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Responses of Annual Variability of Vegetation NPP to Climate Variables Using Satellite Techniques in Gadarif State, Sudan

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Abstract

Plants play an essential role in matter and energy transformations and are key messengers in the carbon and energy cycle. Net primary productivity (NPP) reflects the capability of plants to transform solar energy into photosynthesis. It is very sensible for factors affecting on vegetation variability such as climate, soils, plant characteristics and human activities. So, it can be used as an indicator of actual and potential trend of vegetation. In this study we used the actual NPP which was derived from MODIS to assess the response of NPP to climate variables in Gadarif State, from 2000 to 2010. The correlations between NPP and climate variables (temperature and precipitation) are calculated using Pearson's Correlation Coefficient and ordinary least squares regression. The main results show the following 1) the correlation Coefficient between NPP and mean annual temperature is Somewhat negative for Feshaga, Rahd, Gadarif and Galabat areas and weakly negative in Faw area; 2) the correlation Coefficient between NPP and annual total precipitation is weakly negative in Faw, Rahd and Galabat areas and somewhat negative in Galabat and Rahd areas. This study demonstrated that the correlation analysis between NPP and climate variables (precipitation and temperature) gives reliably result of NPP responses to climate variables that is clearly in a very large scale of study area.

Keywords

Climate Variables, MODIS, NPP, Climate Change, Correlation Coefficient, Gadarif State, Remote Sensing, GIS Applications

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1. Introduction

NPP is defined as the difference between carbon fixed by the vegetation of an ecosystem during photosynthesis and the carbon released during plant respiration or simply as the sum of daily net growth, rates of plant dry matter [1]. Vegetation net primary productivity (NPP), as a biomass increment, plays an important role in the global carbon cycle. It contributes to understanding the contribution of NPP to the carbon exchanges that take place between the biosphere and atmosphere. Vegetation NPP indicates the atmospheric carbon fixed by plants except for the carbon released by respiration. Global vegetation NPP has increased due to climate change over the last few decades [2]. Net primary productivity has received most attention as a significant component in the ecosystem process which removes carbon dioxide CO_2 from the atmosphere and stores it in short-living, foliage, fine roots and long living (wood) tissues. An indicator of the production activity or expansion of terrestrial vegetation is provided by NPP. NPP is the net new carbon that is held as biomass in a plant's stem, leaves, or roots. It is the distinction between the carbon that plant leaves absorb during photosynthesis and the carbon that leaves, stems, and roots expel through respiration [3]. Climate, soils, plant traits, disturbance patterns, and a host of other natural and man-made variables are only a few of the many variables that affect NPP. Determining temporal trend and variability of NPP and its response to climate change is critical for understanding the potential carbon cycle changes in response to precipitation and temperature other factors [4]. Crop yield estimates are also frequently made using NPP data [5], grassland yield [6], forest growth and production [7] [8] and the effects of human-induced land desertification and of climate variability on terrestrial biospheres [9] [10]. However, recent endeavors to identify relationships between inter-annual deviations in NPP and corresponding anomalies in their established mean climatic predictors, obtained conflicting results. Some attempts, did not find any correlation between the inter-annual variability in NPP and equivalent deviations in annual precipitation at continental scale, e.g. in Africa [11] In some regions of Africa, net primary productivity increases depending on the increase in rainfall and vice versa, while the NPP decreases with the increase in temperature and vice versa, and this reflects negatively on food security in those regions, while the NPP appears to be not affected by rain and temperature in some regions and in North America [12] interannual variability in aboveground net primary production (ANPP) was assessed with long-term (mean = 12 years) data from 11 Long Term Ecological Research sites across North America. The greatest interannual variability in ANPP occurred in grasslands and old fields, with forests the least variable. At a continental scale, ANPP was strongly correlated with annual precipitation. However, interannual variability in ANPP was not related to variability in precipitation. Instead, maximum variability in ANPP occurred in biomes where high potential growth rates of herbaceous vegetation were combined with moderate variability in precipitation. In the most dynamic biomes, ANPP responded more strongly to wet than to dry years. Recognition of the fourfold range in ANPP dynamics across biomes and of the factors that constrain this variability is critical for detecting the biotic impacts of global change phenomena. This paper tries to make a temporal analysis of NPP in relation to precipitation and temperature within main areas of Gadarif state of Sudan which is widely spread vegetation degradation.

2. Material and Methods

2.1. Study Area

Gadarif state occupies an area of roughly 57,329.26 km^2 and is situated in eastern Sudan, between 12˚48' and 15˚50' N and 33˚40' and 36˚47' E, as depicted in **Figure 1**. [13] indicated that the state has a semi-arid climate, with an aridity index that ranges from 0.2 to 0.4. The study area's vegetation is mostly reliant on rainfall. Harrison and Jackson claim that the 1958 Gadarif area is located in the low-rainfall forest savannah region with clay soil and a very diverse range of trees, shrubs, and grasses. This region's average temperature ranges from a mean minimum of 22˚C in the winter to a mean maximum of 37˚C in the summer. In the research area, April and May are known to have the highest temperatures. Temperature and rainfall data are frequently utilized to describe the climatic status of the region because they are readily available in both temporal and spatial dimensions [14] [15] [16].

2.2. Data source and processing

2.2.1. Estimation of actual NPP

The difference between the total amount of carbon dioxide fixed during the

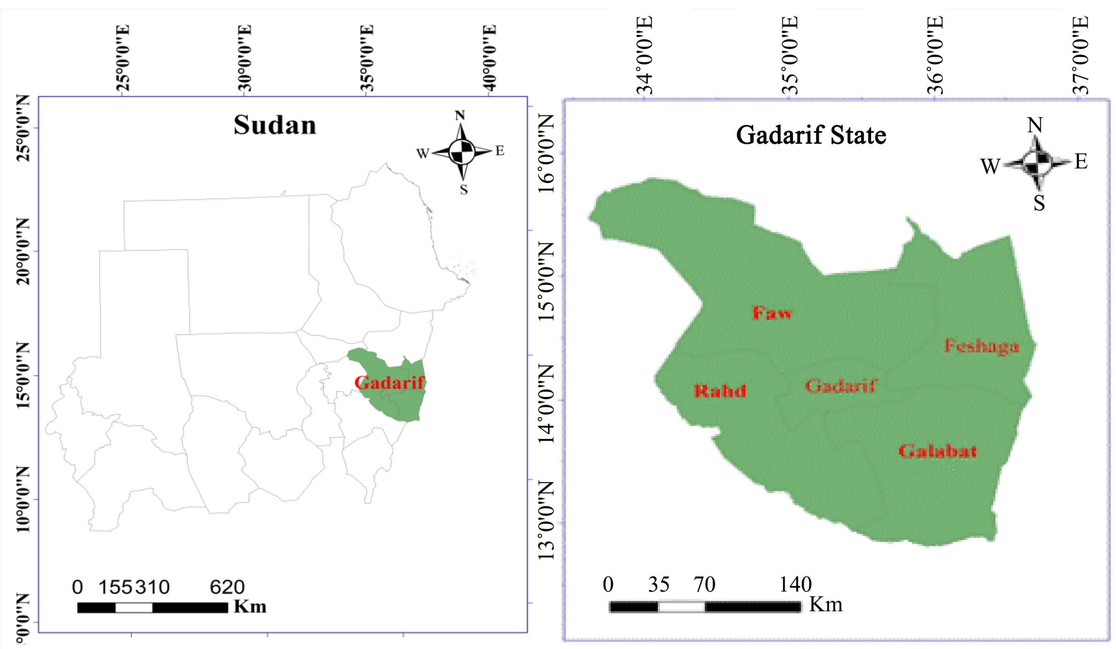

Figure 1. Location of the study area.

photosynthetic process and the amount of carbon dioxide consumed during respiration is the actual NPP estimate. Thus, NPP, respiration (Rd), and gross primary productivity (GPP) are all included in actual NPP:

$$\text{NPP} = \text{GPP} - \text{Rd} \tag{1}$$

The respiratory consumption is expressed as Rd (gC/m^2/yr), the gross primary productivity as GPP (gC/m^2/yr) and the net primary productivity as NPP (gC/m^2/yr).

Using Chang's (1968) formula, the respiratory consumption Rd is computed as follows:

$$\text{Rd} = \text{GPP} * (7.825 + 1.145\text{T})/100 \tag{2}$$

where T is the average temperature $^\circ$C and Rd is the respiration consumption, generating and validating empirical parameters in accordance with Gadarif State.

2.2.2. Remote Sensing Data

Remote sensing data was from the MODIS sensor aboard the NASA Terra satellite, launched in 1999. The MOD17 products provide the first operational, near-real-time estimate of global GPP products and NPP products from EOS MODIS sensor. The MOD17 algorithm has two sub products (MOD17A3, MOD17A2). Sub products (MOD17A2) storing 8-day compound GPP and PsnNet (net photosynthesis) while, sub products (MOD17A3), includes annual NPP and QC. The MODIS land science provides the user with a set of 1 km yearly net primary productivity (NPP) products (MOD17A3) designed for study vegetation cover and land surfaces, with a spatial resolution of 1km to estimate the actual NPP. We obtained the annual net primary productivity (MOD17A3) data sets from the LAADS website (http://www.ladsweb.nascom.nasa.gov/data/search.html) covering the months of January 2000 through December 2010. Using ArcGIS V10.3 (ESRI, California, and the USA), the remote sensing data were projected from the original integer zed sinusoidal projection to Albers equal-area and WGS-84 datum. These data are freely obtainable to the communal from the Numerical Terra dynamic Simulation Group (NTSG) (http://www.ntsg.umt.edu) or the EDC DAAC (EROS Data Center Distributed Active Archive Center).

2.2.3. Metrological Data

The Climate Research Unit website,
https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_3.22/cruts.1406251334.v3.22/,
supplied the metrological data, included annual total precipitation and annual mean temperature (ATP, AMT) at high resolutions of around 0.5°. Using GIS techniques, drawing tools were used to extract the mean values of these two variables at the area level for each pixel for various forms of land cover. The mean values of these variables were extracted at the State level for five areas (Faw, Feshga, Gadarif, Rahd, Galabat) using GIS techniques based on the grid maps of monthly mean values of NPP for distinct land regions, annual mean tempera-

ture, and annual mean precipitation.

2.2.4. Statistical Analysis

Using GIS techniques, the mean values of monthly mean values of NPP for various land regions, annual mean temperature, and annual mean precipitation were extracted at the Gadarif State level for five land areas based on grid maps. The influences of climate variables on NPP are quantified and discriminated contribute of each variable by using the Pearson's correlation coefficients describe as follows:

$$R^2 = Sq\left(\sum_{i=1}^{11}(xi-\overline{x})(yi-\overline{y}) \Big/ \sqrt{\sum_{i=1}^{11}(xi-\overline{x})^2(yi-\overline{y})^2}\right) \quad (3)$$

where yi refers to climate variables (MAT (˚C) and MAP (mm)) in the year i; and $\overline{y}$ represents the mean climate (MAP and MAT) values over the years. When the correlation coefficient was tested for significance (P, 0.01, or P, 0.05), it displayed an extremely significant or significant linear correlation.

3. Results

3.1. Spatial and Temporal Distribution of the Actual NPP in Study Area from 2000 to 2010

The mean actual NPP of the northern Gadarif state from 2000 to 2010was showed moderate spatial heterogeneity (Figure 2). The mean actual NPP of Faw district was smallest and ranged from 0.5 to 18 $g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$. Galabat had the largest annual mean actual NPP (8.5 - 45 $g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$), which was mainly distributed in the south eastern part of study area. The mean actual NPP of Fashega and Rahd districts were relatively high, ranging from 1.65 to 33 $g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$. Meanwhile, the maximum means actual NPP of different districts occurred in 2000 and the minimum mean actual NPP occurred in 2006.

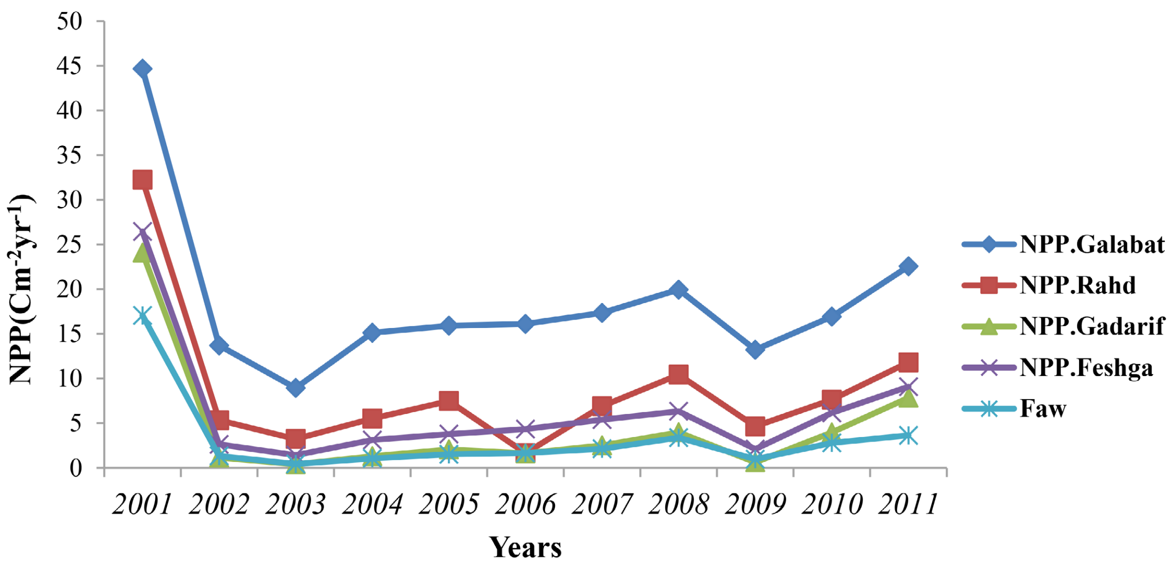

Figure 2. Distribution of Spatial and temporal mean actual NPP in Gadarif State from 2000 to 2010.

3.2. Mean Annual Actual NPP of the Main Areas in Gadarif State from 2000 to 2010

Figure 3 showed the variations in mean annual actual NPP of the main areas in Gadarif state from 2000 to 2010. **Figure 3** shows that the Galabat region was the most productive land cover, with a mean annual NPP of 18.6 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$, followed by Rahd and Feshga with mean annual NPP of 8.8 and 6.4 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$, respectively, it may be due to the increase in rainfall in these areas. The Gadarif and Faw was the least productivity with a mean annual NPP of 4.5 and 3.3 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$, respectively. This is due to the low rainfall in the Faw region, where the mean annual rainfall recorded 59.8 mm. Degradation and decline of vegetation cover have occurred alarmingly over the past 30 years, decrease NPP. In Gedaref State, it has been converted vast tracts of grasslands and forests with high biodiversity and high fertility to agricultural areas. The total area of rangelands and forests decreased due to the expansion of modern mechanized farming as a result of the increase in population to meet the increasing demand for food. Generally, the results showed a wide variation in mean annual NPP, which is increasing from north to south, with mean annual NPP in Faw (North) 3.3 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$ and in Galabat (South) 18.6 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$.

3.3. Climate Data and Analyses

Figure 4 and **Figure 5** showed the variations of annual precipitation and temperature anomaly and the main areas in Gadarif State. Annual precipitation and temperature anomalies showed great fluctuations all over the study area. By alternating the vicissitudes of negative and positive anomalies, the most negative precipitation anomalies periods have been on record, for example, in 2000 and 2002 (**Figure 4**). Wet years were also observed for example, in 2002, 2003, 2006, and 2007. Likewise, temperature showed fluctuations with a generally increasing trend in 2007 and 2008 (**Figure 4**). Generally, the maximum mean annual precipitation of different districts occurred in Galabat and the minimum mean annual precipitation occurred in Faw. The maximum mean annual temperature of different districts occurred in Fashega and the minimum mean annual temperature occurred in Galabat (**Figure 4**). The precipitation was decreasing at the rate

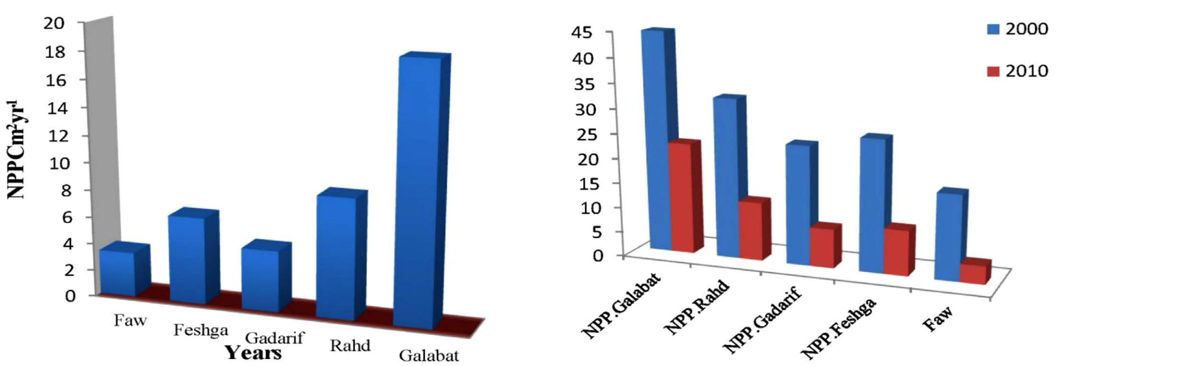

Figure 3. Variations in mean annual actual NPP of the main areas in Gadarif State from 2000 to 2010.

of −50.3 mm/10a, while the temperature was increasing at the rate of 0.02˚C/10a. The analysis of precipitation and temperature data for the study area showed that there was a steep diminishing trend in annual precipitation and a rising trend in temperature. As reported by [17], results indicate that there is an unprecedented increase in annual temperatures (average, maximum and minimum) in Sudan and this coincides with a significant decrease in annual precipitation. As reported by [18], The monthly precipitation showed a downward trend at a rate of −19.8 mm/10a, −0.5 mm/10a, −11.3 mm/10a, and −3.6 mm/10a for July, August, September, and October, respectively, while temperature showed an increasing trend at a rate of 0.02˚C/10a, 0.02˚C /10a, 0.01˚C/10a and 0.01˚C/10a for July, August, September, and October, respectively. [19] found that Gedaref State had observed a significant increase in temperature offset by extreme variability in precipitation from 1941 to 2009.

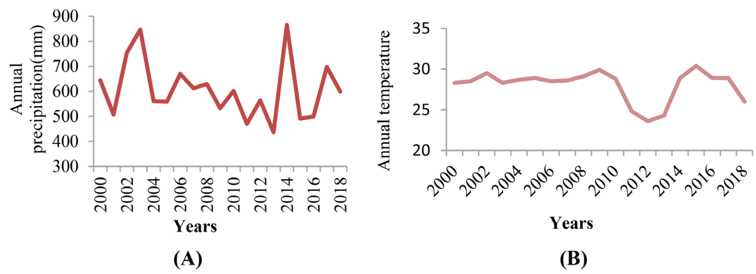

Figure 4. (A) Mean annual precipitation, and (B) Temperature in Gadarif State from 2000-2018.

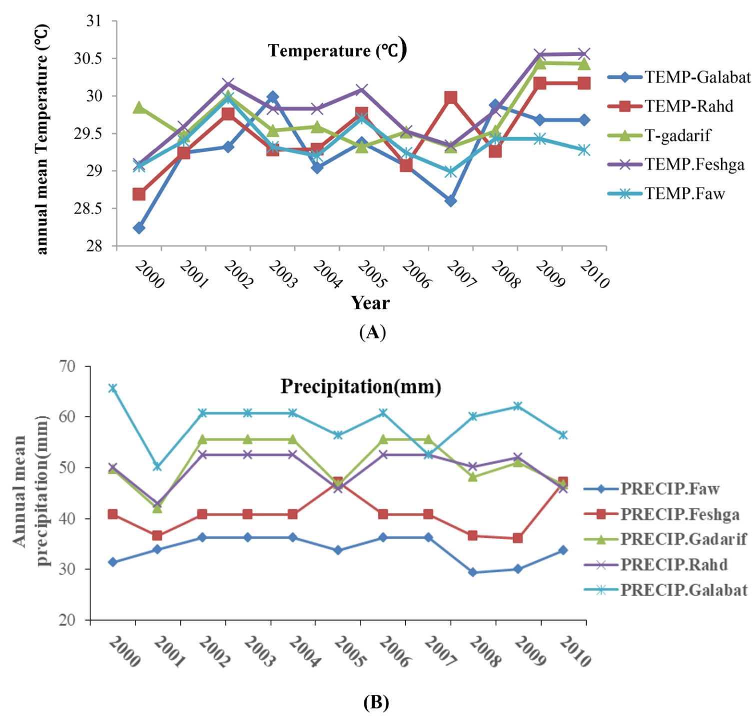

Figure 5. (A) Mean annual temperature, and (B) Precipitation, of the main areas in Gadarif State during 2000-2010.

3.4. The Relationship between NPP, Precipitation and Temperature in the Main Regions in Gadarif State

Significant variation trends are shown by the Determination coefficient R^2 values, which increase from the south to the north. The majority of the regions above have R2 values between −0.49 and −0.09, suggesting a somewhat negative relationship between NPP and temperature (Figure 6). The center and southern marginal counties contain a large number of regions with R^2 values less than −0.5; this could be due to the comparatively low temperatures in these southern and southeastern frontier areas (Figure 6). The research area's northern regions are home to places with R^2 values less than −0.49, likely due to the relatively consistent mean temperature in those locations. Weak negative correlations between NPP and rainfall are indicated by the R values, which are −0.04, −0.01, −0.06, and −0.05, dispersed in the Faw, Feshaga, Rahd, and Galabat, respectively (Table 1).

It is implied that there is a weakly negative association between NPP and rainfall by the fact that R^2 values are almost always between −0.09 and 0 (Figure 6). In contrast to other regions, the Southern Region experiences higher summer temperatures and the most rainfall, which results in drier winter conditions. Rainfall is a major factor in the growth of the vegetation in these places. For this reason, the R^2 values are less than −0.3 in certain regions. Regarding decreasing temperature, the southern and southeastern fringe counties are home to the R^2 values that are less than −0.09. This may be because these counties have an adequate amount of moisture all year round, so that rainfall does not inhibit the growth of vegetation there. The distribution of the R values in the Faw, Feshaga, Rahd, Galabat, and Gadarif, respectively, is −0.48, −0.43, −0.42, −0.65, and 0.28 (Table 1).

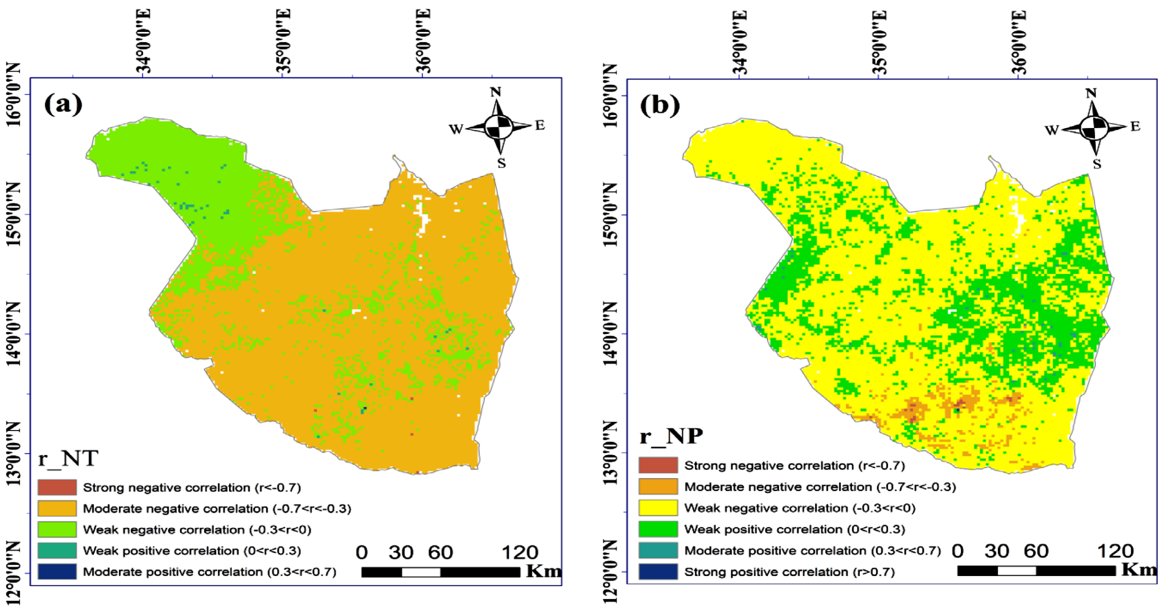

Figure 6. Relationship between NPP with (a) Temperature and (b) with Precipitation.

Table 1. Relationship between NPP, Temperature, and rainfall of the main areas in Gadarif State from 2000 to 2010.

area	Galabat	Rahd	Gadarif	Feshaga	Faw
R NT	−0.65	−0.42	0.28	−0.43	−0.48
R NP	−0.05	−0.06	−0.03	−0.01	−0.04

In contrast to NPP and rainfall, NPP and temperature show a larger declining fashion, suggesting that temperature has a greater influence on both NPP and vegetation growth.

Where R NT refers to Relationship between NPP with Temperature and R NP refer to Relationship between NPP with Precipitation.

4. Discussions

The research area is dominated by a semi-arid climate, which puts it at risk for desertification and land degradation. Crop breakdown hazards arise from the large distribution and temporal variations in precipitation. Farmers are motivated to remove trees by the high economic return that comes from cutting high-fertility forests and grasslands to cultivate crops on a wide scale. Among the factors contributing to deterioration that impacted the ecological balance, biodiversity, and soil were the growth of rain-fed mechanised farming operations, excessive firewood and charcoal chopping, traditional rain-fed agriculture, and overgrazing [20].

In order to prevent the degradation of plant cover, it is crucial, both practically and theoretically, to carefully evaluate the temporal and geographical variability of NPP and its reactions to climate changes. Numerous scholars evaluated the NPP in Gadarif State; nonetheless, there is still a significant lot of debate regarding the NPP's determinants. Growth of plants may be negatively or positively impacted by climate change [21]. Many research has been conducted to assess the response of NPP to climate variables by using three types of NPP; actual NPP, potential NPP, and human NPP [22] [23] [24]. In this study, we also evaluated NPP's reactions to climate variables using correlation coefficients and actual NPP trends. Because of shifting trends in temperature and precipitation, climate change is the main driver of NPP change in the study area. NPP variation reflects the NPP decreasing but vegetation changes areas just reflect vegetation scope. Therefore, assessing vegetation dynamics based on NPP variation and vegetation change areas may be useful to analyze the relationship between climate variables and desertification dynamics. Climate change (Annual total precipitation and mean annual temperature) has directly affected vegetation cover. This study presents the contribution of the two factors on NPP variations and a general picture of the vegetation dynamics in Eastern Sudan. The 1977 United Nations conference classified eastern Sudan as under threat of desertification. Eastern Sudan is considered one of the regions most affected by climate fluctuations in arid and semi-arid regions. It seems that the climatic conditions, in addition to the pattern of resource utilization, are greatly linked to desertification. The domination of the open grazing system of livestock raising, traditional agricultural practices, and traditional water distribution has contributed greatly to desertification. The desertification in this state seems to be more severe due to the above-mentioned reasons. Climate change affected vegetation mainly through temperature and precipitation changes, which further regulated photosynthesis, soil respiration, and growing status [25]. The slight and moderate vegetation reversion induced by climate variables occurred in Feshaga, Gadarif, and the southwest parts of the study area. The correlation between NPP and annual total precipitation is weakly negative in large areas of the study area (Faw, Rahd, Feshaga, and Galabat districts). Moreover, the annual variation in precipitation and temperatures in Gedaref State showed large fluctuations. By exchanging positive and negative anomalies, the periods of most negative precipitation were recorded in 2000 and 2002 (**Figure 5**). Wet years were also observed in 2002, 2003, 2006, and 2007. Likewise, temperature showed fluctuations with a generally increasing trend in 2007 and 2008 (**Figure 5**).

This study proved that the correlation analysis between NPP and climate variables (precipitation and temperature) gives a reliable result of NPP responses to climate variables that are very clear in full-time parts of Gedaref state.

5. Conclusion

The responses of vegetation NPP to climate variables from 2000 to 2010 were assessed in this study by using MODIS imagery, metrological data and observed survey data, NPP indicator. Annual mean Temperature was the principal influence, which resulted correlations coefficient between −0.09 to −0.49 in almost of the study area. This study provides that climate variables especially, annual mean temperature area moderately negative correlated with vegetation reversion in Gadarif State. Therefore, we recommend further studies in this area to identify variables that particularly affect the vegetation NPP, such as human and other activities and to distinguish between the relative roles of human activities and climate change in vegetation changes.

Conflicts of Interest

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

References

[1] Goudriaan, J. (1995) Global Carbon Cycle and Carbon Sequestration. In: Beran, M.A., Eds., *Carbon Sequestration in the Biosphere*, Springer-Verlag, Berlin, 3-18. https://doi.org/10.1007/978-3-642-79943-3_1

[2] Chen, C., Park, T., Wang, X.H., Piao, S.L., Xu, B.D., Chaturvedi, R.K., Fuchs, R., Brovkin, V., Ciais, P., Fensholt, R., Tømmervik, H., Bala, G., Zhu, C.C., Nemani, R.R. and Myneni, R.B. (2019) China and India Lead in Greening of the World through Land-Use Management. *Nature Sustainability*, **2**, 122-129. https://doi.org/10.1038/s41893-019-0220-7

[3] Liu, G., Sun, R., Xiao, Z.Q. and Cui, T.X. (2017) Analysis of Spatial and Temporal Variation of Net Primary Productivity and Climate Controls in China from 2001 to 2014. *Acta Ecologica Sinica*, **37**, 4936-4945.

[4] Govindasamy, B., Jaideep, J., Rajiv, K., Chaturvedi Hosahalli, V., Gangamani Hirofumi, H. and Rama, N. (2013) Trends and Variability of AVHRR-Derived NPP in India. *Remote Sensing*, **5**, 810-829. https://doi.org/10.3390/rs5020810

[5] Patel, N.R., Bhattacharjee, B., Mohammed, A.J., Priya, T. and Saha, S.K. (2006) Remote Sensing of Regional Yield Assessment of Wheat in Haryana, India. *International Journal of Remote Sensing*, **27**, 4071-4090. https://doi.org/10.1080/01431160500377188

[6] Fan, J., Shao, Q. and Liu, J. (2010) Assessment of Effects of Climate Change and Grazing Activity on Grassland Yield in the Three Rivers Headwaters Region of Qingha-Tibet Plateau, China. *Environmental Monitoring and Assessment*, **170**, 571-584. https://doi.org/10.1007/s10661-009-1258-1

[7] Amiro, B.D., Chen, J.M., and Liu, J. (2000) Net Primary Productivity Following Forest Fire for Canadian Ecoregions. *Canadian Journal of Forest Research*, **30**, 939-947. https://doi.org/10.1139/x00-025

[8] Milner, K.S., Running, S.W. and Coble, D.W. (1996) Biophysical Soil-Site Model for Estimating Potential Productivity of Forested Landscapes. *Canadian Journal of Forest Resources*, **26**, 1174-1186. https://doi.org/10.1139/x26-131

[9] Nemani, R.R., Charles, D., Hashimoto, K.H., Jolly, W.M., Piper, S.C. and Tucker, C.J. (2003) Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. *Science*, **300**, 1560-1563. https://doi.org/10.1126/science.1082750

[10] Wessels K.J., Prince S.D., Malherbe J., Small J., Frost P.E. and Van Zyl, D. (2007) Can Human Induced Land Desertification Be Distinguished from the Effects of Rainfall Variability? A Case Study in South Africa. *Journal of Arid Environments*, **68**, 271-297. https://doi.org/10.1016/j.jaridenv.2006.05.015

[11] Prince, S.D. and Goward, S.N. (1995) Global Primary Production: A Remote Sensing Approach. *Journal of Biogeography*, **22**, 815-835. https://doi.org/10.2307/2845983

[12] Knapp, A.K. and Smith, M.D. (2001) Variation among Biomes in Temporal Dynamics of Aboveground Primary Production. *Science*, **291**, 481-484. https://doi.org/10.1126/science.291.5503.481

[13] Elhag, M. (2006) Causes and Impact of Desertification in the Butana Area of Sudan. Ph.D. Thesis, University of the Free State, Bloemfontein.

[14] Aguilar, E., Barry, A.A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., Mbah, J., Mhanda, A., Nascimento, D.J., Peterson, T.C., Umba, O.T., Tomou, M., and Zhang, X. (2009) Changes in Temperature and Precipitation Extremes in Western Central Africa, Guinea Conakry, and Zimbabwe, 1955-2006. *Journal of Geophysical Research*, **114**, D02115. https://doi.org/10.1029/2008JD011010

[15] Choi, G., Collins, D., Ren, G., Trewin, B., Baldi, M., Fukuda, Y., Afzaal, M., Pianmana, T., Gomboluudev, P., Huong, P.T.T., Lias, N., Kwon, W.T., Boo, K.O., Cha, Y.M. and Zhou, Y. (2009) Changes in Means and Extreme Events of Temperature and Precipitation in the Asia Pacific Network Region, 1955-2007. *International Journal of Climatology*, **29**, 1906-1925. https://doi.org/10.1002/joc.1979

[16] Rehman, S. (2010) Temperature and Rainfall Variation over Dhahran, Saudi Arabia (1970-2006). *International Journal of Climatology*, **30**, 445-449. https://doi.org/10.1002/joc.1907

[17] Yagoub, Y.E., Li, Z.Q., Musa, O.S., Anjum, M.N., Wang, F.T. and Zhang, B. (2017) Investigation of Climate and Land Use Policy Change Impacts on Food Security in Eastern Sudan, Gadarif State. *Journal of Geographic Information System*, **9**, 546-557. https://doi.org/10.4236/jgis.2017.95034

[18] Sulieman, H.M. and Elagib, N.A. (2012) Implications of Climate, Land-Use and Land-Cover Changes for Pastoralism in Eastern Sudan. *Journal of Arid Environments*, **85**, 132-141. https://doi.org/10.1016/j.jaridenv.2012.05.001

[19] Elagib, N.A. and Elhaj, M.M. (2011) Major Climate Indicators of Ongoing Drought in Sudan. *Journal of Hydrology*, **409**, 612-625. https://doi.org/10.1016/j.jhydrol.2011.08.047

[20] Idreas, A.E.A. and Abdo Desougi, M. (2015) Potential Impact of Rain Fed Mechanized Farming and Shelter Belts Establishment on the Environment, Case Study Ghadambaliya, Gedaref, Sudan. *Journal of Natural Resources and Environmental Studies*, **33**, 36-43.

[21] Zheng, Y.R., Xie, Z.X., Robert, C., *et al.* (2006) Did Climate Drive Ecosystem Change and Induce Desertification in Otindag Sandy Land, China over the Past 40 Years? *Journal of Arid Environments*, **64**, 523-541. https://doi.org/10.1016/j.jaridenv.2005.06.007

[22] Zhang, C.X., Wang, X.M. and Li, J.C. (2011) Roles of Climate Changes and Human Interventions in Land Degradation: A Case Study by Net Primary Productivity Analysis in China's Shiyanghe Basin. *Environmental Earth Sciences*, **64**, 2183-2193. https://doi.org/10.1007/s12665-011-1046-4

[23] Zika, M. and Erb, K. (2009) The Global Loss of Net Primary Production Resulting from Human-Induced Soil Degradation in Dry Lands. *Ecological Economics*, **69**, 310-318. https://doi.org/10.1016/j.ecolecon.2009.06.014

[24] Jahelnabi, A.E., Zhao, J., Li, C., Fadoul, S.M., Shi, Y., Bsheer, A.K. and Yagoub, Y.E. (2016) Assessment of the Contribution of Climate Change and Human Activities to Desertification in Northern Kordufan-Province, Sudan Using Net Primary Productivity as an Indicator. *Contemporary Problems of Ecology*, **9**, 674-683. https://doi.org/10.1134/S1995425516060068

[25] Foley, J.A., Levis, S., Costa, M.H., Cramer, W. and Pollard, D. (2000) Incorporating Dynamic Vegetation Cover within Global Climate Models. *Ecological Applications*, **10**, 1620-1632. https://doi.org/10.1890/1051-0761(2000)010[1620:IDVCWG]2.0.CO;2