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IMPACTS OF CLIMATE CHANGE ON NET PRIMARY PRODUCTIVITY IN AFRICA CONTINENT FROM 2001 TO 2010

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Abstract: Terrestrial ecosystem is highly sensitive to the global climate change especially the changes in temperature and precipitation which are the dominant factors controlling plant growth. African continent is one of the most regions vulnerable to global climate change, rising the air temperature and changes in precipitation affect the continent net primary productivity NPP. Here, we used the Thornthwaite memorial model and Climatic Research Unit (CRU) climatic data to simulate the dynamic variations in terrestrial NPP of African ecosystems driven by climate factors during 2001–2010. The results indicate that: for annual climatic data, the main annual precipitation was positively correlated with mean annual NPP ($R^2$0.99), while the mean annual temperature was negatively correlated with mean annual NPP ($R^2$0.001). The mean annual precipitation and temperature show and increasing trend by 1.5mm/year and 0.01 respectively during 2001 to 2010. In regard to NPP, the Western and Central Africa, dominated by tropical forests, which the most productive regions and accounted for 50% of the carbon sequestered as NPP in Africa. Our results indicate that warmer and wetter climatic conditions have resulted in a significant increase in African terrestrial NPP during 2001–2010, with the largest contribution permanent wet land.

Keywords: Africa continent, net primary productivity and Thornthwaite memorial model.

Introduction

net primary productivity(NPP) has received more attention as an important 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 [6, 1]. NPP provides a measure of the production activity or growth of terrestrial vegetation. NPP represents the net new carbon stored as biomass in stems, leaves or roots of plants. It is the difference between the carbon assimilated by plant leaves during photosynthesis and carbon expended through respiration by leaves, stems and roots [46].

A number of studies have been conducted about the impact of climate change on NPP [29, 21, 7, 41, 49 and 17]. Nemani *et al.* [34] pointed out that climatic changes have eased multiple climatic constraints on plant growth, and have increased NPP over large regions of Earth.

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Knapp and Smith [22] found a significantly positive correlation between NPP and precipitation in their researches. Recently, threats to the terrestrial carbon cycle from climate variability, CO_2 fertilization, nitrogen deposition and human-controlled land use changes are increasingly gaining concern [38, 22]. Early studies [12, 28 and 29] stated that changes in patterns of terrestrial NPP are expected in response to the above mentioned factors, which emphasizes the need for assessing sensitivity of terrestrial vegetation to climate variability and natural and man induced disturbances [36]. Previous studies have predicted significant carbon loss to the atmosphere from vegetation changes in response to global warming [33, 40]. Regional and global patterns of NPP and their relation to mean climatic factors (mainly temperature and precipitation) have been described since the mid of last century [18, 37 and 24].

Africa is a continent increasingly recognized for its role in the global carbon cycle and has been identified as one of the region's most vulnerable to climate change and climate variability [8, 32 and 20]. Understanding the response of NPP to environmental changes in African ecosystems is particularly important because Africa is well known for its widespread poverty, slow economic growth, and agricultural systems, which are particularly sensitive to frequent and persistent droughts [44, 9].

Africa takes up about 20%of the earth's land surface, and also contains about 20%of all know n species of plants, mammals, and birds in the world, as well as one-sixth of amphibians and r eptiles (Siegfried, 1989). And at the same time Africa has the highest annual population growth rate in the world, at 2.3%in 2008 [43]. The population of Africa exceeded one billion inhabitants in 2009 [43]. Africa has the lowest Gross Domestic Product GDP of any continent and its economies rely mostly on natural resources, especially small-scale agriculture. In fact, 64% of people in sub- Saharan Africa are employed in the rural sector and an estimated 90% of the continent's population depends on rain-fed crop production and pastoralism to meet its basic food supplies [19, 35 and 43].

In this study we use Thornthwaite memorial model to simulate changes in NPP patterns as well as their response to climate factors in the African continent during 2001–2010. The climate factors include temperature and precipitation. The main objectives of this study are (1) to estimate the spatial patterns in terrestrial NPP in Africa, (2) to better understand mechanisms controlling spatial and temporal patterns of terrestrial NPP, (3) to assess the biome NPP response to changes in climate factors.

Material and methods

Study area

Africa is the world's second-largest and second-most-populous continent. At about 30.2 million km^2 (11.7 million sq mi) including adjacent islands, it covers 6% of the earth's total surface area and 20.4 % of the total land area. With 1.1 billion people as of 2013, it accounts for about 15% of the world's human population. The continent is surrounded by the Mediterranean Sea to the north, both the Suez Canal and the Red sea along the Sinai Peninsula to the northeast, the Indian Ocean to the southeast, and the Atlantic Ocean to the west (Figure 1).

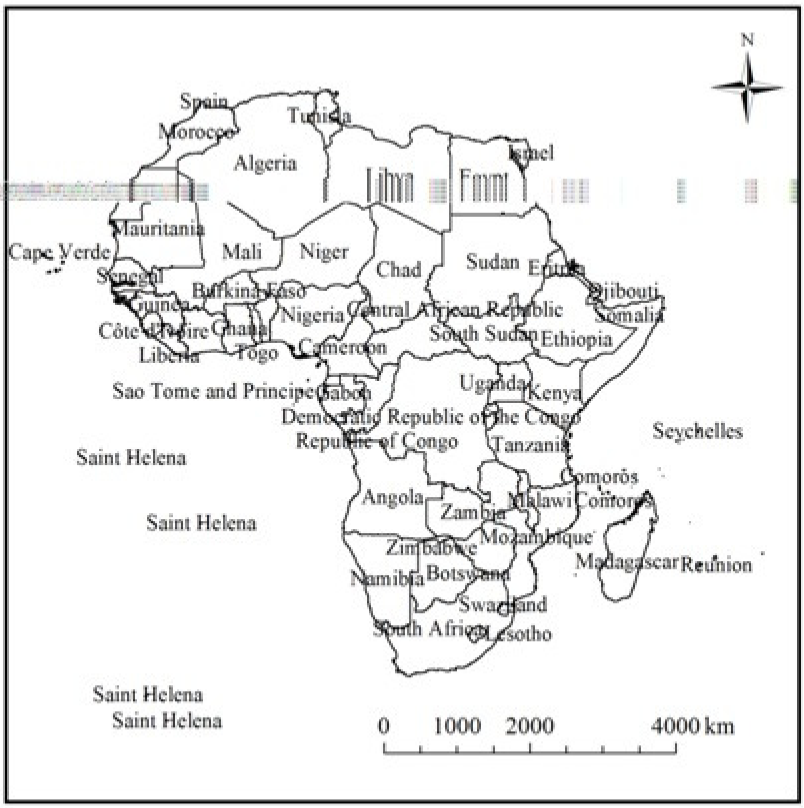

Figure 1: The study area

Climate

The climate of Africa ranges from tropical to subarctic on its highest peaks. Its northern half is primarily desert, or arid, while its central and southern areas contain both savanna plains and very dense jungle (rain forest) regions. In between, there is a convergence, where vegetation patterns such as Sahel and steppe dominate.

Temperature

Africa is hottest continent in the world. There is no excessive variation of temperature in the continent, and it lying almost entirely within tropics, and equator. The desert region and lower plains of North Africa, experienced great heat, removed by the great width of the continent from the influence of the ocean, thus the contrast between summer and winter, and between day and night is great. The moisture brought from the ocean modified the extent of the heat in the farther south portion of the continent, while in East Africa the range of temperature is wider than in the Congo basin or the Guinea coast, as the result of the greater elevation of a large part of surface. In extreme North and South the climate is a warm temperate, the northern countries as the whole hotter and drier than those in the southern part of the continent; the south part is narrower than the north part, the influence of surrounding ocean is more felt.

Precipitation

The continent rainfall is highly variable; it is range from less than 100 mm/year in the Sahara to 9.500mm/year in near mount Cameroon. Africa is the world's hottest continent, and the dry lands and desert cover about 60% of the land surface area. The main African deserts are (Kalahari, Sahara, and Namibia). The rainfall zones are, however, somewhat deflected from west to east direction, the drier northern condition extending south words along the coast, and those of south north words along the west. Within the equatorial zone cretin areas, especially on the shores of Gulf of Guinea and upper Nile basin, have intensified rainfall, with mean annual rainfall of about 9.906mm. Annually, the rainfall belt across the continent marches north word into sub-Saharan Africa by August, then moves back south word into south-central Africa by March [42].

Data source and processing

Monthly mean precipitation and monthly mean temperature data from the global climate dataset CRU TS v3.22 the climate research unit (CRU), (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_3.22), [16], was used in this study to estimate net primary productivity based Thornthwaite memorial model in African continent for the time period 2001 to 2010. It consists of multivariate mean monthly climatology records at 0.5° resolution for global land areas (excluding Antarctica) for the period 1901–2013. The CRU TS 3.22 data are monthly gridded fields based on monthly observational data, which are calculated from daily or sub-daily data by National Meteorological Services and other external agents. The CRU has contributed to the development of a number of the data sets widely used in climate research, including one of the global temperature records used to monitor the state of the climate system, as well as statistical software packages and climate models. In this study, temperature and precipitation were adopted as two elements of climatic data. Annual data was calculated from monthly data.

The MODIS land cover map **(MCD12Q1)** 2001 was derived from global land cover facility website http://glcf.umd.edu/data/lc/.

NPP estimation method

To simulate African continent net primary productivity in this study we used Thornthwaite memorial model, it was established based on the data used in Miami model but modified to include Thornthwaite's potential evaporation model [26]. In this study, we simulated potential NPP using the Thornthwaite memorial model, which is expressed as follows:

NPP= $3000(e^{-0.0009695(v-20)}$

Where NPP is the annual NPP ($gC\cdot m^{-2}\cdot yr^{-1}$), and V is the average annual actual evapotranspiration (mm). The calculated equations are expressed as:

$V=\frac{1.05r}{\sqrt{1+(1+\frac{1.05r}{l})2}}$

$L= 3000+25t+0.05t^3$

Where L is the annual average evapotranspiration (mm), r is the annual total precipitation (mm), and t is the annual average temperature (℃).

Correlation between NPP and climate factors

The Pearson correlation coefficient was employed to reflect the relationship between NPP and climate factors, including mean annual precipitation MAP and mean annual temperature MAT. The correlations between NPP and climate factors were obtained through the equation of correlative analysis, which is expressed as follows:

$$r = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) \div \sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 + (y_i - \bar{y})^2}$$

Where y_i refers to climate factors (including MAP (mm) and MAT (℃) in year i; and $\bar{y}$ represents the mean climate 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 [15].

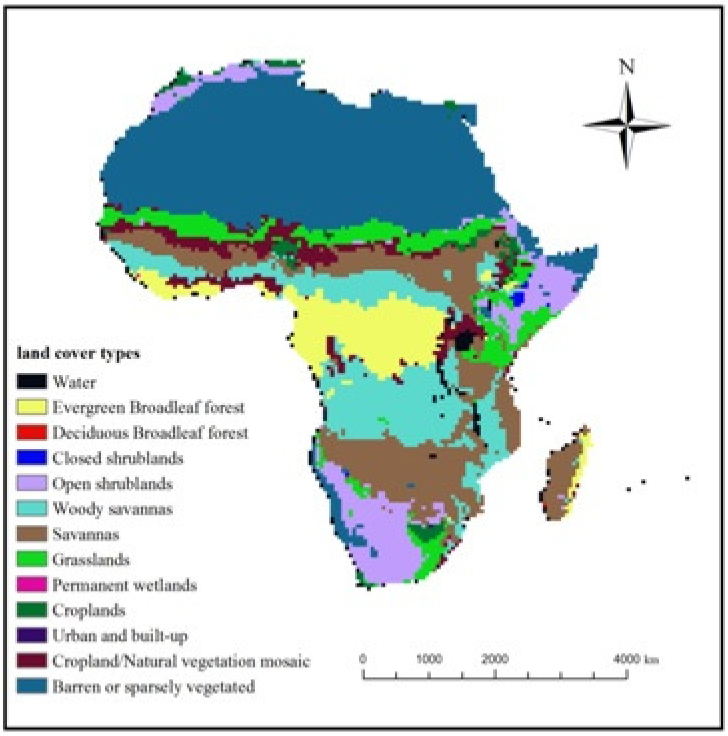

Figure 2: Africa continent land covers types

Results

Spatial variation of terrestrial NPP in Africa continent during 2001 to 2010

The annual pattern of NPP estimated by the Thornthwaite memorial model shows an increasing trend in mean annual NPP from 2616.58 in year 2001 to 2675.13 and 2674.58 in years 2002, 2007 respectively. Our results show substantial variation in terrestrial NPP (Figure 3). Regions such as Egypt, Libya, Algeria and Mauritania which situated in the northern part of the study area characterize by least productivity 0 – 200g $C.m^{-2}.yr^{-1}$, the northern part is dominate by desert and shrubs. While the regions like guinea, Liberia and Gabon, which located in the western part of the continent, and this part is dominated by forests, was most productive region with an NPP more than 2000g $C.m^{-2}.yr^{-1}$. In the central part of the continent we found regions with relatively high productivity such as democratic republic of Congo and Cameroon with NPP 1600-1800 g $C.m^{-2}.yr^{-1}$.

Across Africa, spatial patterns of NPP for each year show that the year 2005 was a year with relatively lower NPP, as the result of the decreasing in the mean annual precipitation in this year. The reduction in NPP in year 2005 was followed by recovery in NPP during 2007, when increased precipitations result in larger increase in NPP in most part of the continent. In addition, increasing the precipitation during the year 2002 resulted in the largest increase in

NPP across Africa. The year 2002 was a year where most of the Africans regions experienced the largest increase in NPP.

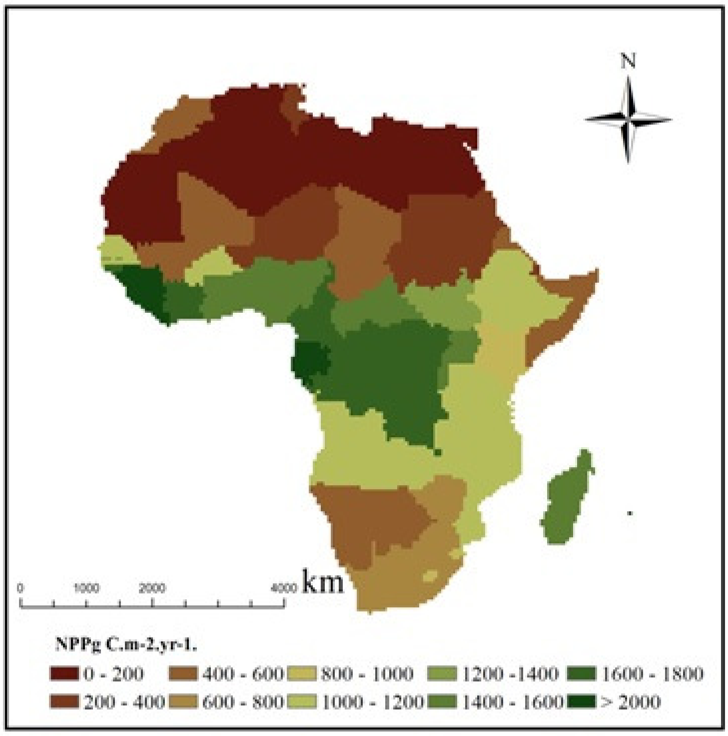

Figure 3: Spatial distribution of NPP in African continent from 2001 to 2010

Changes of climate factors during 2001–2010

Climate factors influence the ecosystem function and structure, mainly through temperature range and precipitation availability. According to our research air temperature shows an overall increasing trend by 0.01. The highest temperature occurred in 2001 and 2009, which exceeded the 10years mean by 0.04 and 0.02, respectively. Similarly, precipitation shows an increasing trend by 1.5mm/year. Precipitation in the Africa continent shows substantial inter-annual variation, with highest precipitation in years (2002, 2007 and 2010). Across Africa, the higher precipitation occurred mainly in western Africa (guinea, Sierra Leone, and Equatorial Guinea) and central Africa (democratic republic of Congo, Uganda and part of Burundi), while the lower precipitation mainly concentrated in northern Africa regions, specifically in the Sahara desert regions such as (Libya, Algeria, morocco and Mauritania), (Figure 4). Rainfall variability has become more significant over the last century. For instance, precipitation in Eastern Africa show a highly degree of spatial and temporal variability dominated by variety of physical processes. Report by Williams and funk [47] described that over the last 3 decades rainfall has decreased over eastern Africa. There will also be major changes in rainfall in terms of annual and seasonal trends, and extreme events of flood and drought. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean cost is approached.

In regard to temperature changes, (Figure 5) show that most of northern Africa, western Africa and central Africa had higher annual temperature (more than 28). Studies in the continent temperature revealed that, near surface air temperature anomalies in Africa were significantly higher for the period 1995–2010 compared to the period 1979–1994 [11]. The equatorial and southern parts of eastern Africa have experienced a significant increase in temperature since the beginning of the early 1980s [2]. Similarly, recent reports from the Famine Early Warning Systems Network (FEWS NET) indicate that there has been an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan, and Uganda over the last 50 years [13, 14]. In addition, warming of the near surface temperature and an increase in the frequency of extreme warm events has been observed for countries bordering the western Indian Ocean between 1961 and 2008 [45]. In recent decades, most of southern Africa has also experienced upward trends in annual mean, maximum, and minimum temperature over large extents of the sub region during the last half of the 20th century, with the most significant warming occurring during the last two decades [50, 11 and 23].

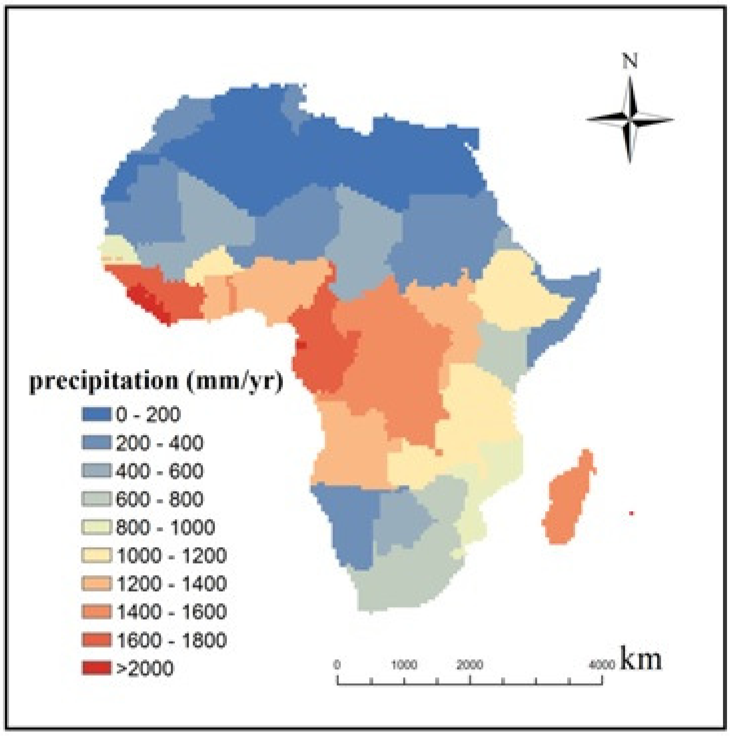

Figure 4: spatial patterns of average annual precipitation in Africa for the period 2001-2010

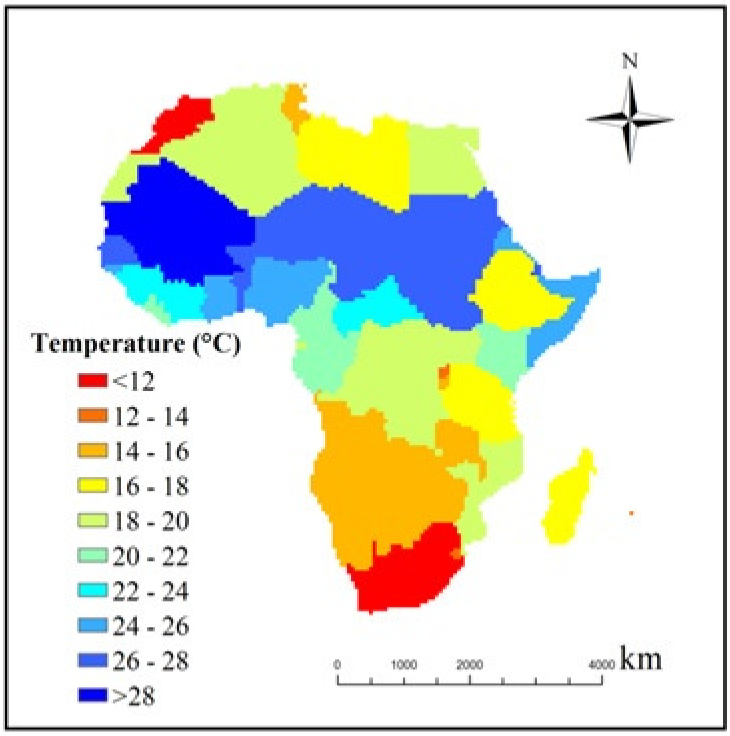

Figure 5: Spatial patterns of average annual temperature in Africa for the period 2001-2010

Variations in NPP of the Africa continent land cover types during 2001to 2010

Africa continent NPP generally increases from north to south and from dry to moist land cover types. The average annual NPP in Africa increased by 0.12 g $C.m^{-2}.yr^{-1}$, from (Table1) we can show that the permanent wetlands was the most productive land cover types, with mean annual NPP of 2266.9 g $C.m^{-2}.yr^{-1}$, followed by evergreen broadleaf forest and woody savannas with mean annual NPP of 1656.5 and 1399.5 g $C.m^{-2}.yr^{-1}$, respectively, That as the result of the changes in annual precipitation explaining 80, 75 and 65% of the variations, respectively. The deciduous broadleaf forest and barren or sparsely vegetation was the least productivity with mean annual NPP of 523.3 and 758.5 g $C.m^{-2}.yr^{-1}$, respectively. In this region's the inter-annual variability in the NPP primary controlled by water availability where mean annual precipitation in range between 0 and 200mm/year. Similarly the cropland had mean annual NPP of 845 g $C.m^{-2}.yr^{-1}$, where precipitation explain 50% of the variation while an increase in temperature had negative association.

Further our results show that the spatial variation in NPP differs among the 11 major land cover types. Dry land such as barren or sparsely vegetation and open shrub land had largest spatial variation in NPP, with a coefficient of variation of 11-13%. In contrast, permanent wet land had the smallest spatial variation, with a coefficient of variation of 3%. According to our results we conclude that, spatial variation of NPP within a land cover types is driven by variation in climate. Spatial variation in precipitation and temperature within and between the lands covers types were large, which results in the different in the coefficient of variation in NPP among the land cover types. The coefficient of variation in precipitation was large in barren or sparsely vegetation and open shrub, but small in permanent wet land.

Table 1 Net primary productivity for land cover types in Africa continent from 2001 to 2010

Land cover types	NPP (g $C.m^{-2}.yr^{-1}$)
Evergreen Broadleaf forest	1656.5
Deciduous Broadleaf forest	523.3
Closed shrub lands	864.7
Open shrub lands	777.5
Woody savannas	1399.5
Savannas	1189.4
Grasslands	990.8
Permanent wetlands	2266.9
Croplands	845
Cropland/Natural vegetation mosaic	1228.9
Barren or sparsely vegetated	758.5

Correlations between NPP and climate factors

Through the study time period positive correlation between NPP and MAP was observed R^2 0.99 (Figure 6). 90% of the Africa regions showed extremely significant correlation. Compared with other areas the western parts of the continent tend to be wetter in summer and drier in winter, lower temperature and higher rainfall. Vegetation growth in this area strongly depends on rainfall. The R value accordingly is 0.99. The R values below 0.99 are in northern and southern part of the study area. This could be because rainfall is not constraint to vegetation growth in these areas.

In contrast, the correlation between NPP and MAT (Figure7), R value in most areas are 0.001, indicating that the correlation between NPP and temperature is not significant. Those areas with R values below 0.001 are in the northern and southern parts of the study area, this maybe because the temperature in these areas is relatively constant.

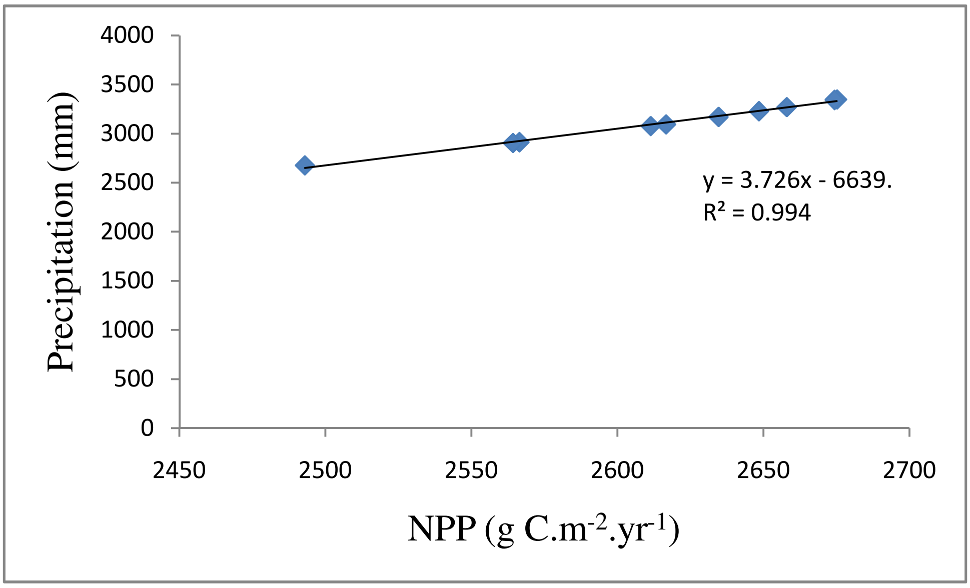

Figure 6: Effect of inter-annual variation in precipitation on African continent NPP during 2001–2010

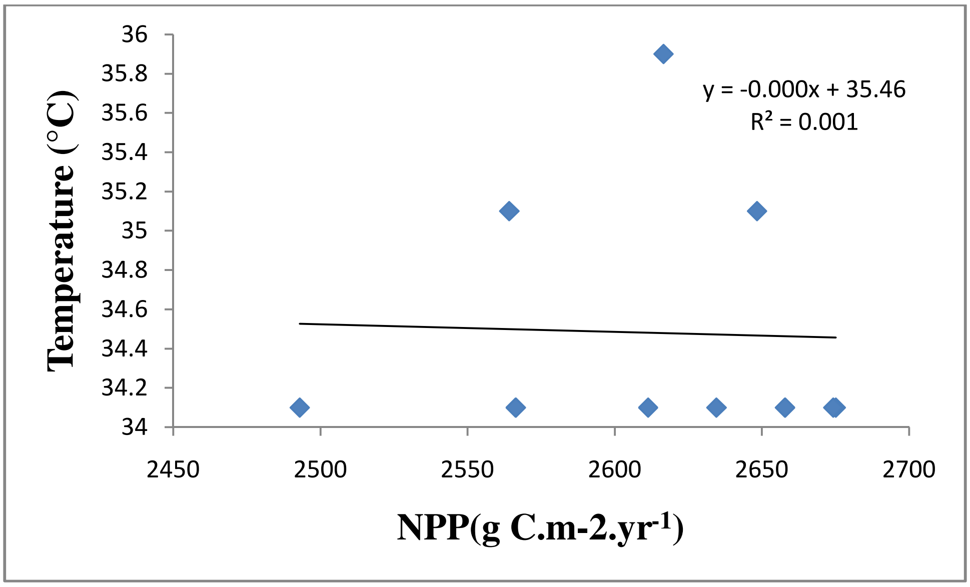

Figure 7: Effect of inter-annual variation in temperature on African continent NPP during 2001–2010

Claussen and Gayler (1997) and Brovkin et al. (1998), [10, 5] observed positive feedbacks between rainfall and vegetation in the Sahel/Sahara regions. Mohamed *et al*. [31] found large NPP declines in tropical regions due to greater impacts of drought, and higher sensitivity and weaker physiological adjustment to changes in precipitation pattern.

Disscusion

According to the analysis of climate data we found that both annual temperature and precipitation in Africa continent increased from 2001 to 2010. The rate of change in annual temperature 0.01, and the change rate in precipitation 1.5mm/year.

The average annual NPP in Africa increased by 0.12 g C.m^{-2}.yr^{-1}. the spatial distribution indicates that about 50% of the study area showed an increasing trend in NPP, which may be related to climate change. We also found precipitation is more positively correlated with NPP than temperature in Africa continent. The increase in precipitation is more beneficial to vegetation compared with increasing in temperature, because soil moisture rises, which enhances photosynthesis and as the result improve productivity. However, the situation is deferent for temperature, especially in dry area. Temperature not only influences photosynthesis and respiration, it also strengths evapotranspiration and reduces soil moisture [30, 4]. High temperature will give rise drought and will limit the growth of grasslands, leading to a downward trend in NPP [48].

The annual pattern of NPP estimated by the Thornthwaite memorial model shows an increasing trend in mean annual NPP from 2616.58 in year 2001 to 2675.13 and 2674.58 in years 2002, 2007 respectively. The upward trend in NPP is as the results of increasing precipitation.

Our results show an increasing trend in terrestrial NPP over the last 10 years. This increasing trend strongly related to those climatic factors (temperature and precipitation). The high NPP values in western and central part of the study area was related to high vegetation density and larger area of tropical forests that have high carbon density [27, 25]. However, in the northern portion of the study area, the vegetation is sparse and mainly consist of shrubs, grasses and crop lands, which characterize by low productivity compared with the forests.

Our results show that dry land such as barren or sparsely vegetation and open shrub land had largest spatial variation in NPP, with a coefficient of variation of 11-13%. Similar result was found by [3], which note, a decline in NPP was estimated for open shrub lands located in south-west United States and Alaska, which was probably caused by MAP decrease and MAT increase.

Temperature, radiation, and water interact to impose complex limitations on vegetation activity in different parts of the world, and ultimately determine the spatial and temporal NPP patterns [34]. However, these factors tend to be co-limiting, and differ in their contribution in different ecosystems.

Conclusions

In this study we used CRU climatic data and the Thornthwaite memorial model to estimate NPP for the Africa continent from 2001 to 2010 and to examine the correlation between climate factors and the spatial pattern in the NPP of the continent. And we successfully found a positive correlation between NPP and precipitation, while negative correlation was found between NPP and temperature.

Study the effect of climate factors on NPP is very importance for the region like Africa, where the climate change already affect the continent vegetation, and were most of the continent population rely on natural resource in their daily live as the source of income.

Net primary productivity reflects the ability of the vegetation to sequester the atmospheric carbon. African continent has a vast and dense rain forest and grass lands, this can make the content as major carbon sink.

The climate change is not the only one factor that affects the continent vegetation but also the human have a great impact, so farther research is needed in the effect of human on vegetation net primary productivity.

References

[1] Ahl DE, Gower ST, Mackay DS, Burrows SN, Norman JM, Diak GR (2004). Heterogeneity of light use efficiency in a northern Wisconsin forest: implications for modeling net primary production with remote sensing. Remote Sens. Environ. 93, 168–178.

[2] Anyah, R. O., and W. Qiu. (2012). Characteristic 20th and 21st century precipitation and temperature patterns and changes over the Greater Horn of Africa. International Journal of Climatology 32(3):347–363.

[3] Arguez, A., A.M. Waple, and A.M. Sanchez-Lugo, (2007): State of the Climate in 2006 Executive Summary. Publications, Agencies and Staff of the US Department of http://sandmc.pwv.gov.za/atlas/rain/ default.asp. (Accessed october 8, 2008)

[4] Brohan P, Kennedy JJ, Harris I *et al.*, (2006). Uncertainty estimates in regional and global observed temperature change: a new data set from 1850. *Journal of Geophysical Research-Atmospheres*, 111(D12). doi: 12110.11029/12005JD00 6548.

[5] Brovkin V., Claussen M., Petoukhov V., Ganopolski A., Journal of Geophysical Research 103 (1998) 31,613-31,624.

[6] Canadell JG, Mooney HA, Baldochi DD, Berry JA, Ehleringer JR, Field CB (2000). Carbon metabolism of the terrestrial biosphere: a multi-technique approach for improved understanding. Ecosystems 3, 115–130.

[7] Cao M K, Woodward F I, (1998). Dynamic responses of terrestrial ecosystem carbon cycling to global climate change. *Nature*, 393(6682): 249–252. doi: 10.1038/30460.

[8] Ciais, P., S. L. Piao, P. Cadule, P. Friedlingstein, and A. Che´din. (2009). Variability and recent trends in the African terrestrial carbon balance. Biogeosciences 6(9):1935–1948.

[9] Cilliers, J. (2009). Climate change, population pressure and conflict in Africa. Paper 178. Institute for Security Studies, Tshwane, South Africa.

[10] Claussen M., Gayler V (1997). Global Ecology and Biogeography Letters 6, 369-377.

[11] Collins, J.M., (2011): Temperature variability over Africa .Journal of Climate, 24(14), 3649-3666. doi: 10.1126/science.1082750.

[12] Eamus D, Jarvis PG(1989). The direct effects of increase in global atmospheric CO_2 concentration on natural and commercial temperate trees and forests. Adv Ecol Res; 19:1– 55.

[13] Funk, C., G. Eilerts, J. Verdin, J. Rowland, and M. Marshall, (2011): A Climate Trend Analysis of Sudan.USGS Fact Sheet 2011-3072,U.S.Department ofthe Interior U.S. Geological Survey (USGS), Reston, VA, USA, 6 pp.

[14] Funk, C., J. Michaelsen, and M. Marshall, (2012): Mapping recent decadal climate variations in precipitation and temperature across Eastern Africa and the Sahel. In: Remote Sensing of Drought: Innovative Monitoring Approaches [Wardlow, B.D., M.C. Anderson, and J.P. Verdin (eds.)]. CRC Press, Boca Raton, FL, USA, pp. 331-358.

[15] Gao QZ, Li Y, Wan YF, Qin XB, Jiangcun WZ, et al. (2009) Dynamics of alpine grassland NPP and its response to climate change in Northern Tibet. Climatic Change 97: 515–528.

[16] Harris, I., Jones, P.D., Osborn, T.J. and Lister, D.H. (2014). Up dated high-resolution grids of monthly climatic observations the CRU TS3.10 Dataset. Int. J. Climatol., 34: 623 642. doi: 10.1002/joc.3711.

[17] Hicke J A, Asner G P, Randerson J T *et al.*, (2002). Trends in North American net primary productivity derived from satellite observations, 1982–1999. *Global Biogeochemical Cycles*, 16 (2): 1–14. doi: 10.1029/2001GB001550.

[18] Holdridge L.R., *Science* **105** (1947) 367-368.

[19] IFAD: Rural Poverty Report (2001). The Challenge of Ending Rural Poverty, International Fund for Agricultural Development, Rome, 266 pp., 2001.

[20] IPCC. (2014). The physical science basis: Working Group I contribution to the IPCC Fifth Assessment Report. Cambridge University Press, Cambridge UK.

[21] Keeling RF, Piper SC, Heimann M (1996). Global and hemispheric CO_2 sinks deduced from changes in atmospheric CO_2 concentration. Nature; 381:218– 21.

[22] Knapp A K, Smith M D, (2001). Variation among biomes in temporal dynamics of above ground primary production. *Science*, 291(5503): 481–484. doi: 10.1126/science.291.5503.481.

[23] Kruger, A.C. and S.S. Sekele, (2012): Trendsin extreme temperature indicesin South Africa: 1962-2009. International Journal of Climatology, 33(3), 661-676.

[24] Leith, H., (1975). Modeling the primary productivity of the world. In: Primary Productivity of the Biosphere (H. Leith and R. H. Whittaker, Eds.), Springer-Verlag, Berlin and New York. pp. 237-263.

[25] Lewis, S.L. (2006). Tropical forests and the changing earth system. Philosophical Transactions of the Royal Society B 361(1465):195–210.

[26] Lieth, H., Box, E., 1972. Evapotranspiration and primary productivity. Publ. Climatol. 25, 37–46.

[27] Malhi, Y., and J. Grace. (2000). Tropical forests and atmospheric carbon dioxide. Trends in Ecology and Evolution 15(8):332– 337.

[28] McGuire AD, Joyce LA, Kicklighter DW, Melillo JM, Esser G, Vorosmarty CJ (1993). Productivity responses of climax temperate forests to elevated temperature and carbon dioxide: a North American comparison between two global models. Climatic Change; 24:287– 310.

[29] Melillo J M, McGuire A D, Kicklighter D W *et al.*, (1993). Global climate change and terrestrial net primary production. *Nature*, 363(6426): 234–240. doi: 10.1038/363234a0.

[30] Miyashita K, Tanakamaru S, Maitani T *et al.*, (2005). Recovery responses of photosynthesis, transpiration, and stomatal conductance in kidney bean following drought stress. *Environmental and Experimental Botany*, 53(2): 205–214. doi: 10. 1016/j.envexpbot.2004.03.015.

[31] Mohamed, M., I. S. Babiker, Z. Chen, K. Ikeda, K. Ohta, and K. Kato. (2004). The role of climate variability in the inter-annual variation of terrestrial net primary production (NPP). Science of the Total Environment 332(1):123–137.

[32] Mu¨ ller, C., W. Cramer, W.L. Hare, and H. Lotze-Campen. (2011). Climate change risks for African agriculture. Proceedings of the National Academy of Sciences 108(11):4313–4315.

[33] Neilson RP (1993). Vegetation redistribution: a possible biosphere source of CO_2 during climatic change. Water Air Soil Poll; 70(1– 4):659– 73.

[34] Nemani RR, Keeling C D, Hashimoto H *et al.*, (2003). Climate- driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, 300(5625): 1560–1563.

[35] Patt, A.G. and Winkler, J. (2007). Applying Climate Information in Africa: An Assessment of Current Knowledge, Written in support of NOAA, Boston University and the International Institute for Ap- plied Systems Analysis (IIASA).

[36] Peng C, Apps MJ (1999). Modelling the response of net primary productivity (NPP) of boreal forest ecosystems to changes in climate and fire disturbance regimes. Ecol Model;122:175–93.

[37] Rosenzweig ML (1968). Net primary productivity of terrestrial communities: prediction from climatological data. Am Nat; 102(923):67– 74.

[38] Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M,Wall DH (2000). Global biodiversity scenarios for the year 2100. Science; 287(5459):1770–4.

[39] Siegfried, W.R. (1989). Preservation of species in southern African nature reserves. In: Biotic Diversity in Southern Africa: Concepts and Conservation [Huntley, B.J. (ed.)]. Oxford University Press.

[40] Smith TM, Shugart HH (1993). The transient response of terrestrial carbon storage to a perturbed climate. Nature; 361:523–6.

[41] Tian H, Melillo J M, Kicklighter D W *et al.*, (1999). The sensitivity of terrestrial carbon storage to historical climate variability and atmospheric CO2 in the United States. *Tellus*, 51(2): 414–452. doi: 10.1034/j.1600-0889.1999.00021.x.

[42] Todd Mitchell (October 2001). *Africa Rainfall Climatology*. *University of Washington*. Ret Atlantic Oceanographic and Meteorological Laboratory, Hurricane Research Division. "Frequently Asked Questions: What is an easterly wave?" NOAA. Retrieved 2006-07-25.

[43] UN Department of Economic and Social Affairs, United Nations Population Division, World Population Prospects: The 2010 Re- vision, http://esa.un.org/unpd/wpp/index.htm, 2011.

[44] United Nations. (2002). The least developed countries report 2002: escaping the poverty trap. United Nations Conference on Trade and Development, Geneva, Switzerland.

[45] Vincent, L.A., E. Aguilar, M. Saindou, A.F. Hassane, G. Jumaux, D. Roy, P. Booneeady, R. Virasami, L.Y.A. Randriamarolaza, F.R. Faniriantsoa, V.Amelie, H. Seeward and B. Montfraix, (2011b): Observed trends in indices of daily and extrem temperature and precipitation for the countries of the western Indian Ocean, 1961-2008. Journal of Geophysical Research D: Atmospheres, 116(D10), D10108, doi:10.1029/2010JD015303.

[46] Waring and Running, (1998). R.H. Waring and S. W. Running: Forest ecosystem, Analysis at multiple scales. San Diego, California, Academic Press, Inc, pp. 370.

[47] Williams, A.P. and C. Funk, (2011): A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. Climate Dynamics, 37(11-12), 2417-2435.

[48] Zha Y, Gao J, Zhang Y, (2005). Grassland productivity in an alpine environment in response to climate change. *Area*, 37(3): 332–340. doi: 10.1111/j.1475-4762.2005.00637.x.

[49] Zhou L M, Tucker C J, Kaufmann R K *et al*., (2001). Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical.*

[50] Zhou, L., R.E. Dickinson, A. Dai, and P. Dirmeyer, (2010): Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999: comparingmulti-modelsimulationswith observations. Climate Dynamics, 35(7), 1289-1307.