. The mean NPP differed significantly among all

months ranged from 32.05 to 169.64 $\text{gC m}^{-2} \text{yr}^{-1}$. Annual total NPP is shown in Figure 3 and total NPP were mapped at a 250 m grid cell size.

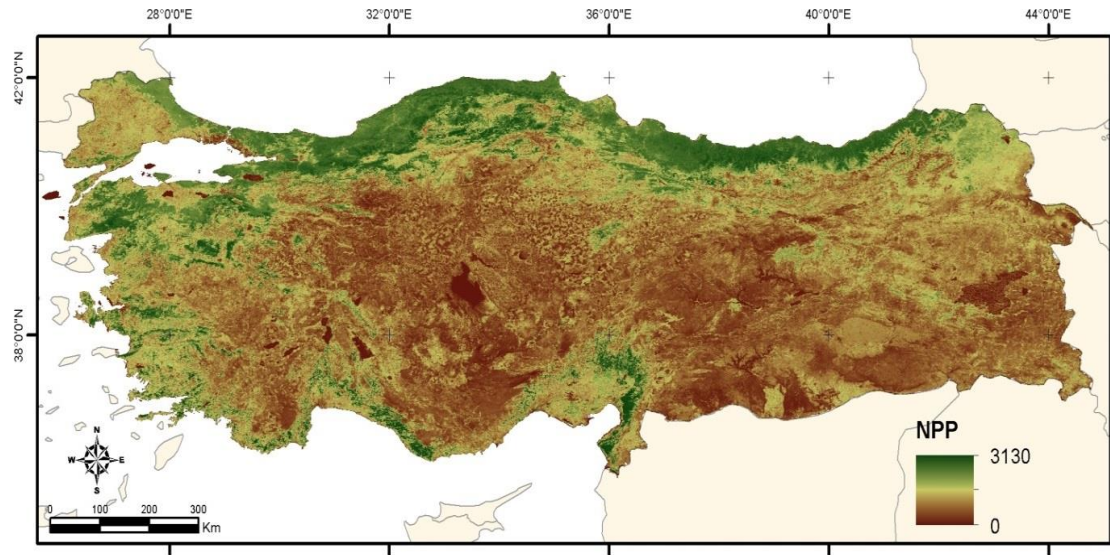
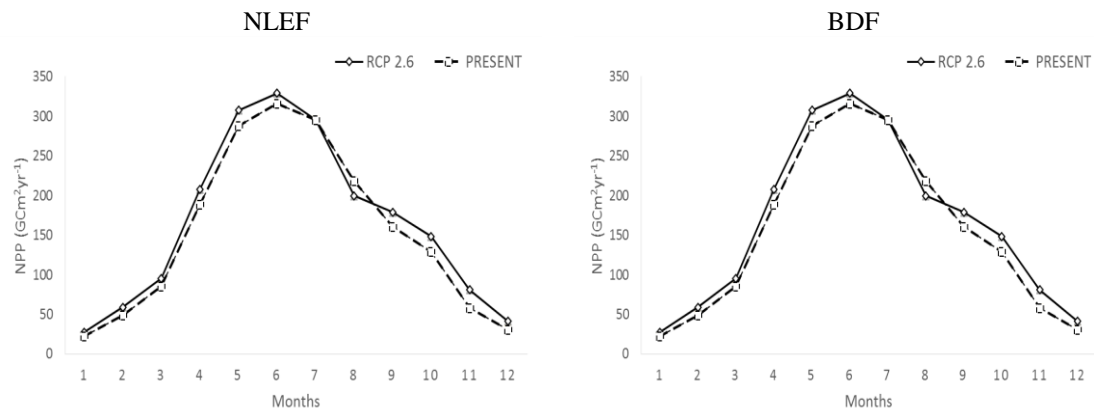


Figure 3. Total NPP map derived from CASA model (250 m)

The NASA-CASA model was run over Turkey for a 20 year (2060–2080) simulation with respect to projected climate time-series. Model simulations were intended to reflect the monthly and annual variability of NPP response in RCP 2.6 scenario defined by IPCC where rainfall and air temperature can vary substantially for long-term average amounts. The long-term mean annual temperature indicated an increase of 1.5–2°C for

scenario RCP 2.6 for 2060–2080 compared to present conditions.

The CASA Model simulations indicated a significant increase for spring season for 2060–2080 period. However, a dramatic decrease was simulated for scenario RCP 2.6 during summer. Monthly variations of NPP for the land cover classes in Figure 4.



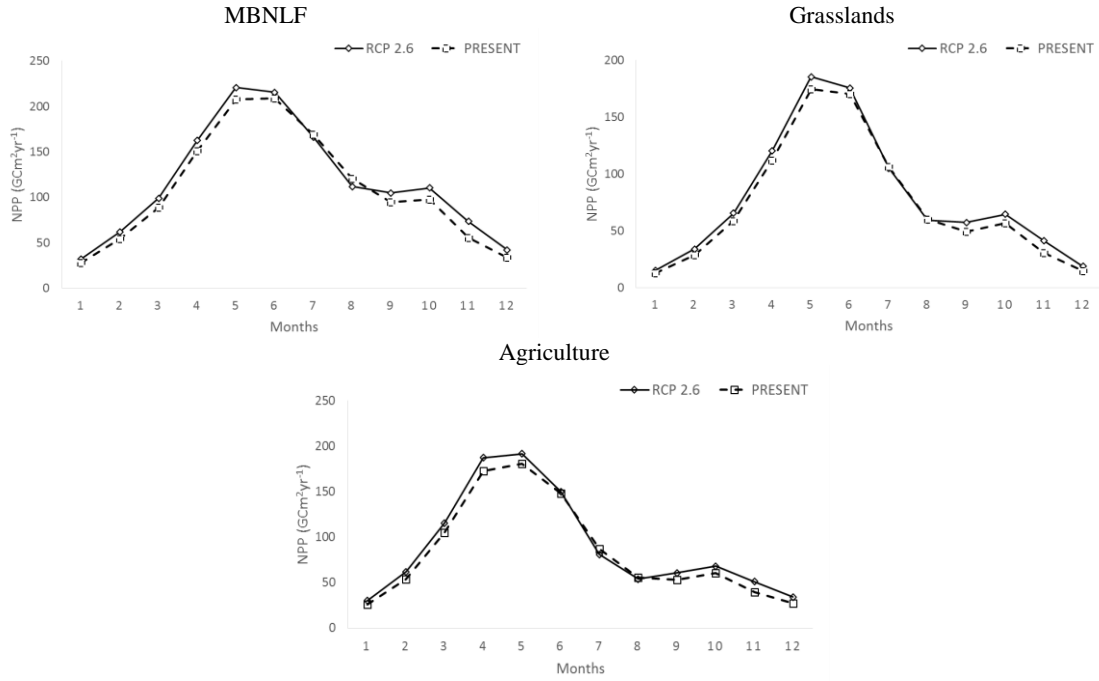


Figure 4. Monthly differences of NPP fluxes for different land cover classes between present and future (NLEF: Needle Leaf Evergreen Forest, BDF: Broadleaf Evergreen Forests, MBNLF: Mixed Broadleaf and Needleleaf Forests)

An increase will occur in spring and winter seasons due to projected temperature increases for RCP 2.6. In summer, a decrease of NLEF NPP occurs due to higher temperature. The total NPP was estimated as $1969.54 \text{ gCm}^2\text{y}^{-1}$ for 2060-2080.

MNBDF stands cover wide areas in the region and its productivity is an important indicator for the ecosystem performance and carbon fluxes. Total annual MNBDF NPP was estimated as $1400 \text{ gCm}^2\text{y}^{-1}$ for RCP 2.6 scenarios. Monthly Grassland NPP are estimated approximately between 10 and $200 \text{ gCm}^2\text{y}^{-1}$.

Agricultural production provides a significant contribution to Turkey’s economy. NPP amounts indicate the performance of agricultural productivity. CASA model was simulated a minor increase in NPP of agriculture areas. An increase will occur with approximately $+102 \text{ gCm}^2\text{y}^{-1}$.

The assessment of the climate change scenarios and their impact on the NPP and its variations

were constituted by analyzing the model predictions. Model results were interpreted and summed for each land cover class over Turkey. Model NPP estimations for the land cover classes and total NPP carbon amounts are shown in Table 1.

Table 1. Annual Total NPP Estimations and their responses to different climate scenarios for Turkey (MT: Million tons)

| Land Cover Classes | 2000-2010 | | 2060-2080 | |
|--------------------|--|------------|--|------------|
| | Present NPP | | RCP2.6 | |
| | Annual ($\text{gCm}^2\text{y}^{-1}$) | Total (MT) | Annual ($\text{gCm}^2\text{y}^{-1}$) | Total (Pt) |
| BDF | 1839.71 | 9.34 | 1969.54 | 10.00 |
| MBNLF | 1311.06 | 18.50 | 1400.43 | 19.76 |
| NLEF | 1665.93 | 9.96 | 1810.18 | 10.82 |
| Grasslands | 875.59 | 10.06 | 943.90 | 10.84 |
| BSBS | 1260.99 | 1.39 | 1329.12 | 1.47 |
| Bare Soil | 665.35 | 12.93 | 708.10 | 13.76 |
| Agriculture | 1008.15 | 42.60 | 1084.36 | 45.82 |
| Total | 3130 | 104.78 | 3056 | 112.47 |

The mean annual NPP simulations of BDF stands indicated an increase of $+130 \text{ gCm}^2\text{y}^{-1}$ for scenario

RCP 2.6. NLEF and MBNLF stands also indicated a reasonable increase of up to $+140 \text{ gCm}^2\text{y}^{-1}$ for future. MBNLF stands showed also significant differences in terms of their NPP amounts in future. The strongest impact of the projected climate change was estimated on NPP in BDF stands. Grasslands and agricultural fields also showed a critical response to the temperature and

precipitation changes that were included in modelling process.

The difference between present and future NPP fluxes were mapped with 250 m spatial resolution for the RCP 2.6 scenario. The difference NPP maps of present and future (RCP 2.6) are shown in Figure 5.

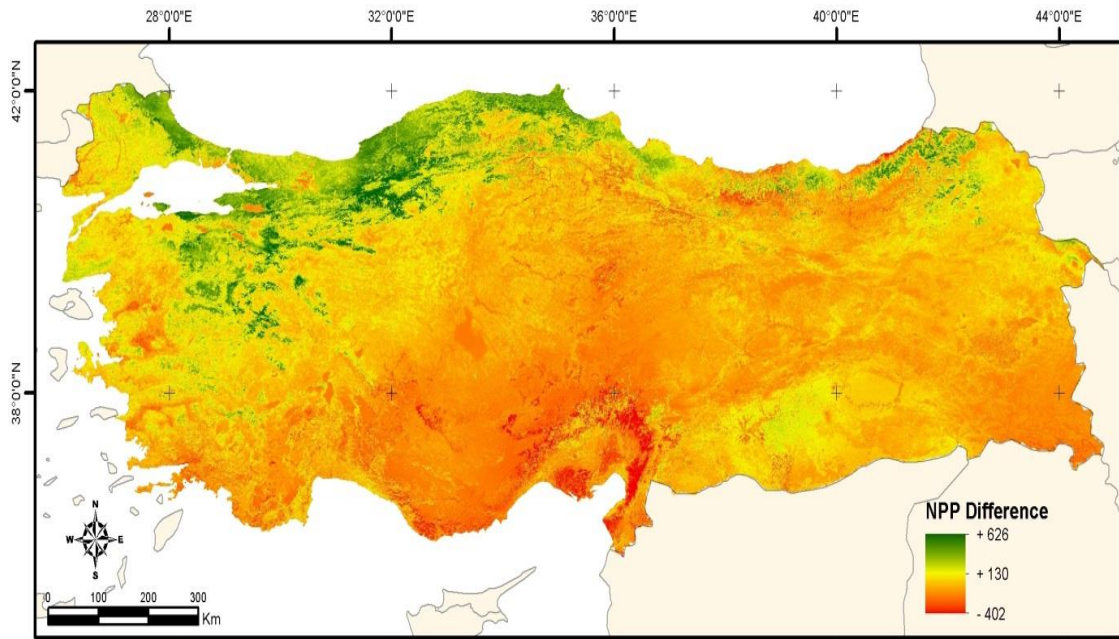


Figure 5. Difference NPP Map between 2000-2010 and 2060-2080 (RCP 2.6)

Spatial distribution of the NPP for present and future were also estimated using the CASA model. NPP showed significant differences in terms of its spatial distribution in the region. An increase of $+626 \text{ gCm}^2\text{y}^{-1}$ was estimated within RCP 2.6 scenario. The increase will occur mostly in northern part of Turkey where the BDF stands are located. Future simulation results indicated an increase in northern areas and a strong decrease in southern part. The spatial distribution in the difference NPP maps indicates that the higher elevation regions are experiencing the largest increase primarily because of a large increase in temperature and a decrease in precipitation. The decrease of annual NPP was estimated as $-402 \text{ gCm}^2\text{y}^{-1}$.

4. DISCUSSION

The time frame 2060-2080 were modelled and the changes in monthly and annual NPP fluxes were estimated. The results indicated a slight increase of total NPP and carbon. The increase of NPP showed slight differences in terms of its spatial distribution. The distributed model results emphasised the importance of high resolution input data for regional impact analysis in respect to the climate changes. Higher spatial data contributed to increase the capability of the model to capture the local changes in vegetation NPP and its distribution. In particular, MODIS data hold great potential for predicting NPP with CASA model because of its appropriate spatial and

spectral resolutions. Its spatial capability can include the heterogeneity of the region to the NPP modelling. Moreover, CASA was the appropriate model for handling the vegetation heterogeneity in the region which has sparse coverage and high species diversity.

A distinct increase in forest NPP was simulated, resulting from the lower precipitation and higher temperature for the lowland regions. Particularly, Mediterranean part of Turkey is already a relative temperate and humid region that would even have worst conditions due to the projected future climate changes during summer. These conditions can have major influence on vegetation potential and its productivity. Such influences would have negative future effects on the ecosystem performance in the lower regions of Turkey.

Total carbon amounts in respect to terrestrial NPP was also calculated for present and future conditions. The present NPP carbon was simulated as 9.34 MT annually. The results indicated an increase of 0.66 MT for scenario RCP 2.6 by the period of 2060-2080. The results indicated an increase of NPP particularly in higher zones. Addressing the temperature increases, the central part of the region can have more dry conditions that will indicate a decrease for NPP and local carbon budgets.

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