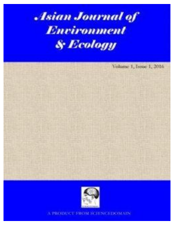

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Estimation of Biophysical Properties in Lower River Kaduna Catchment Area Kaduna, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Understanding the nature and composition of vegetation resources in Nigeria is very valuable. Biophysical properties of lower river Kaduna catchment area was estimated. ModisTerra imageries from 2000-2014 were used to extract NDVI and Kc. Mann- Kendall and Sen's Slope analysis were computed for both the indices. The results of the study revealed that both the indices exhibited a similar pattern of vegetation variation. It also indicates that the Afaka forest reserve has the highest NDVI and Kc value. The result also reveals that during spring and autumn there is an increase of vegetation while winter and summer, as well as that of annual, indicate a decrease of vegetation This result shows a depletion of the vegetation which might be a consequence of human activities particularly agricultural purposes and deforestation as well as climate variability. It also has implication for global carbon dioxide loading and temperature.

Keywords: Biophysical; NDVI; Kc; estimation; vegetation; Nigeria; Kaduna.

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1. INTRODUCTION

Nigeria is endowed with a large expanse of arable land, and a huge potential for vegetation is being threatened by both climate change [1] and human activities [2,3]. These Human activities include deforestation, agricultural and urban development (i.e. land use/ land cover changes) [4]. This has over the years proven to be the cause of the major decline in vegetation cover in the region [2]. Even though the consumption of fuel wood is undoubtedly high in the region [1]. A notable example is a work of [5], who reported that the way in which vegetation is being used for fuel wood in some areas of northern part of Nigeria, for example, Borno State would lead to the absence of vegetation cover in the area by 21s [1]. It reported that vegetation of Kaduna state is declined, a notable example is Kagoro forest [6] and Afaka forest reserved. According to [4] in the inner core city of Kaduna and its environs, there is an intensive conversion of vegetation to build up area. Most of this area mention before are part of Lower river Kaduna catchment area. As such, estimation of biophysical properties in this ecosystem if very important especially if the importance of vegetation is to look into consideration. Vegetation is important in the maintenance of an attractive vegetation environment, provision of opportunity for relatively intense outdoor recreation, provision of habitat for wildlife, watershed function, general conservation including minimization of soil erosion and the production of wood for various uses [6,7]. Also, serves as an effective sink for carbon dioxide and releases oxygen from its photosynthetic activity [6]. It has a major influence on the hydrology of surface and ground water [8]. It depletion has led to changes in the water balance in any catchments which have led to land and river salinization, changed flood frequency and flow regime, increased surface water logging [9], reduced infiltration and evapotranspiration [10]. Therefore, Assessing and monitoring the state of the earth surface is a key requirement for global change research. Classifying and mapping vegetation is an important task for managing natural resources as vegetation provides a base for all living beings and plays an essential role in affecting global climate change [11]. This is large because vegetation has considerable control on the earth's energy balance, and hydrological cycles, which in turn influence climate [12]. Monitoring can be done by using of remote sensing data to observe the biophysical properties. These properties have been defined using following vegetation indices, primarily calculated using band reflectance of Red and NIR, these include Normalized Difference Vegetation Index (NDVI), SAVI (Soil Adjusted Vegetation Index) introduce by [13] and Crop coefficient (Kc) which is a dimensionless number (usually between 0.1 and 1.2) which used to calculate actual evapotranspiration (ETc). Kc can be estimated using satellite data through the relation between Kc and Normalize Difference Vegetation Index NDVI which used by [14] and evaluated by [15]. These indices have been used to monitor crop condition and forecast yield as well as production in many countries of the world [16]. Also, they are representative of plant's photosynthetic efficiency, which has been widely used for presenting vegetation cover from different data source [16]. While Crop coefficients primarily depend on the dynamics of canopies, light absorption by the canopy, canopy roughness, which affects turbulence, plant physiology, leaf age and surface wetness [17]. As a plant canopy develops, the ratio of transpiration to evapotranspiration increases, until most of the evapotranspiration comes from transpiration, and soil evaporation is a minor component [10].

Therefore, the objective of this study is to assess the condition and the spatio-temporal variation of biophysical properties by the used of the normalized difference vegetation index (NDVI), and crop coefficient (Kc) in lower river Kaduna catchment area, Nigeria.

2. METHODOLOGY

The study area lies between latitudes 10.245^{o}N and 10.808^{o}N and longitude 7.021^{o}E and 7.786^{o}E (Fig. 1). It is within the Highland climatic zone of Nigeria with an Altitude of 591 m. The mean evaporation loss annually is 2448 mm. It is drained by River Kaduna through its tributaries such as Rivers Rigachikun, Ruza and Romi. Kaduna River takes its source from Jos Plateau state and flows for about 210 km to Kaduna Town. It crosses the town, dividing it into North and South areas. The River flows beyond Kaduna for about 100 km into the Shiroro dam and continues until it finally discharges into the River Niger about 200 km from Shiroro dam [18].

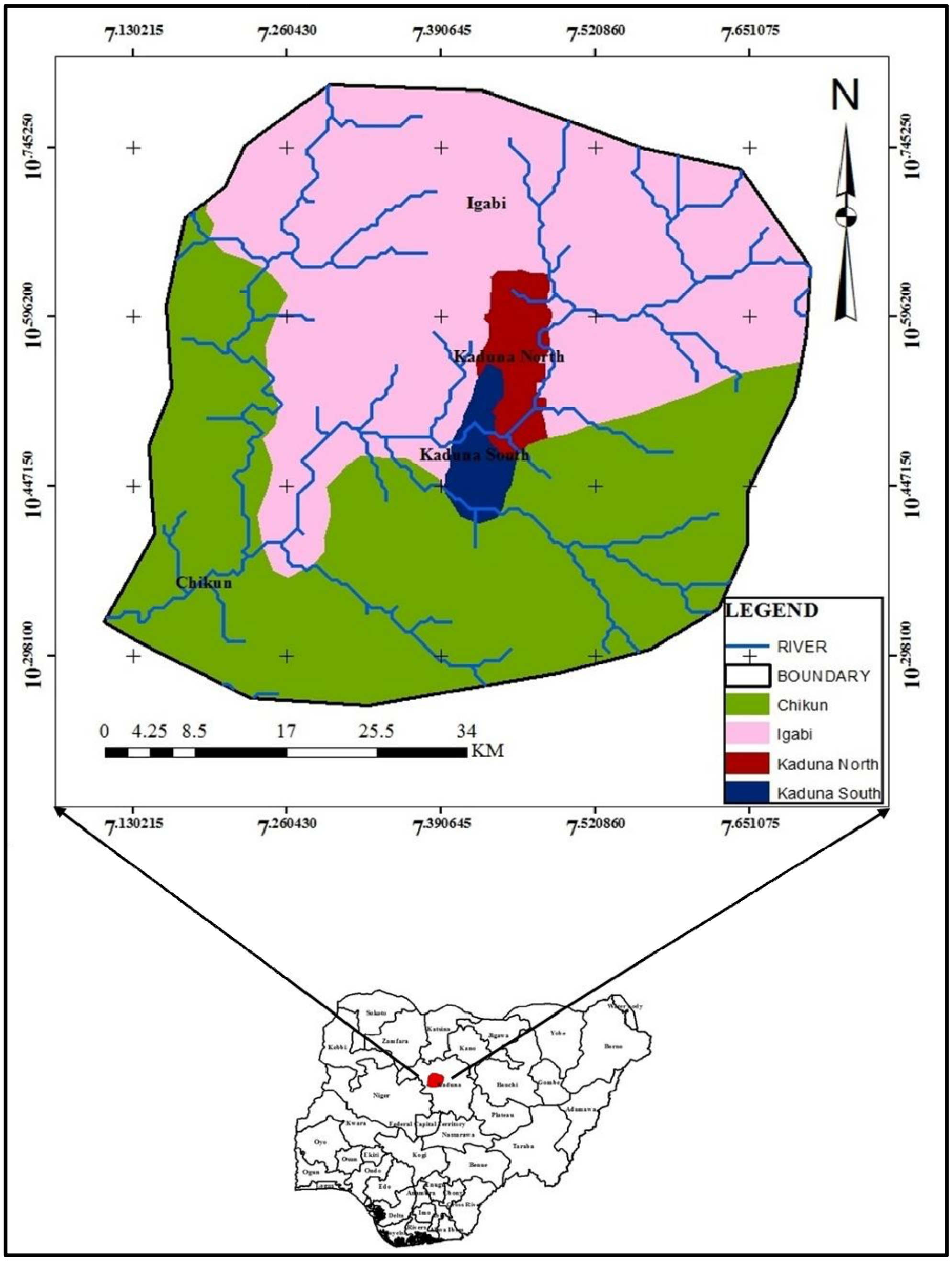

Fig. 1. Map of the lower river Kaduna Catchment area
Source: Author (2016) modified shape file from www.digitalglove.com

2.1 Remote Sensing Data

MODIS Terra data (MOD 13) were downloaded from the Land Processes Distributed Active Archive Center (LP DAAC), NASA. The spatial resolution of MODIS data is 1Km, for fifteen epoch (2000 to 2014) were used.

2.2 Methods

Geometric and radiometric corrections were carried out according to [19,20]. All the operation from importing to the analysis of the data was carried out in Erdas Imagine 2014 and ArcGIS 10.2.1 respectively.

Crop coefficient (Kc) was determined based on the relation with Normalized Difference Vegetation Index NDVI represented below (Eq. 1) which used by [14] and evaluated by [15]

$$K_C = \frac{1.2}{NDVI_{dv}}(NDVI - NDVI_{mn}) \quad (1)$$

Where; 1.2 is the maximum Kc (FAO), $NDVI_{dv}$ is the difference between the minimum and maximum NDVI value for vegetation and $NDVI_{mv}$ is the minimum NDVI value for vegetation.

There are several statistical tools for trend and seasonal variation assessments, but the procedure for calculating the trends has been widely discussed by the scientific community. Broadly, two groups of mathematical tools are available to calculate these trends: parametric and nonparametric. Parametric trend tests are more powerful than nonparametric ones, but they require data to be independent and normally distributed [21]. Non-Parametric (Mann-Kendall and Sen's) statistical analyses have used this study.

3. RESULTS AND DISCUSSION

3.1 Normalized Difference Vegetation Index (NDVI)

3.1.1 Annual variation of NDVI

The annual NDVI maps were generated for the study area which revealed increased in spatial pattern towards the surrounding part of lower river Kaduna catchment (Fig. 2E). The Afaka forest reserve situated in the North Western part of lower river Kaduna catchment shows distinguished high annual NDVI. High values of NDVI indicates greater vigour and amounts of vegetation [22]. Also, the South Western part of the lower river Kaduna catchment area shows a high range of NDVI. Whereas, the Kangimi Dam in the North Eastern part of the study area indicates lower NDVI. In the central part of the study area, where Kaduna metropolis is located also shows a low NDVI value.

This spatial pattern of NDVI is not same for all years. This implies that the spatio-temporal

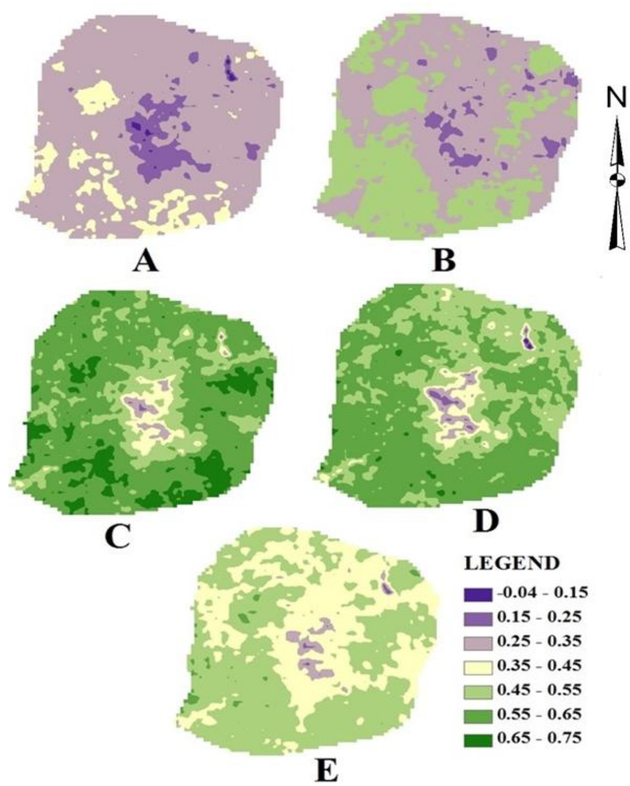

Fig. 2. Spatio-temporal variation of NDVI in Lower River Kaduna Catchment (A) December-January (B) March – May (C) June – August (D) September – November (E) Annual mean

the pattern of NDVI has been changed with time (Fig. 3). In The year 2008, NDVI of lower river Kaduna catchment area was significantly low. This shows an absence of healthy vegetation. The NDVI for the year of 2010, and 2011, shown a close related mean value, while 2012, 2013 and 2014 shows a depletion of vegetation covers which might fully depend upon the climatic condition [10,22] such as decrease in rainfall in the lower river Kaduna catchment area [23,24] and implied the intensified habitat desiccation and declined vegetation production [22]. In Table 1 shows an overall annual NDVI mean of 0.447 with 0.004 standard deviations. It has a coefficient of variance less than 0.1 (10%). This implies low variability of NDVI in lower river Kaduna catchment area. Annual trend of NDVI (Table 1) shows a negative trend which indicates a decrease of annual vegetation in the catchment. Similar results are found in Pakistan by [16]. Therefore, these results have confirmed the statement of [10] that NDVI is an indicator of the density of vegetated cover and plant vigour.

3.1.2 Seasonal variability of NDVI

The four seasonal NDVI analyses were computed for the study area these include winter (Fig. 2A), spring (Fig. 2B), summer (Fig. 2C) and autumn (Fig. 2D). Fig. 4 revealed that The Apaka forest reserve situated in the North Western part of lower river Kaduna catchment shows distinguished high winter seasonal NDVI. The South Western part of the lower river Kaduna catchment area shows a medium range of NDVI which differs to that of annual NDVI. Kangimi Dam in the North Eastern part of the study area and central part of the study area, where Kaduna metropolis is located shows lower NDVI. Despite the variation from one season to another (Table 1), the Apaka forest reserve remained an area having the high NDVI this can link to being protected by the state government (Fig. 2A). In Fig. 4 shows that 2007 and 2008 had the lowest NDVI value. The high NDVI value experienced on 2010. In Table 1 shows an overall winter NDVI mean of 0.3121 with 0.008 standard deviations. It has a coefficient of variance of about 2.5% that is less than 0.1 (10%).Winter seasonal trend of NDVI (Table 1) shows a negative trend which indicates a decrease of vegetation in the catchment.

Fig. 2B shows the spatio-temporal variation of NDVI during spring (MAM). The results reveal that the lower NDVI value that is orange colour is

Table 1. Statistical distribution of NDVI in Lower River Kaduna Catchment Area from 2000-2014

Statistic	ANNUAL	MAM	JJA	SON	DJF
Mean	0.4465	0.3458	0.5722	0.5554	0.3121
Variance	0.0000	0.0002	0.0001	0.0004	0.0001
STD	0.0048	0.0142	0.0098	0.0200	0.0081
CV	0.0108	0.0411	0.0171	0.0359	0.0258
Z VALUE	-0.2762	0.1810	-0.2952	0.1048	-0.0476
Sen's slope:	-0.0004	0.0009	-0.0008	0.0008	-0.0001

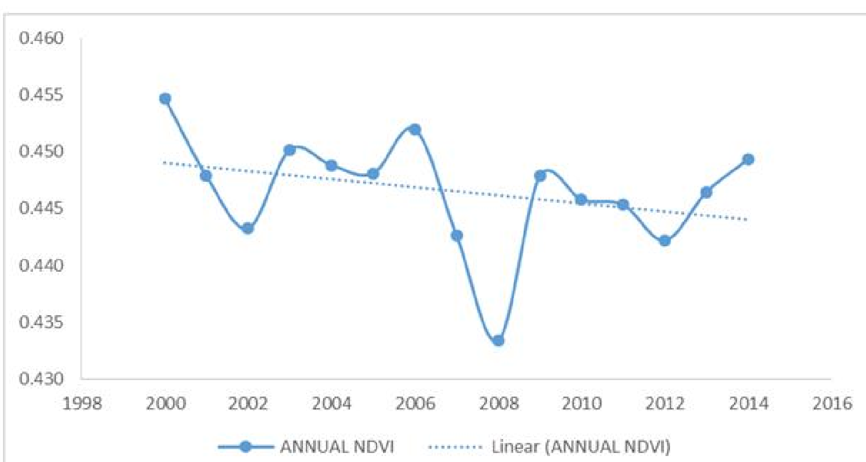

Fig. 3. Annual time series of NDVI of lower river Kaduna Catchment

more concentrated in the central part of lower river Kaduna catchment area. Similarly, Kangimi dam and river Kaduna has lower NDVI value. The southern part of the study area shows a high NDVI value. The Afaka forest reserved remained an area that has distinguished high NDVI value because of its healthy vegetation.

From the Fig. 5 shows that 2001 has the highest spring (MAM) NDVI value follows by 2014. The NDVI value drops from 2002 but it shows a gradual increase until 2008 where it drops. Table 1 shows that the overall spring mean NDVI is 0.3458 with standard deviations of 0.0142. It has a coefficient of variance of 4.1%. The trend of the pattern of spring NDVI for lower river Kaduna catchment area shows a negative trend which implies a decrease of vegetation over time.

Fig. 2C shows spatio-temporal distributions of summer NDVI (JJA). It increases in most parts of catchment comparing to those in winter and spring. In the south southern part of the catchment, area show distinguishes high NDVI value. The Afaka forest reserved has the highest NDVI value in the catchment. The increase spatial distribution of summer NDVI might be associated with the rainfall because it is the peak season of rainfall.

From Table 1 the overall summer (JJA) NDVI mean is 0.5722 with standard deviations of 0.0098. Among the seasons, the summer has the highest NDVI value even more than that of annual mean NDVI value. The coefficient of variance is about 1.7% (>10%) of JJA NDVI in lower river Kaduna catchment area. From Fig. 6 reveal that from 2002 where the NDVI is low it gradually rises and fall until 2010 where another lower NDVI occurs similar to that of 2002. Linear slope indicates a decreasing trend of summer NDVI this is similar to that of Mann-Kendall and

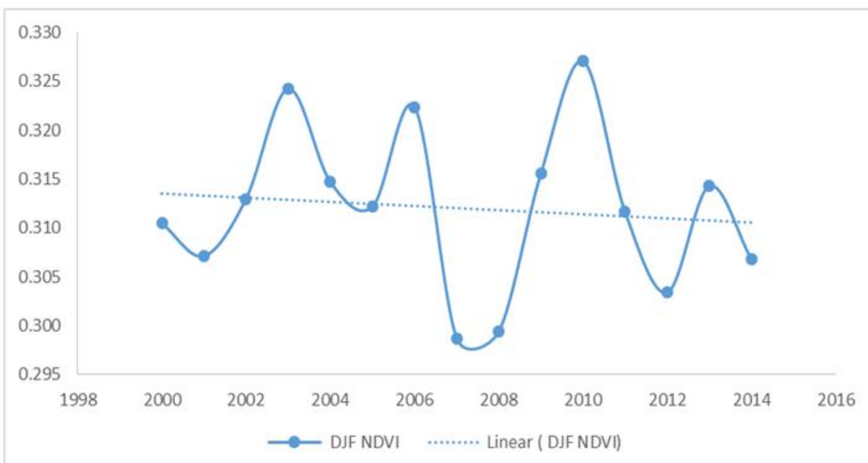

Fig. 4. Winter (DJF) NDVI time series of lower River Kaduna Catchment

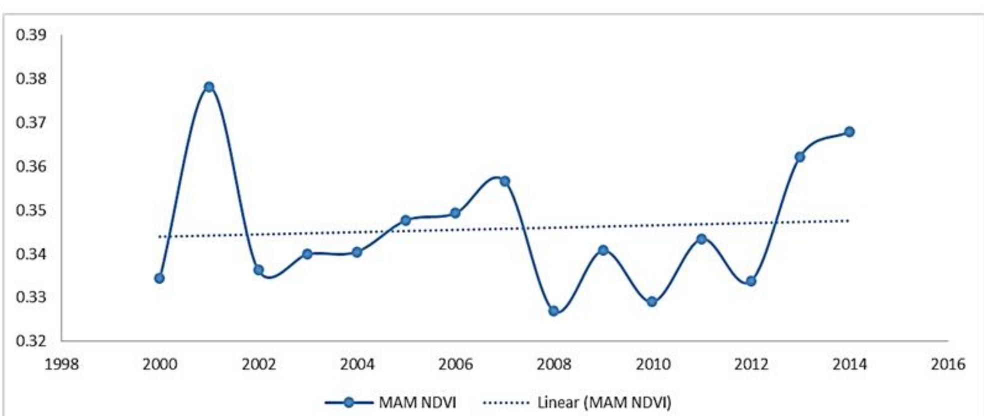

Fig. 5. Spring (MAM) NDVI time series of lower river Kaduna Catchment

Sen's slope (Table 1). Despite that the summer (JJA) NDVI being the season of rainfall but the result shows a decrease of vegetation over time during the period of the study. This may be related to the climate variability experienced in the catchment area [25].

The spatio-temporal distribution of NDVI during autumn (SON) shows that the NDVI value for the central part that is Kaduna metropolis has decreased over the period of the study (Fig. 2D). It also gradually increased toward the surrounding part of the catchment area. Southwest and South South part of the catchment show a distinguished high NDVI value, for example, Afaka forest reserved, while the northern part shows a medium range.

From the Fig. 7, 2001 has the least autumn NDVI value. It differs with that of spring NDVI value. The NDVI value gradually rises until 2007 where it drops. 2012 has the highest autumn NDVI value follows by 2002 and 2009. Table 1 shows that the overall spring mean NDVI is 0.5554 with standard deviations of 0.0200. It has a coefficient of variance of 3.6%. The trend in the pattern of autumn NDVI for lower river Kaduna catchment area shows a positive trend which implies an increase of vegetation during this season. This is the season that all vegetation both the cultivated, grassland and the forested area are fully grown.

3.2 Crop Coefficient (Kc)

3.2.1 Annual variation of Kc

The spatio-temporal study of Kc revealed that it has been changed with time. Fig. 8 shows that 2000 has the highest mean value, followed by 2011, while 2008 has the lower value, followed by 2009. The linear slope shows a downward slope. From Table 2 shows that the overall annual crop coefficient mean is 0.79 with standard deviations of 0.03. The coefficient of

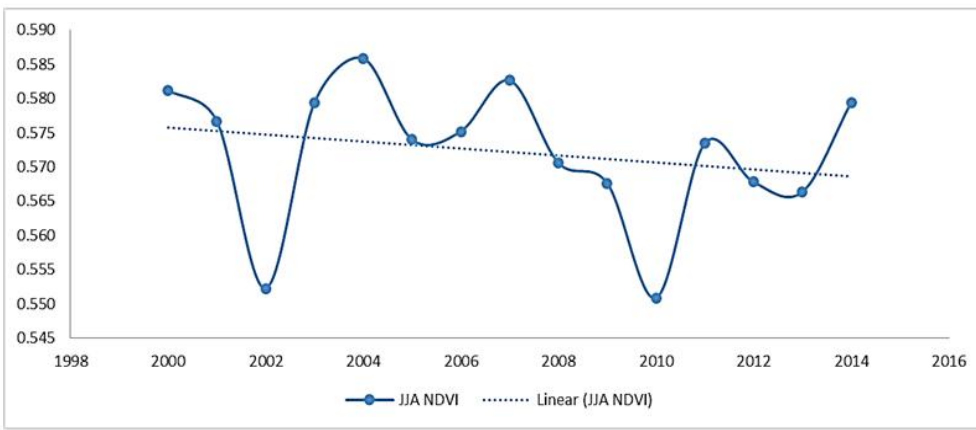

Fig. 6. Summer (JJA) NDVI time series of lower river Kaduna Catchment

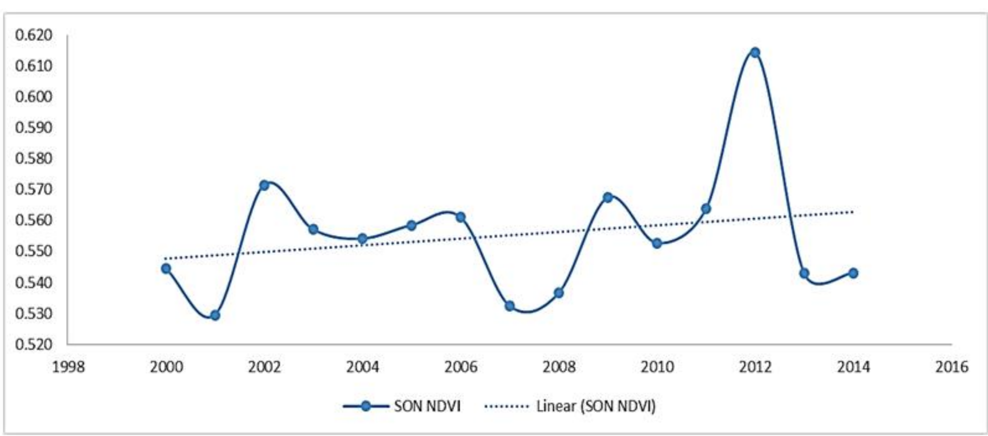

Fig. 7. Autumn (SON) NDVI time series of lower river Kaduna Catchment

variance is about 3% of annual Kc. The annual Kc trend shows a negative trend in lower River Kaduna Catchment Area both from linear, Mann Kendall and Sen's slope. The result reveals that the phenology, canopy and other properties of vegetation are on decreased over the period of the study.

The annual crop coefficient maps (Fig. 9E) were generated for study area which revealed the increase spatial pattern towards surrounding part from the centre i.e. Kaduna metropolis of lower river Kaduna catchment area. The Apaka forest reserve situated in the North Western part of lower river Kaduna catchment showed distinguished high Kc. The close spacing of plants and taller canopy height and roughness of many full grown of Afaka forest reserved caused the plants to have maximum Kc factors. Also the South Western part of the lower river Kaduna catchment area shown a high range of Kc, whereas, the Kangimi Dam in the North Eastern part of the study area indicated lower Kc. In the central part of the study area where Kaduna metropolis is located also showed a low Kc value this is due to the natural surface which is converted to an impervious surface which makes the soil surface dried, and evaporation is restricted.

3.2.2 Seasonal variation of crop coefficient

During winter, 2007 and 2008 have the lowest value of crop coefficient. The highest crop coefficient for winter was experienced on 2000, 2001 and 2003 (Fig. 10). From Table 2 it shows that the overall mean of winter (DJF) crop coefficient was about 0.7970 with the standard deviations of 0.0727, which is more than that of annual and spring (MAM) crop coefficient. The coefficient of variance for winter is about 9.12%. The trend analysis shows that winter has a negative trend of crop coefficient. This implies that there is a decrease of crop coefficient during this season.

The spatio-temporal distribution of winter (DJF) crop coefficient was presented in Fig. 9B. The results reveal that area with high NDVI corresponds to that of crop coefficient. This implies that the forested area such as Afaka forest reserve at the southwest part of the catchment has the high Kc. The built up area at the central part of catchment has the lowest

Table 2. Statistical distribution of crop coefficient in lower River Kaduna Catchment area from 2000-2014

Statistic	ANNUAL	MAM	JJA	SON	DJF
Mean	0.7884	0.6284	0.7899	0.9207	0.7970
Variance	0.0009	0.0021	0.0010	0.0055	0.0053
STD	0.0300	0.0460	0.0318	0.0739	0.0727
CV	0.0381	0.0732	0.0403	0.0803	0.0912
Z VALUE	-0.3714	0.2571	0.0095	0.2571	-0.4667
Sen's slope:	-0.0028	0.0019	0.0003	0.0034	-0.0098

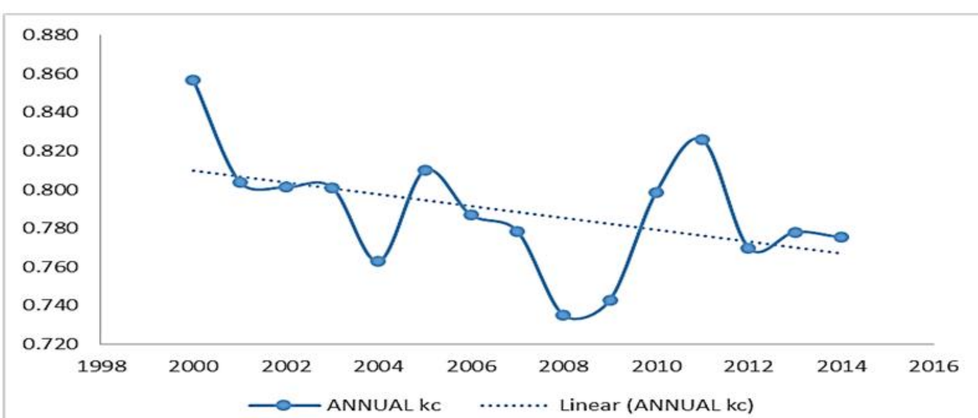

Fig. 8. Annual Kc time series of lower river Kaduna Catchment Area

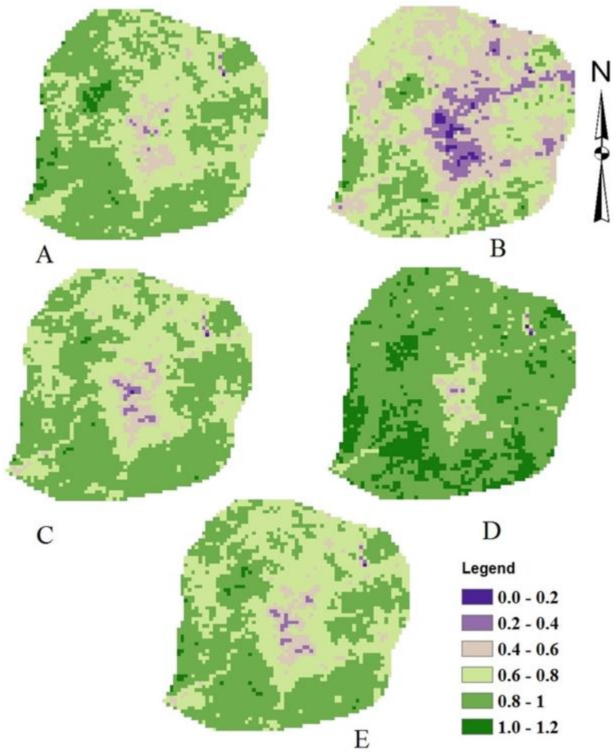

Fig. 9. Spatio-temporal variation of Kc of Lower River Kaduna Catchment(A) September – November (B) December – February (C) March – May (D) June – August (E) Annual Mean

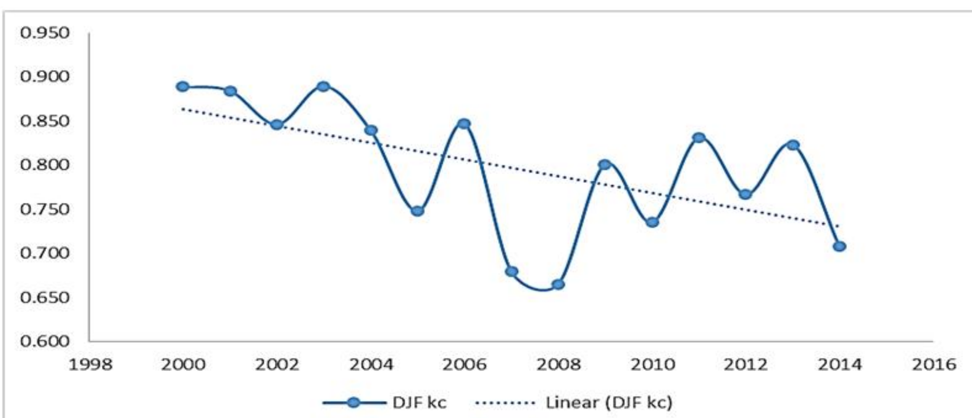

Fig. 10. Winter (DJF) Kc time series of lower river Kaduna Catchment

a value similar to that of Kangimi dam in the northeast area. The northern part of the catchment has a medium range of winter crop coefficient.

From Table 2 spring crop coefficient has the lowest value of about 0.6284 among the other season with the standard deviations of about 0.046. It has 7.3% coefficient of variance. In Fig. 11 it shows that 2011 has the highest spring crop coefficient, while 2005 has the lowest value. 2000, 2004, 2008 and 2013 have similar spring crop coefficient. The trend analysis (Table 2) shows that the spring crop coefficient has a positive trend.

The map of spring crop coefficient was generated for the period of the study (Fig. 9C). The result shows a variation in lower river Kaduna catchment area. The spatio-temporal coincides with the pattern of NDVI having higher values where NDVI is high and vice versa. During this season the Kc value reduces significantly compare with that of another season, even the forested area such as Afaka forest reserved. However, the south part of the catchment has the highest Kc value as well as that of Afaka forest reserved. The northern part has the medium range value, while the central part of the catchment and that of Kangimi dam in the northeast part has the lowest Kc value.

The temporal distribution of summer (JJA) Kc is not the same for all the year (Fig. 12). The result reveals that 2002 has the highest Kc value follows by 2004. 2007, 2011 and 2014 has a similar Kc value. The lowest Kc value was observed in the year of 2013. Table 2 shows that the summer (JJA) has the second highest Kc value after autumn (SON). It differs from annual Kc value by 0.1%. The standard deviation of Kc was about 0.0318 with 4% coefficient of variance. The trend analysis of Kc during this season shows a positive trend.

From Fig. 9D shows a spatial distribution of summer (JJA) crop coefficient. The result reveals that the lowest value dominated the central part of the catchment where Kaduna metropolis located. It shows that the percentage of at which lower value covered is less than that of winter (DJF) and spring (MAM) seasons. The highest value almost remained as it's, that is the southern as well as northwest part of the catchment, where Afaka forest reserved located, has the highest value only that the percentage of the area covered increased compared to winter (DJF) and spring (MAM) seasons. The medium range value dominated most part of the catchment.

From Table 2 autumn (son) crop coefficient has the highest value of about 0.9207 among the other season with 13% more than that of annual.

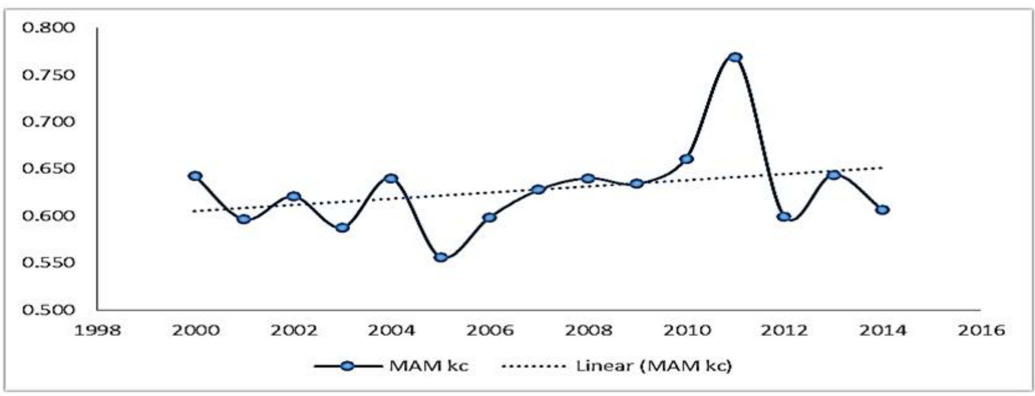

Fig. 11. Spring (MAM) Kc time series of lower river Kaduna Catchment

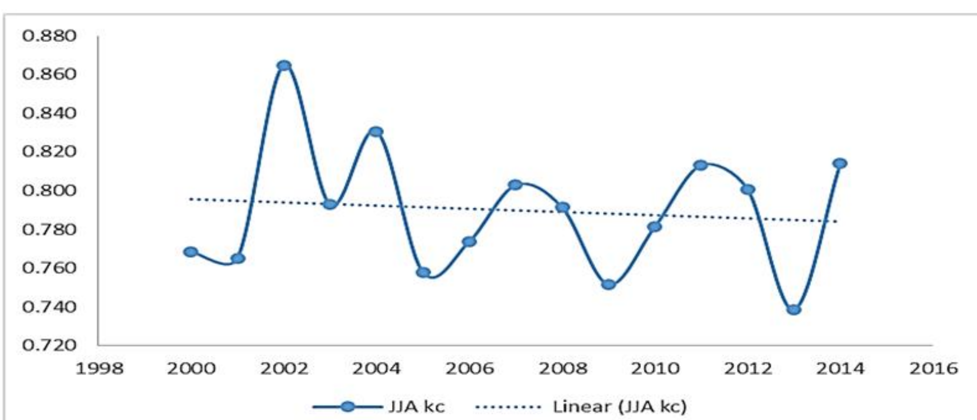

Fig. 12. Summer (JJA) Kc time series of lower river Kaduna Catchment

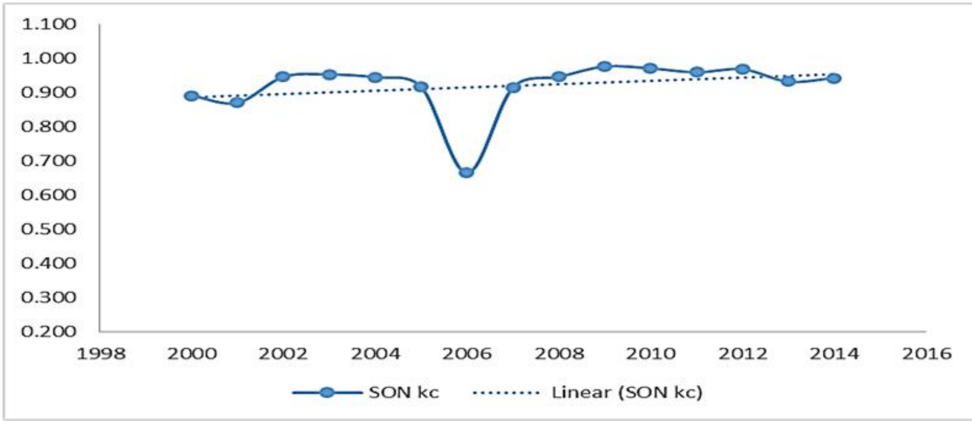

Fig. 13. Autumn (SON) Kc of lower River Kaduna Catchment

It has a standard deviation of about 0.0739 and 8% coefficient of variance. In Fig. 13 shows that 2006 has the lowest autumn (son) crop coefficient while 2009 has the highest value. 2002 to 2004 as well as that of 2011and 2013 have similar spring crop coefficient. The trend analysis (Table 2) shows that the autumn (SON) crop coefficient has a positive trend. The map of autumn (SON) crop coefficient was generated for the period of the study (Fig. 9A). The result shows a spatial variation in lower river Kaduna catchment area. During this season the Kc value increased significantly compared with that of another season. However, the south part of the catchment has the highest Kc value as well as that of Afaka forest reserved. The northern part has the medium range value, while the central part of the catchment and that of Kangimi dam in the northeast part has the lowest Kc value. It shows that the percentage of at which lower value covered is less than that of winter (DJF) and spring (MAM) season.

The Kc result shows a similar pattern with NDVI. This implies that the NDVI as an indicator of the density of vegetation cover and plant vigour, it captures most of the variation observed in Kc. The study shows an annual variability of Kc. As Kc representative of well-watered conditions, during the crop growing season that is summer (JJA), the value of Kc for most vegetation increases from a minimum value at emergence, in relation to changes in canopy development, until a maximum Kc is reached at about full canopy cover especially during autumn (SON). The Kc tends to decline at a point after a full cover is reached in a case of winter (DJF) and spring (MAM). The declination extent primarily depends on the particular climatic condition and crop growth characteristics [26]. The result has clearly shown that Kc primarily depends on the dynamics of canopies, light absorption by the canopy, canopy roughness, which affects turbulence, crop physiology, leaf age and surface moisture [17]. The Kc indicate that the influenced of soil moisture on actual evapotranspiration is less than that of surface net radiation, vegetation conditions (vegetation indices) and temperatures in vegetated regions.

The decrease of vegetation in lower river Kaduna catchment area showed similarities with other studied such as [12] whose studied land use/land cover change in Talata Mafara, [27] whose studied land use/land cover in Ilesha, [8] whose analysed the spatio-temporal dynamics of land use/ land cover structures' in the Kaduna inner core city region, Nigeria, [28] whose studied fuel wood consumption in Nigeria and the energy ladder: A review of fuel wood use in Kaduna State and that of [29] whose studied the Sustainability of Fuel Wood Harvesting from Afaka Forest Reserve, Kaduna State.

These losses of vegetated cover lead to an increase dryness ratio during the period of study in the region [24]. It is known that plants play a vital role in stabilizing the soil, maintaining the hydrological cycle, providing shade among others. The consequences of the above are poor air quality in the metropolis. Intense heat is experienced in the lower river Kaduna catchment area due to the high rate of evaporation in the absence of vegetation and significant area covered with tar and concrete pavements. High noise pollution is experienced in many parts of the metropolis [30]. More so, the absence of vegetation as windbreaker result in the parkingoff of roofs and buildings during wind storms. Due to lack of vegetation, high electrical energy is required to power electrical appliances such as fridge and air-condition to supplement natural cooling [30].

4. CONCLUSION

The result reveals that the vegetation condition differs from one season to another as well as from one location to another. It can be concluded that if the present annual trend continues unabated the vegetation may disappear in no distant time. From the results, it justified that intensified cultivation, overgrazing, deforestation with improper land use can make the area vulnerable to the extreme event such as the frequent occurrence of drought, flood and watershed of the area will be hinder. From the result, the following recommendation is deducted for further research.

Climate variability and change analysis should be incorporated to that of biophysical properties so as to understand the mechanism of their variation and provide possible mitigation and adaptation.

The impact of population and environmental changes on vegetation should be assessed.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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