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CLASSIFICATION AND NET PRIMARY PRODUCTIVITY OF THE AFRICA CONTINENT POTENTIAL NATURAL VEGETATION FROM 1981 TO 2013

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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 factor controlling plant growth. Africa continent is one of the most regions vulnerable to global climate change, rising the air temperature and changes in precipitation affect the continent potential natural vegetation PNV types and distribution. In this study we used CRU TS v3.22 datasets and geographic information system (GIS) software to simulate the distribution of PNV of Africa continent based on the comprehensive and sequential classification system approach CSCS for the time period 1981 to 2013. The result showed that; African continent had 8 broad PNV categories namely; Savanna, Semi-desert, steppe, sub-tropical forest, temperate forest, temperate grassland, tropical forest, and warm desert. In regard to the net primary productivity NPP Thornthwaite memorial model was used in this study to estimate the potential NPP. The result showed; the tropical forest is the highly productive with mean NPP 2073.85 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$, while the sub-tropical forest, temperate forest and savanna show relatively highly productivity of 1733.2 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$, 1358 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$ and 1087.5 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$ respectively. The least productive class was warm desert with mean NPP 627.7 $g\cdot C\cdot m^{-2}\cdot yr^{-1}$.

Keyword: Potential natural vegetation, comprehensive and sequential classification system approach, African continent, net primary productivity and Thornthwaite memorial model.

Introduction

Climate – vegetation interaction studies is one of the hottest issues in recent scientific research worldwide. Climate determines the types and distribution of vegetation; at same time vegetation is a direct indictor of climate change (Matthews 1983; Gu *et al.*, 2007). The main climate factors that have a direct impact on vegetation are temperature and precipitation, for e.g.; Rainfall is a key element that determines relevant parameters of the vegetation such as its distribution (Woodward and Williams, 1987), diversity (Pauses and Austin, 2001),

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functionality (Holbrook *et al*., 1995) and structure (Williams and Albertson, 2006). The interaction between climate factors and vegetation is crucial for ecosystem health, since plants develop and maintain feedback processes with the environmental factors that drive the ecosystem processes and hence its stability (Chapin, 2003). The vegetation can be grown naturally in their ecosystems without human interface (potential natural vegetation), but in the reality humans have significantly modified the terrestrial environment, intensively replacing natural ecosystems by croplands (Ramankutty and Foley, 1998). Consequently, the vegetation distribution for a large part is the result of human intervention. Tuxen, (1956) defined the potential natural vegetation PNV as the vegetation that would become established if all successional sequences were completed without major natural or direct human disturbances under present climatic, edaphic, and topographic condition. Potential vegetation is considering as the reference point or context for describing successional relationships and correlations between the vegetation and environment (Henderson et al. 1992). Simulating the PNV is hottest issue in the scientific research and it gain more attention in recent years, several models were used to simulate the PNV most of these models used temperature and precipitation as an input parameters. In this study comprehensive sequential classification system CSCS was used to simulate the potential natural vegetation of the Africa continent and their distribution. The Comprehensive and Sequential classification System (CSCS) (Ren 1959) is a vegetation classification method based on bioclimatic data and differs from other vegetation models in the world. This system can comprehensively, systematically and evenly classify the global terrestrial vegetation. In particular, the grassland vegetation which accounting for a quarter of the global land area can be classified by the CSCS approach in great detail (Liang *et al*. 2012).

Net primary productivity for the potential natural vegetation is basic component in the studying of the global carbon cycle. Carbon balance studies and the understanding of factors controlling carbon fluxes, as well as their spatial and temporal variation, are key features of recent research relating to climate change (Scheme *et al*., 2001, Galantine *et al*., 2012). Vegetation net primary productivity is the one of the most importance component of the global carbon cycle, especially with the global increasing in temperature and high concentration of CO_2.

By estimating vegetation NPP we can determine how much of carbon can be stored in vegetation (carbon sinks), and how much of carbon that can be burning by vegetation respiration (carbon source). NPP provide information on vegetation characteristic, forest production, crop yields and range land forage, which have a great impact on economic of the global inhabitants. For instance the data about forest products are importance for forest harvest and monitor and preserve forest. From an ecological perspective, NPP measures the rate at which solar energy is stored by plants as organic matter, and is therefore a measure of the rate at which solar energy is captured and made available to the rest of the food chain (Odum, 1976). It provides a link between the biosphere and the climate system through the global cycling of carbon, water and nutrients (Roy et al., 2001).

Study the PNV and their net primary productivity is prerequisite for future planning in region like Africa which already affected by the global climate change and where the population are totally depend on the natural resources in their daily live.

With the advancement of studies of global change and terrestrial ecosystems, the estimation of NPP of natural vegetation with modeling, especially with remote sensing data, and the responses of NPP to global change locally and regionally have been one of the most important aspects in Climate-vegetation relationship studies (Zhang et al. 2002).

Materials and Methods

Study area

Africa (Figure 1) 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.

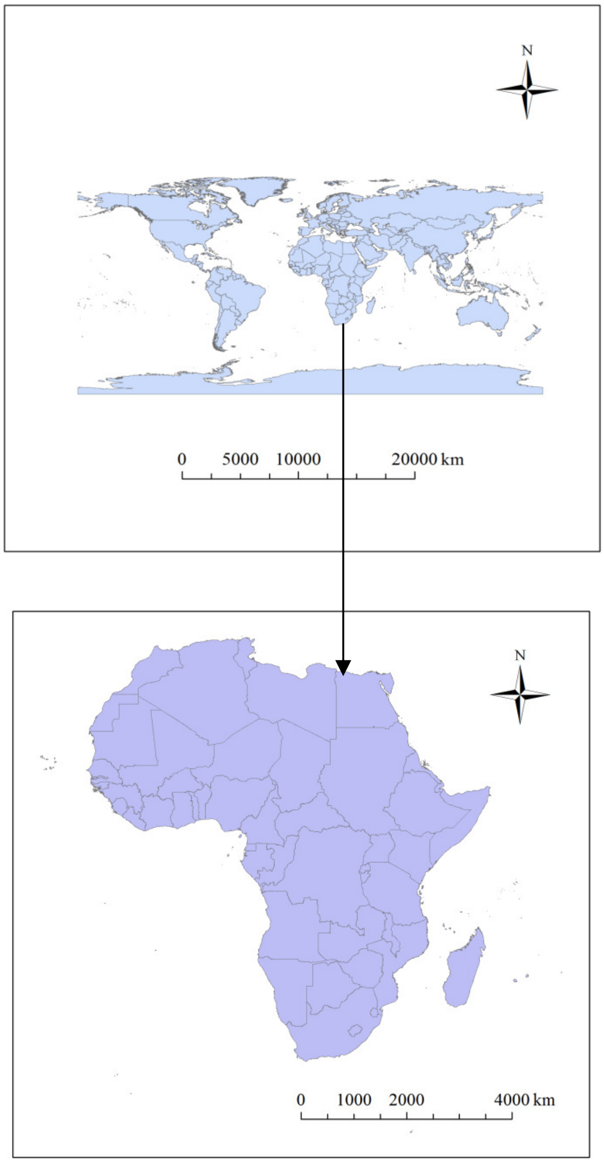

Figure 1 location of the study area

Climatic data

In this study, the global climate dataset CRU_TS 2.1 from the climate research unit (CRU) (climate dataset CRU TS v3.22 the climate research unit (CRU), (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_3.22), (Harris *et al*. 2014) was employed in the CSCS to generate Africa PNV maps and in the Thornthwaite memorial model to estimate NPP. The dataset of grids extends from 1901 to 2013, covers the global land surface (excluding Antarctica) at 0.5° resolution, and provides best estimates of month-by-month variations in climate variables. The mean annual temperature (MAT) and mean annual precipitation (MAP) data from the period 1981to 2013 were incorporated from monthly grid data using ArcGIS virsion10 software (ESRI, Redlands, CA, USA).

The CSCS approach for mapping potential natural vegetation

The CSCS approach is formulated through grouping or clustering units with similar properties of moisture and temperature (Ren *et al*., 2008). The CSCS consists of three-class level: Class, Subclass and Type. At the first level, vegetation is grouped into classes according to an index of moisture and temperature. At the second level, vegetation subclasses are differentiated by the edaphic conditions. At the third level, vegetation types within a subclass are distinguished by vegetation characteristics.

The class level is the basic unit, which is identified according to characteristics of zonal biological climate. In practice, the class is determined by combining quantitative biological climate indices of average annual cumulative temperature above 0°C ($\Sigma\theta$) (i.e. Growing Degree-Days on 0°C base, GDD0) and humidity (K), calculated by (Hu and Gao 1995);

$K = MAP / (0.1\times \Sigma\theta) = MAP / (0.1\times GDD0)$

Where MAP is the mean annual precipitation (mm); and 0.1 is an adjusted coefficient of the model.

Based on decades of studies (Ren 1959; Ren *et al*. 1965, 1980; Hu and Gao 1995; Liang *et al*. 2001), seven thermal zones and six humidity zones (Figure 2) have been identified and used to differentiate vegetation classes. The CSCS recognizes 42 vegetation classes (Table 1). To more explicitly reflect the spatial distribution of potential vegetation at a large scale, classes are merged into 10 broad vegetation categories (Table 2). In this study, the accumulative temperature above 0°C ($\Sigma\theta$) and mean annual precipitation (MAP) data in the period 1980 to 2013 were incorporated from monthly grid data using Arc GIS virsion10 software, and generate the daily accumulative temperature maps and mean annual precipitation maps, to simulate the PNV distribution maps according to CSCS approach.

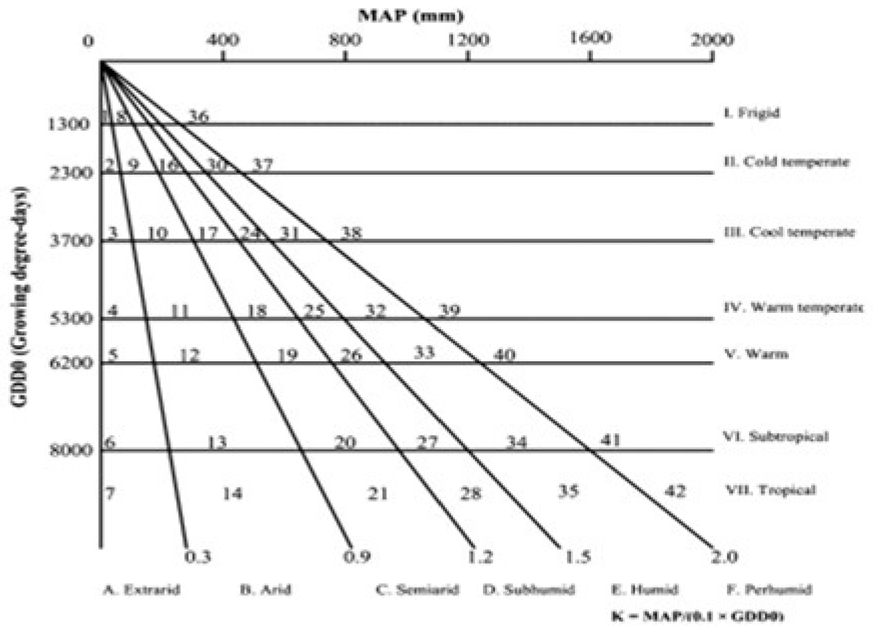

Figure 2 Index chart for potential vegetation class (refer to Table 1) in the CSCS-derived model (Ren *et al*. 2008).

Table 1: the PNV classes recognized by the CSCS approach

Class-ID	code	Thermal grade	Humidity	Class name
IA1	1	frigid	extrarid	frigid desert, alpine desert
IIA2	2	cold temperate	extrarid	montane desert
IIIA3	3	cool temperate	extrarid	temperate desert
IVA4	4	warm temperate	extrarid	warm temperate desert
VA5	5	warm	extrarid	subtropical desert i
VIA6	6	subtropical	extrarid	subtropical desert ii
VIIA7	7	tropical	extrarid	tropical desert
IB8	8	frigid	arid	frigid semidesert, alpine semidesert
IIB9	9	cold temperate	arid	montane semidesert
IIIB10	10	cool temperate	arid	temperate semidesert
IVB11	11	warm temperate	arid	warm temperate semidesert
VB12	12	warm	arid	subtropical semidesert
VIB13	13	subtropical	arid	subtropical desert brush
VIIB14	14	tropical	arid	tropical desert brush
IC15	15	frigid	semiarid	dry tundra, alpine steppe
IIC16	16	cold temperate	semiarid	montane steppe
IIIC17	17	cool temperate	semiarid	temperate typical steppe
IVC18	18	warm temperate	semiarid	warm temperate typical steppe
VC19	19	warm	semiarid	subtropical grasses-fruticous steppe
VIC20	20	subtropical	semiarid	subtropical brush steppe
VIIC21	21	tropical	semiarid	savanna
ID22	22	frigid	subhumid	moist tundra, alpine meadow steppe

IID23	23	cold temperate	subhumid	montane meadow steppe
IIID24	24	cool temperate	subhumid	meadow steppe
IVD25	25	warm temperate	subhumid	forest steppe
VD26	26	warm	subhumid	deciduous broad leaved forest i
VID27	27	subtropical	subhumid	sclerophyllous forest
VIID28	28	tropical	subhumid	xerophytic forest
IE29	29	frigid	humid	tundra, alpine meadow
IIE30	30	cold temperate	humid	montane meadow
IIIE31	31	cool temperate	humid	forest steppe, deciduous broad leaved forest
IVE32	32	warm temperate	humid	deciduous broad leaved forest ii
VE33	33	warm	humid	evergreen deciduous broad leaved forest
VIE34	34	subtropical	humid	evergreen broad leaved forest i
VIIE35	35	tropical	humid	seasonal rain forest
IF36	36	frigid	perhumid	rain tundra, alpine meadow
IIF37	37	cold temperate	perhumid	perhumid taiga forest
IIIF38	38	cool temperate	perhumid	mixed coniferous broad leaved forest
IVF39	39	warm temperate	perhumid	deciduous broad leaved forest iii
VF40	40	warm	perhumid	deciduous-evergreen broad leaved forest
VIF41	41	subtropical	perhumid	evergreen broad leaved forest ii
VIIF42	42	tropical	perhumid	rain forest

Table 2 the PNV classes recognized by the CSCS approach

Code	> 0 Annual cumulative temperature (GDD0)	Humidity (K)	Broad vegetation name	Corresponding class code
1	0–1300	>0	tundra and alpine	1, 8, 15, 22, 29, 36
2	1300–5300	0–0.3	steppe	2, 3, 4
3	1300–6200	0.3–0.9	frigid desert	9, 10, 11, 12
4	1300–6200	0.9–1.2	semi-desert	16, 17 ,18 ,19
5	1300–3700	1.2–2.0	steppe	23, 24, 30
6	1300–5300	>1.2	temperate humid	25, 31, 32 ,37, 38, 39
7	5300–8000	>1.2	grassland	26, 27, 33, 34, 40, 41
8	>8000	>1.5	temperate forest	28, 35, 42
9	>5300	0–0.3	sub-tropical forest	5, 6, 7
10	>6200	0.3–1.5	tropical forest	13, 14, 20, 21
			warm desert	
			savanna	

NPP model

To estimate Africa continent net primary productivity we used Thornthwaite memorial model, it was established based on the data used in Miami model but modified to include Thornthwaite potential evaporation model (Lieth and Box, 1972). 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 (g Cm_2 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 (C).

By using the GIS software virsion10, the NPP was calculated according to Thornthwaite memorial model. Every PNV categories shape file was extracted (by using spatial analysis tools_ extract by mask) to calculate the NPP value for each PNV categories.

Result and discussion

Spatial distribution pattern of hydro-thermal conditions in Africa continent

Growing degree-days (GDD) are often used as surrogate to represent the length and thermal properties of the growing season (Cramer and Solomon, 1993). A sufficient amount of heat during the growing season is required to drive photosynthesis reactions (Bonan, 2002). The responses function for GDD was designed to simulate these physiological constraints and is prescribed as a sigmoid curve, as suggested by a preliminary analysis of GDD versus NPP.

Figure 3 showed the spatial distribution of Σθ of the Africa continent (based on CSCS approach) for the time period 1981 to 2013. It showed a latitudinal zonality of Σθ, increasing gradually from north to south. It was found that Σθ in the far north portion of the study area range between 2300 to 3700°C, while it more than 8000°C in the most of the study area. In southern part the accumulative temperatures range between 6200 to800°C.

On the ArcGIS 10 platform, the distribution map of humidity index in Africa continent from 1981 to 2013 was formed according to the relevant theory and formula of the CSCS approach (Figure 4) It was found that there existed some variations in the humidity index (K) of the study area. The K value in northern part was the lowest, generally between 0 and 0.3. The K value ranged from 1.2 to 1.5 in central portion. The K value in most part of middle and Eastern part turned out to be more than 2, and was generally in a range between 1.5 and 2. The reasons for the differences of K value might be related to larger area, complicated topography, altitude, unbalanced precipitation in Africa continent.

Increase the temperature affecting the precipitation distributions, and resulting in PNV change classes. Change in humidity distribution has a direct effect on vegetation productivity associated with changes in available soil moisture.

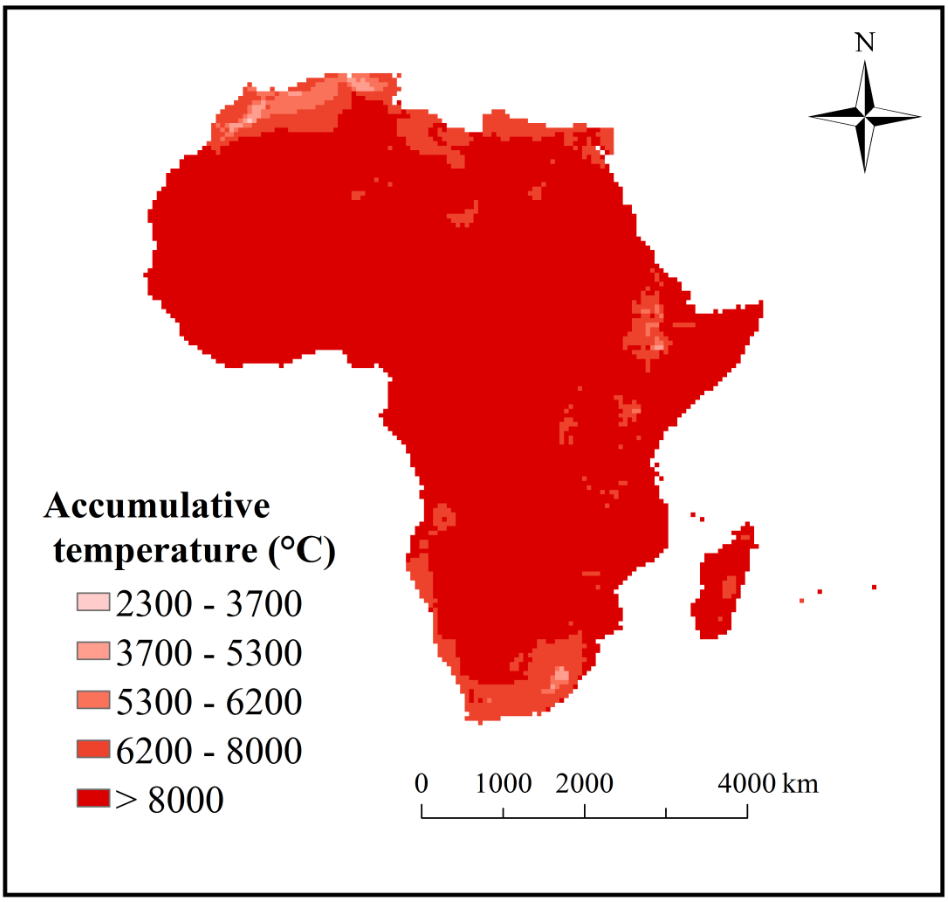

Figure 3 The distribution of the annual accumulated temperature above 0°C from 1981 to 2013 in Africa continent.

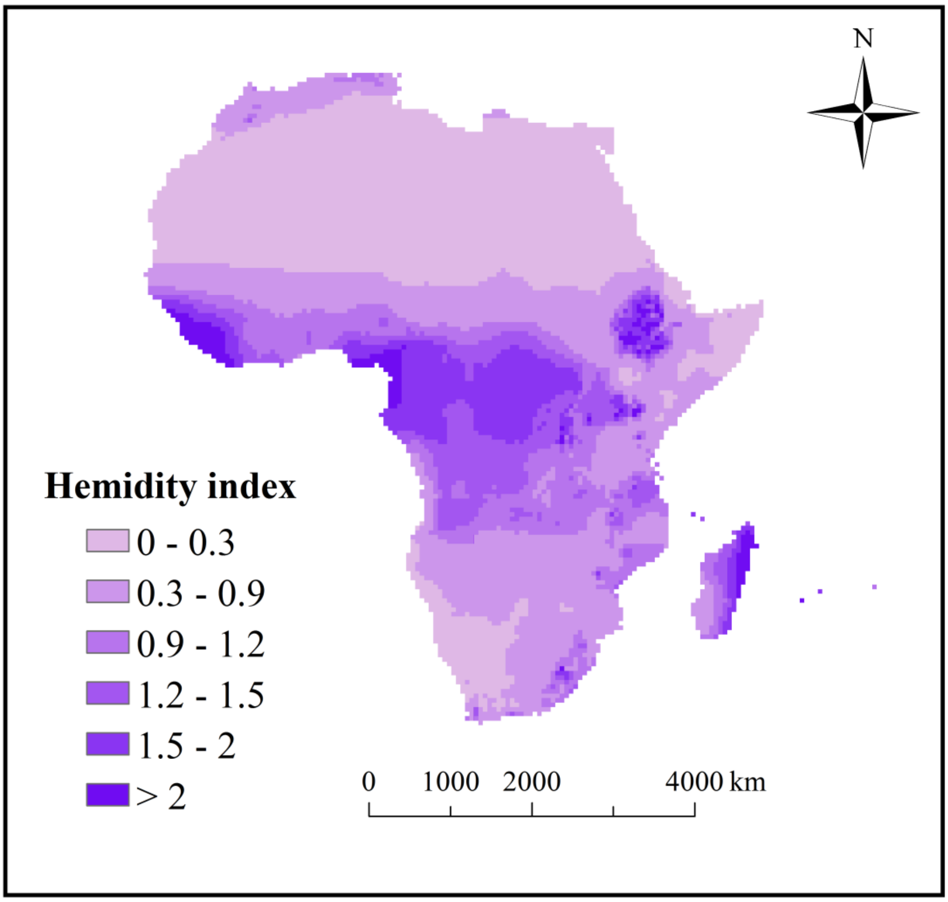

Figure 4 The distribution of humidity index (K) from 1981 to 2013 in Africa continent.

The potential natural vegetation and their spatial characteristics

The map of Africa continent's potential natural vegetation classes was drawn using the CSCS approach and the data set of annual precipitation and accumulated temperature from 1981 to 2013(Figure 5). It was found that there were 8 broad PNV classes in Africa continent, namely, Savanna, Semi-desert, steppe, sub-tropical forest, temperate forest, temperate grassland, tropical forest, and warm desert. The warm desert class among all distributed in the large part of the study area and it mostly situated in the northern part of the area of study. There was obvious vertical zonality in Savanna class, which was located in the middle part of the continent. While in the eastern part we found the tropical forest class. The western direction dominated by sub-tropical forest and in the far north we found steppe and semi-desert classes. Temperature and precipitation play decisive roles in controlling the distribution of vegetation on large spatial scales. Heat and moisture are requirements for plant life and are the key factors that select for diverse plant traits and life forms (Harrison et al. 2010). The interactions between vegetation and climate factors have a direct impact on vegetation distributions; past vegetation regions have shifts in response to temperature change of a similar magnitude as that which is expected to occur during the next 100 years or less (Baker, 1983; Bernabo and Webb, 1977; Butzer, 1980; flohn, 1979; Muller, 1979; van devender and Spaulding, 1979; COHMAP members, 1988). In Africa temperature affecting precipitation distribution, and as the result controlling the productivity and distribution of vegetation.

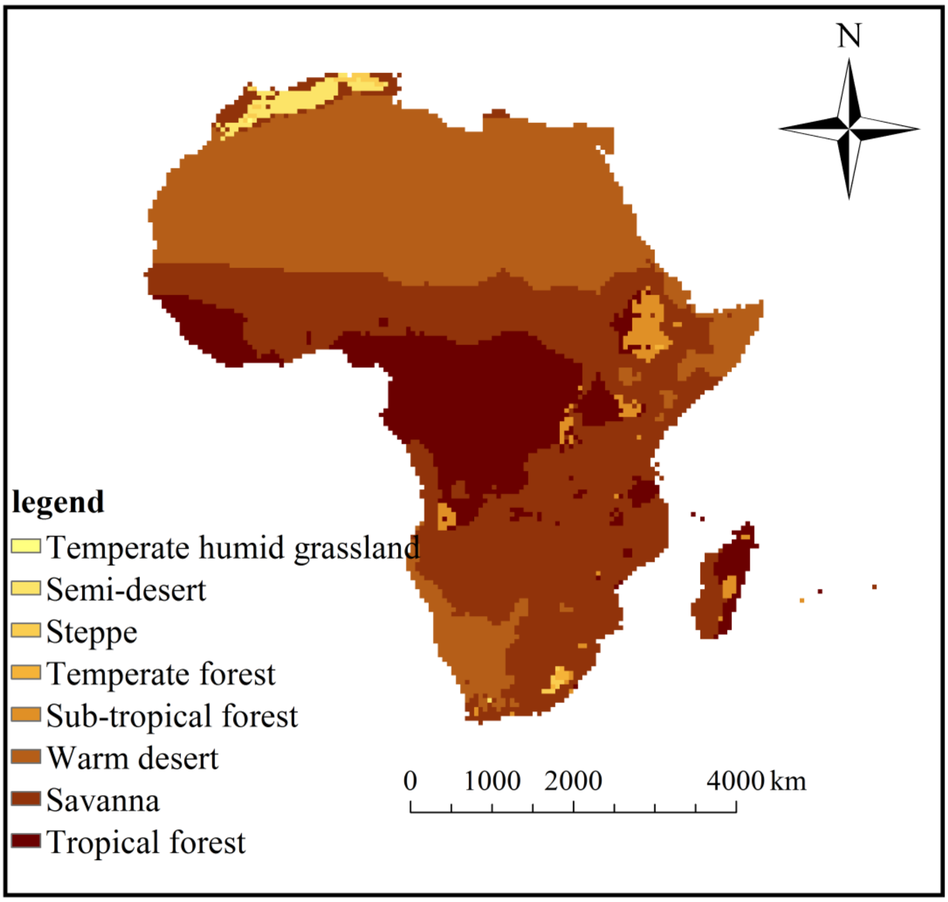

Figure 5 the spatial distribution of the PNV in the African continent based on CSCS approach from 1981 to 2013.

The spatial pattern distribution of net primary productivity for the Africa continent from 1980 to 2013

Figure (6) showed the spatial pattern distribution of net primary productivity for the Africa continent through the study time period, we can show that the northern part of the study area characterize by low NPP value it range from 0 to 200 $g \cdot C \cdot m-^{2} \cdot yr^{-1}$, this low value related to the fact that northern part is dominated by desert and shrubs, which characterized by least productivity. The western and central parts of the continent are dominated by rain forest which showed high productivity more than1000 g·C·m–^{2}·yr^{-1}and 900 -1000 g·C·m–^{2}·yr^{-1}respectively. While the areas surrounding the rain forest north and south the equator are dominated by Savanna, which have different moderate productivity 600 - 700 g·C·m–^{2}·yr^{-1},700 - 800 g·C·m–^{2}·yr^{-1}, and 800 – 900 g·C·m–^{2}·yr^{-1}.

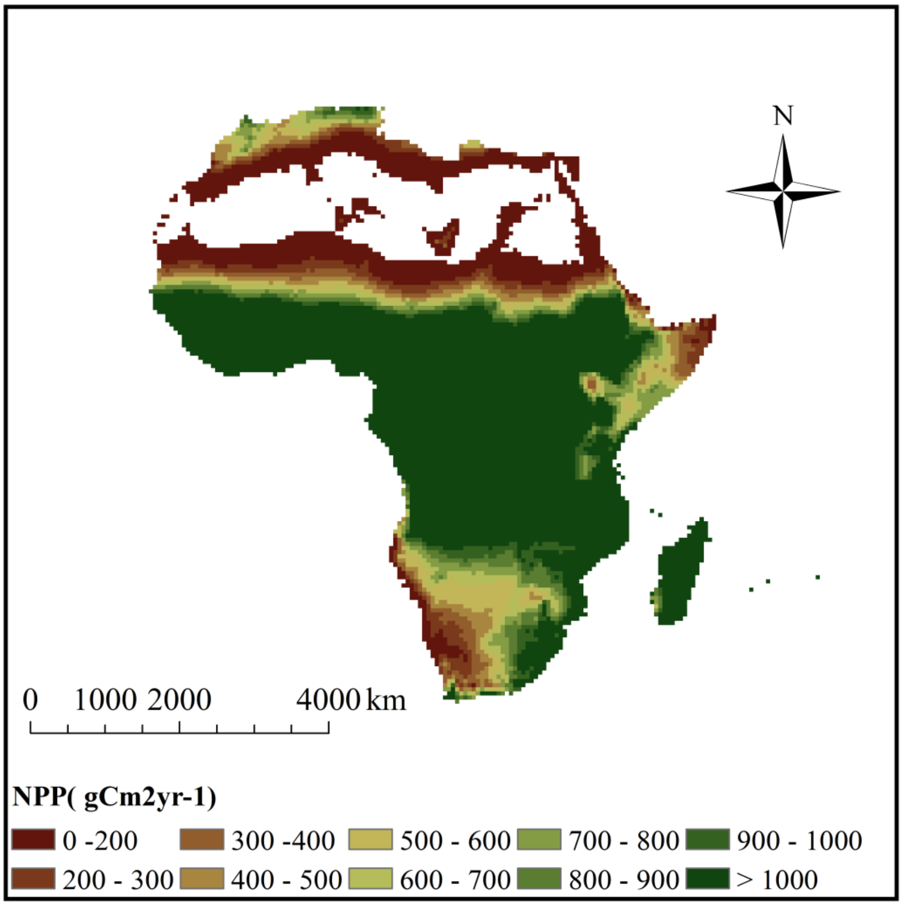

Figure 6 the spatial distribution of the potential NPP in the Africa continent based on Thornthwaite memorial model from 1981 to 2013.

Net primary productivity for the Africa continent broad potential natural vegetation categories from 1981 to 2013

Terrestrial net primary productivity NPP is an essential to food security and ecosystem sustainability in the region like Africa; where the people are mostly depend on natural resources, and where there are a large variation of ecosystem diversity, and climate variables such as temperature and precipitation. Table 3 shows the net primary productivity for the Africa continent broad PNV categories from 1981 to 2013, we can see that; the warm desert formed the lest productivity and it is account 23% of the total productivity and the semidesert form the second lowest productivity with about 24% of the total productivity. While the highest productivity was achieved by the tropical forest, it is about 78% of the total productivity. The sub-tropical forest, temperate forest and savanna show relatively highly productivity by 65%, 51% and 40% respectively.

The highly productivity of the tropical forest 2654.7 $g \cdot C \cdot m^{-2} \cdot yr^{-1}$, is result for the suitability of the environment inside this forest where the temperature and precipitation available for plant which consider the dominant factor enhancing plant growth and productivity. Africa tropical forest characterize by highly productivity regionally and globally. Some studies reveled that About 1/3 of the tropical biomass carbon sink (16% of the total terrestrial carbon sink) over the period 2000 to 2005 is thought to result from the African tropical forests (Lewis et al., 2009; Malhi, 2010). Lewis et al. (2009) collected data from repeated surveys of 79 forest plots in central and West Africa, and reported a net biomass carbon sink of 0.63 (range 0.22–0.94) t C ha−1 yr^{-1}. Malhi (2010) estimated a net biomass carbon sink of 0.31±0.15 Pg C yr^{-1} in the African forest biome (i.e. 33% of the global tropical forest carbon sink and 16% of the global terrestrial carbon sink). Forests play major roles in the global carbon cycle through their influence on the dynamics of the terrestrial carbon cycle (Bonan, 2008; Canadell and Raupach, 2008). Forests contain 422 Pg C, 76% of the C in terrestrial vegetation and about the same amount as in the atmosphere (Houghton and Skole, 1990).

The second most productive region after the forests is the Savanna region 1087.5 $g \cdot C \cdot m^{-2} \cdot yr^{-1}$, which cover large area of the continent south and north the equator and dominated by trees, shrub, wood land, and grasses. Africa savanna plays an importance role in Africa economic and most of the inhabitant lived inside this region. This region gain more attention, many studies estimate the African savanna NPP. Grace *et al.,* (2006) noted an average of 720 ± 200 $g \cdot C \cdot m^{-2} \cdot yr^{-1}$, and the entire African savanna biome gives an NPP of 8.9 Pg·C·yr−1, accounting for 13.6% of the global NPP.

The lowest net primary productivity is found in the northern part of the study area in the warm desert region, which dominated by Sahara desert, the driest, hottest, and most sunning region in the world, the NPP value range from 0 in the area that free of the vegetation to 627.7 $g \cdot C \cdot m^{-2} \cdot yr^{-1}$in the area characterized by low vegetation density such as; the area along water bodies (e.g. Nile River and other seasonal River), in addition to the harsh climate of the Saharan desert this region is affect by frequent events of drought, which result in the clearing or shifting of the vegetation cover and decreasing of the NPP. Because water availability limits plant growth in most parts of Africa, drying has reduced plant productivity (Schlesinger et al. 1990, Glantz 1994).

Table 3 NPP of the 8 broad PNV categories in Africa continent from 1980 to 2013.

Broad PNV categories	**Net primary productivity $g \cdot C \cdot m^{-2} \cdot yr^{-1}$**		
	mean	minimum	maximum
Savanna	1087.5	234.3	1940.6
Semi-desert	658.9	393.7	924
Steppe	939.5	734.2	1144.8
Sub-tropical forest	1733.2	1250.8	2215.5
Temperate forest	1358	1030	1686
Temperate grassland	821	0	821
Tropical forest	2073.85	1493	2654.7
Warm desert	627.7	0	627.7

Conclusion

The equator divided Africa continent into two parts (Africa north the equator and Africa south the equator), the vegetation zones is repeated through the two parts. The continent have a variety of climate zones and each zone characterize by different vegetation; the tropical rain forest which situated in the area with high precipitation and high temperature, the vegetation of this area are highly productive as the result of the availability of the growing factors (temperature, precipitation and CO_2. The Savanna zone, which covers about third of the continent land area and most of the productive area of that region, is the area bordering the tropical rain forests, the vegetation of this zone is mainly grass, shrub lands, scattered trees, woodlands and deciduous trees. Savanna is relatively high productive region, but this region facing several problems affect their productivity, such as; fire, human pressure, drought, land use land cover change (mainly conversation of forest land to agriculture land). Africa has the largest area located in the desert zone about 40% of the continent land area (mainly in the northern part of the continent boarding the Savanna zone), most of the desert zone area are free of the vegetation cover, except scatter trees and shrub along the water courses, the area is very hot the temperature can be reach 50C$^{\circ}$ with the lack of precipitation. The Steppe (semi-arid region) is the narrow area situated just south the deserts some time called the Sahel region.

Africa potential natural vegetation characterizes by deferent net primary productivity for the deferent PNV categories, it ranges from high productive vegetation (tropical forest), to moderate productivity (sub-tropical forest, temperate forest and savanna) and less productivity (Desert and Semi-desert).

The major sink in the global carbon cycle is the terrestrial ecosystems, it sequestering carbon and slowing the increasing CO_2 concentration in the atmosphere. The world's land ecosystems act as a major sink in the contemporary global carbon cycle and, hence, alleviate the rise of atmospheric CO_2 concentrations from global CO_2 emissions and as a consequence climate change (IPCC, 2013).

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