Journal of Applied Life Sciences International

13(1): 1-12, 2017; Article no.JALSI.32981
ISSN: 2394-1103

Spatio-Temporal Variation of Actual Evapotranspiration of Lower River Kaduna Catchment, Nigeria

Isa Zaharaddeen[1*], Auwal F. Abdussalam[1], Seidu O. Muhammad[2], Yusuf Sale[1] and Yunusa Buhari Kabir[1]

[1]*Department of Geography, Kaduna State University, Kaduna, Nigeria.*
[2]*National Space Research and Development Agency, Abuja, Nigeria.*

Authors' contributions

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

Article Information

DOI: 10.9734/JALSI/2017/32981
Editor(s):
(1) Nndamuleleni Murovhi, Agricultural Research Council, South Africa.
Reviewers:
(1) Murat Yildirim, Canakkale Onsekiz Mart University, Turkey.
(2) Sebahattin Kaya, Bingol University, Turkey.
(3) Hossein Sahour, Western Michigan University, USA.
Complete Peer review History: http://www.sciencedomain.org/review-history/20181

Original Research Article

Received 25th March 2017
Accepted 13th June 2017
Published 24th July 2017

ABSTRACT

Assessing spatio-temporal variation of actual evapotranspiration is very important, most especially in the areas that are prone to changing climate. Lower River Kaduna is one of the critical ecosystems in the northwest, Nigeria. As such it is critical to investigate the evapotranspiration of this area, because of its impact on water availability for both human, plants, and other organism population dwelling the basin. ModisTerra imageries from 2000-2014 were used to computecrop coefficient (Kc) through a relationship with normalize difference vegetation index (NDVI). Makkink method was used to estimate the reference evapotranspiration using temperature and solar radiation obtained from Nigerian Meteorological Agency. Actual evapotranspiration was estimated by multiplying evapotranspiration and crop coefficient. Trend analysis was determined using Mann-Kendall and Sen's slope. The results reveal that the actual evapotranspiration of annual is less than 61% of winter and 71% of autumn. Spring and summer Actual evapotranspiration value are less than annual with 51% and 79%. Annual, winter and summer have a decreased of actual evapotranspiration. It also reveals that spring and autumn has an increased of actual

**Corresponding author: E-mail: isazaharaddeen@gmail.com;*

evapotranspiration. The spatio-temporal result reveals that the vegetated area has a high Actual evapotranspiration while the non-vegetated area has lower Actual evapotranspiration value.

Keywords: Evapotranspiration; spatio-temporal; variation; crop coefficient; Nigeria; season; Kaduna.

1. INTRODUCTION

In recent years, increased awareness of environmental issues has led to the idea of sustainability, in which river basins, dams and groundwater among others are controlled to maintain a balance between the availability and the use of their resources [1]. The demand for water all over the world is on the increase for various needs [2] such as agricultural irrigation, domestic water uses, industrial use, and frequent droughts [3]. This major ingredient of life become scarce in many parts of the world and Nigeria in particular [4,5]. The driving force behind this problem can be observed in efficient consumption of ground water for human activities [3], and change in climate have a significant impact on the availability of water [4,6], the effect of this water losses could be attributed more especially in the crop lands, to actual evapotranspiration (AET) [7]. Moreover, if the AET rate has been increased it can be contributed to water scarcity problems [8]. AET is typically known as the crop water requirement since total crop water requirement is directly proportional to AET [9]. The knowledge of AET is very important in the design and maintenance of irrigation schemes as it helps to predict whether there would be any deficit or excess in demand for water, hence, the required amount of water can be estimated and necessary precautions can be taken earlier [5]. Therefore, its accurate estimation can be helpful for efficient management of water within the catchment area and Kaduna state in general. However, the lower river Kaduna catchment area might be associated with the problems of climate change such as the high rainfall variability annually, drought, floods, desertification, groundwater shrinking and surface water subject to high evaporative losses [10-12]. Human alteration of the land cover is escalating, in which forested area are converted to agricultural area and urban area due to its rapid development and high population being experienced in the study area [13]. Lower River Kaduna catchment has been subject to wide fluctuations in water levels. These natural fluctuations, coupled with consumption by humans, changes in land cover over time and climate variability have led to decrease of the water levels which have led to shrinking of the catchment especially during the dry season [11,14]. This change can significantly impact evapotranspiration in regional ecosystems, which in turn influences the hydrological cycle of the basin. Considering these problem and challenges, for the better assessment and management of hydrological cycle and irrigation water requirement, the estimation of actual evapotranspiration (AET) is very important. There are no research studies on the spatial and temporal variation in AET of lower river Kaduna catchment area. Also, to date few studies have been conducted for ET estimation in the northwest region of Nigeria for examples [4,15] especially in Kaduna State. This research therefore intends to bridge this gap in which to provide data, to enable climate change, and water scarcity (fresh) assessment. This research is designed to assess the spatial and temporal distribution of actual evapotranspiration in lower river Kaduna catchment area.

2. MATERIALS AND METHODS

The study area lies between latitudes 10.245°N and 10.808°N and longitude 7.021°E and 7.786°E (Fig. 1) with an area of 3,159 Km^2. The Lower Kaduna River Catchment it is within the highland climatic zone of Nigeria with an Altitude of 591 meters above sea level. The climate of Kaduna is also affected by inter-tropical discontinuity as a result of seasonal winds that blow from the north Tropical Continental (T_C) and the one from the south Tropical Maritime (T_M) during dry months. During the wet season, the area is influenced by the T_M from the south. The dry season is also characterized by Harmattan dust haze and hot and dry northerly winds that blow from the Sahara Desert in West Africa [16]. The mean annual rainfall ranged from 1,016 mm to 1,524 mm [16].

The mean annually evaporation is 2448 mm. The catchment 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. The River flows

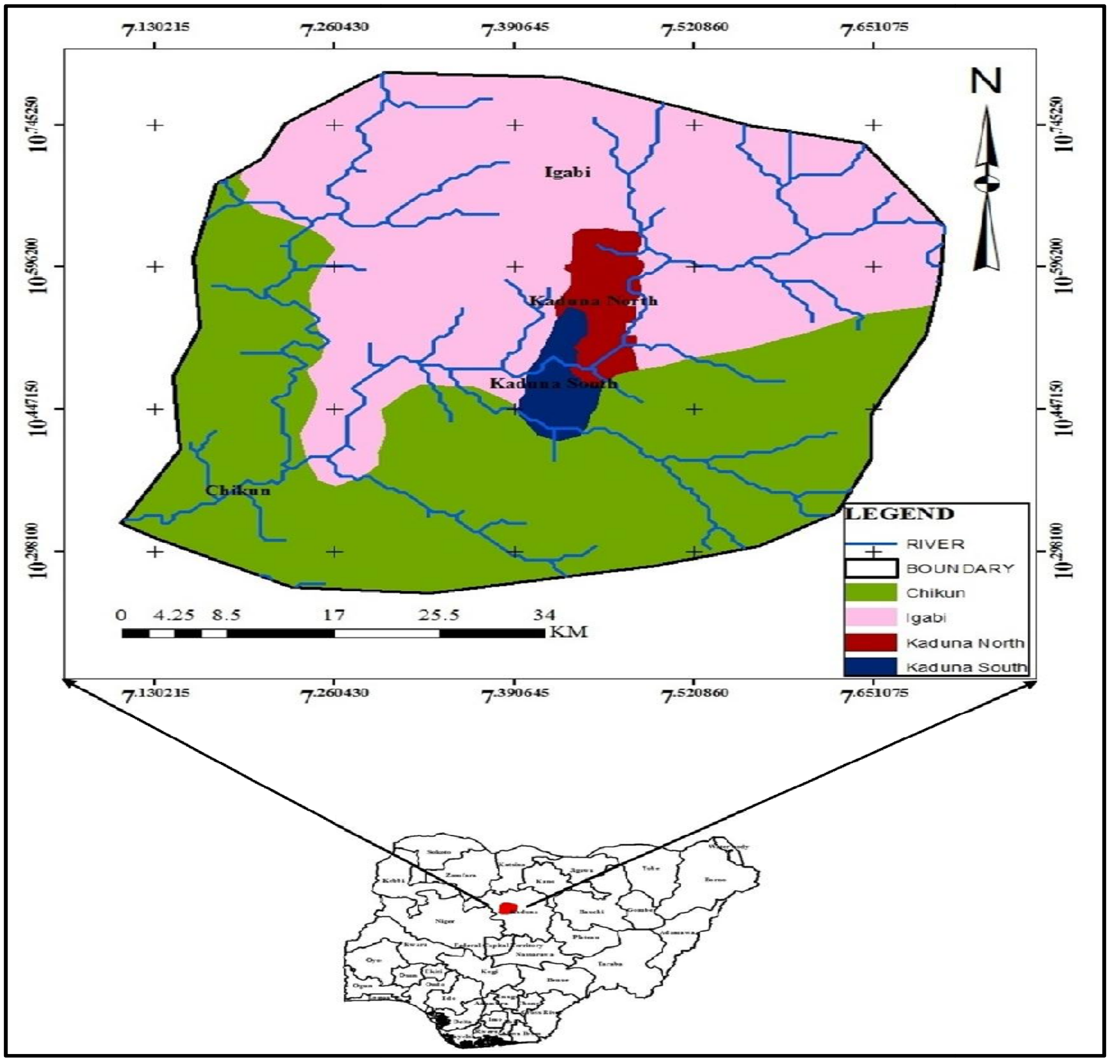

Fig. 1. Map of the lower river Kaduna Catchment Area
Source: author (2016) modified shape file from www.digitalglove.com

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 [17]. Land use in the catchment include built-up area, agricultural area which include mechanized farming such as the Wushishi farms, and Niyya farms, among other, had also taken over large portions of land for cultivation. Most of the natural savanna wood land has been cleared. What seems to be left of the forests is the forest reserve of Afaka. The Water bodies in the catchment include dams or lakes such as Kangimi dam which were constructed under the policy of Kaduna State government to encourage irrigation farming in the State [18].

2.1 Materials

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

Mean daily Temperature (Tmean) and solar radiation (Rs) data were obtained from Nigerian meteorological agency (NIMET) Kaduna, for the period of 15 years from 2000-2014.

2.2 Methods

In this study the crop coefficient approach was used by combining Kc (from satellite images) with reference evapotranspiration (ET) from meteorological station observations allowed us to calculate Actual Evapotranspiration (AET) [9]: The analysis was carried out in ArcGIS and Erdas Imagine software respectively.

$$AET = K_C \times ET \tag{1}$$

Where,

AET = Actual evapotranspiration [mm d^{-1}],
Kc = Crop coefficient [dimensionless],
ET = Reference evapotranspiration [mm d^{-1}].
Kc was estimated using satellite data through the relation between Kc and Normalize Difference Vegetation Index NDVI represented below (Eq. 2) which was developed by [19] and evaluated by [20].

$$K_C = \frac{1.2}{NDVI_{dv}}(NDVI - NDVI_{mn}) \tag{2}$$

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

Makkik (1957) proposed a method for ET estimation by using only temperature and radiation parameters [7] which was adopted in this research. The Makkik equation is as given below:

$$ET = 0.61\left(\frac{\Delta}{\Delta+\gamma}\right)\left(\frac{Rs}{\lambda}\right) - 0.12 \tag{3}$$

Where, Δ is the slope vapour curve (kPa °C−1); γ is the psychrometric constant (kPa °C−1); *Rs* is the solar radiation of the crop surface (MJm−2 day−1); and λ is the latent heat of vapour (MJ kg−1). The statistical analysis was carried out such as Coefficient of variance (CV), and trend analysis using Mann Kendall and Sen's slope for the annual and seasonal AET using AddinSoft XLStat software.

3. RESULTS AND DISCUSSION

3.1 Annual Trend and Variability of Actual Evapotranspiration

The AET was estimated from Kc and ET (Fig. 2A) which revealed that 2001 has the highest mean value followed by 2009 and 2014 while the 2010 has the lower value follows by 2011. Table 1 shows that the overall annual AET mean is 3.32 with standard deviation of 0.14. It has 4% coefficient of variance in the catchment. The temporal trend analysis of annual AET shows a negative trend. This result conforms to that of [21-23].

The annual AET maps (Fig. 3) were generated for the study area which revealed that it has increased spatially towards surrounding part from the centre i.e. Kaduna metropolis. The Apaka forest reserve situated in the North Western part lower river Kaduna catchment shows distinguished high AET in almost all of the year. Also the South Western part of the lower river Kaduna catchment area shown a high value of AET, whereas, the Kangimi Dam in the North Eastern part of the study area indicated lower AET value. In the central part of the study area where Kaduna metropolis is located also showed a low AET value, these exhibited similar pattern with Kc.

3.2 Seasonal Trend and Variability of Actual Evapotranspiration

Fig. 2B presented the winter (DJF) actual evapotranspiration time series. The results revealed that the year 2000 had the highest value follows by 2003. The similarity was observed in the year of 2006, 2009 and 2014. The lowest winter (DJF) AET was observed in 2007. It exhibits a downward slope. Table 1 shows that the winter (DJF) AET has an overall

Table 1. Statistical distribution of actual evapotranspiration of lower River Kaduna Catchment area

Statistic	Annual AET	DJF AET	MAM AET	JJA AET	SON AET
Mean	3.32	3.93	2.81	2.53	4.03
Variance	0.02	0.17	0.06	0.01	0.01
STD	0.14	0.41	0.24	0.12	0.12
CV	0.04	0.10	0.09	0.05	0.03
Z VALUE	-0.47	-0.39	0.18	-0.16	0.43
Sen's slope:	-0.02	-0.06	0.01	0.00	0.02

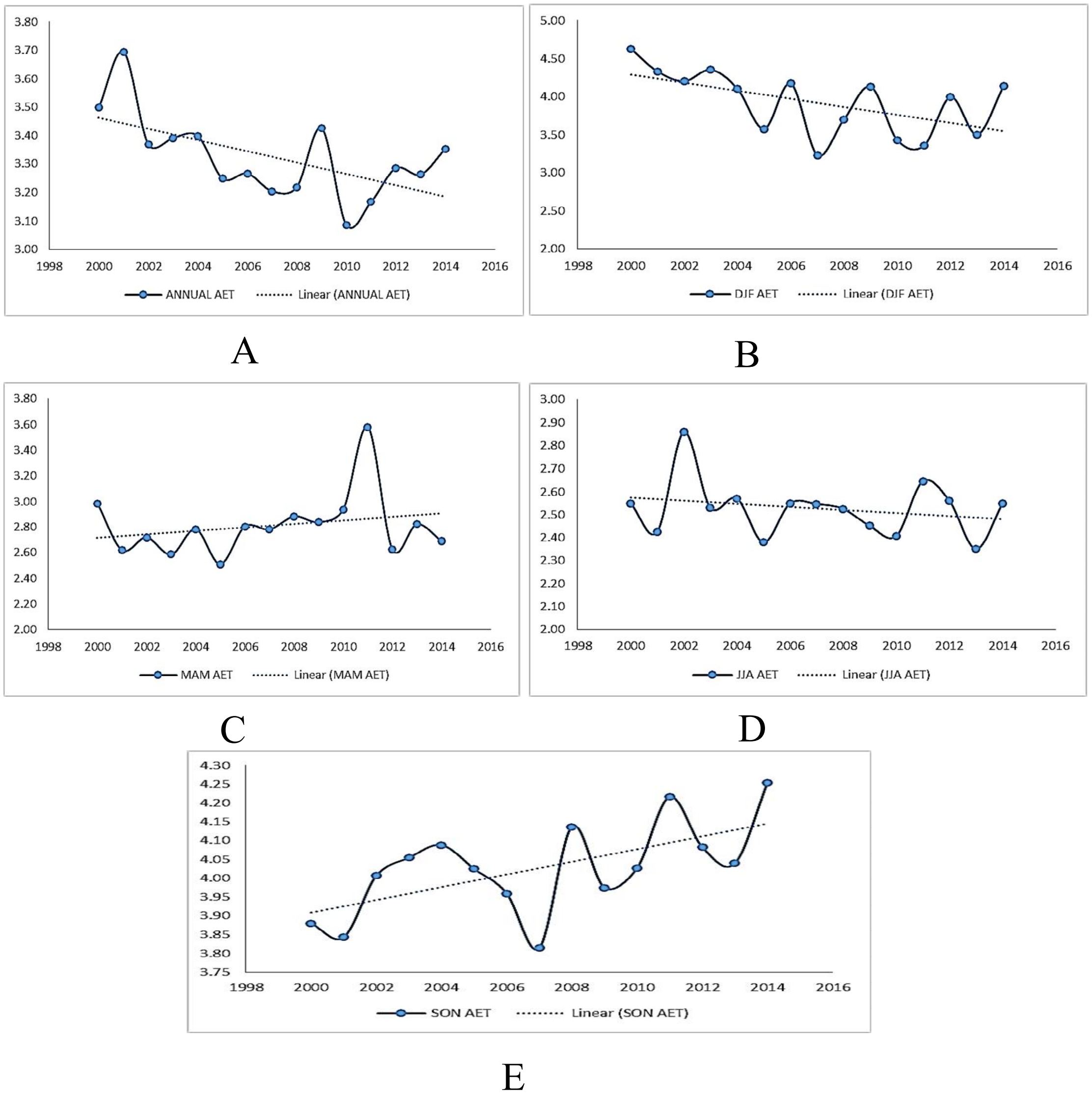

Fig. 2. AET time series of the catchment based on (A) annual, (B) winter: DJF (December, January, February), (C) spring: MAM (March, April, May), (D) summer: JJA (June, July, August) and (E) autumn: SON(September, October, November)

mean of about 3.93 with a standard deviation of 0.41. It has about 10% coefficient of variance with the negative trend. Fig. 4 presents the spatio-temporal distribution of winter (DJF) AET. The Apaka forest reserve situated in the North Western part of the lower river Kaduna catchment shows distinguished high AET. The South Western part of the lower river Kaduna catchment area showed the high value of AET, whereas the Kangimi Dam in the North Eastern part of study area indicated lower winter (DJF) AET value. In the central part of the study area where Kaduna metropolis is located also showed a lower AET value. Some northern part of the catchment showed a medium range of winter (DJF) AET.

From the Table 1, It shows that the spring (MAM) AET has an overall mean of about 2.81 with a standard deviation of 0.24 which less than that of winter (DJF). The coefficient of variance was about 9% for spring (MAM) AET of the catchment. The positive trend of AET during spring (MAM) for the period of study was observed. Fig. 2C revealed that 2011 had the highest value while 2000 and 2010 shared a close mean value. The lowest value was observed in 2005.

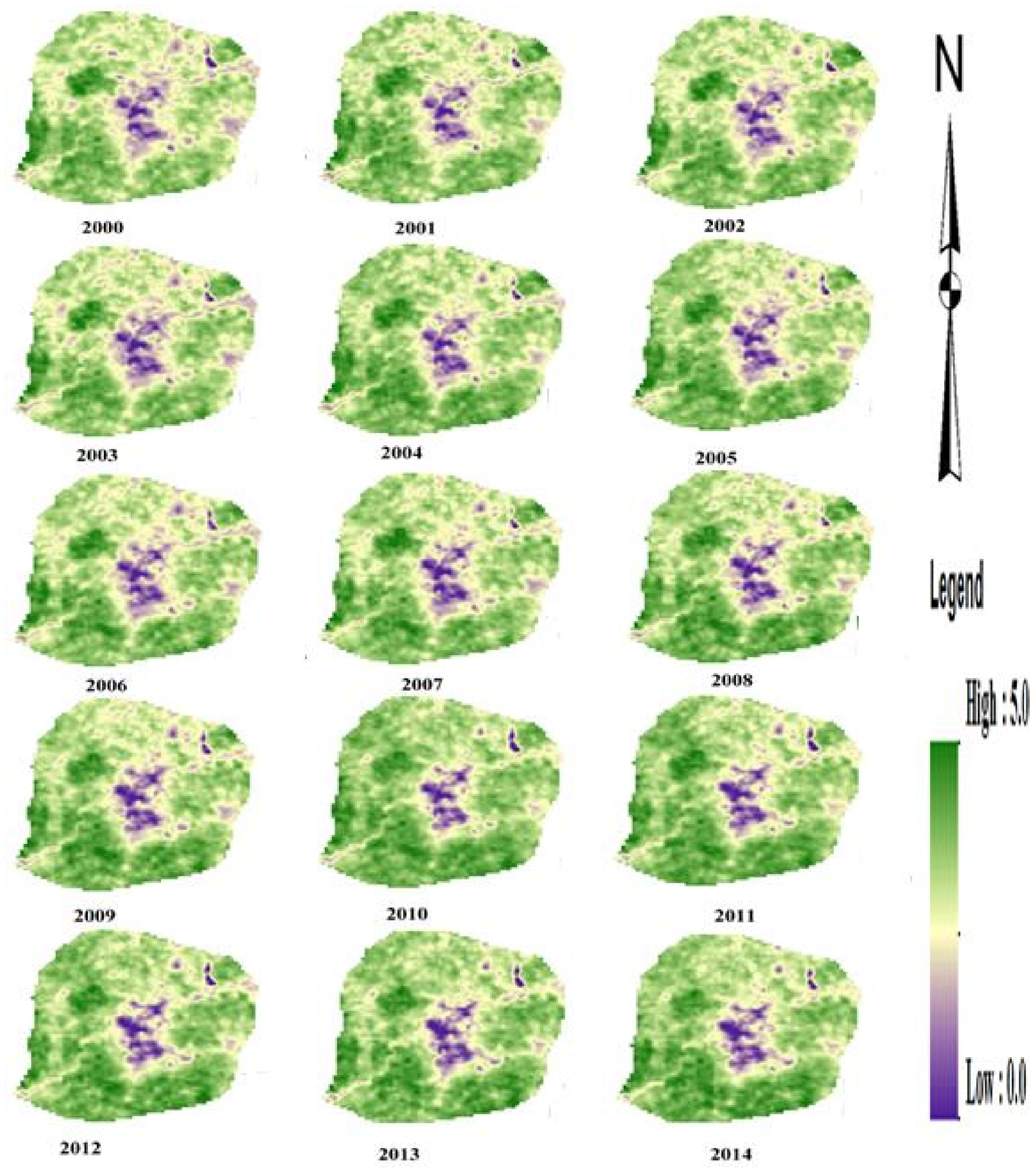

Fig. 3. Spatio-temporal variation of annual AET of Lower River Kaduna Catchment

The map of spring (MAM) AET was generated for the period of study (Fig. 5.) The result shows a variation in lower river Kaduna catchment area. During this season the AET reduced significantly compared with that of other seasons. However, the south part of the catchment had the highest AET value as well as that of Afaka forest reserved. The northern part had the medium range value, while the central part of the catchment and that of Kangimi dam in the northeast part had the lowest Kc value. The area at which the low value covered had increased.

In Fig. 2D, 2002 has the highest value of summer (JJA) AET. The lowest value was observed in 2005 and 2013 while 2004, 2006 and 2014 shared a close mean value. Table 1 shows that summer (JJA) AET had an overall mean of about 2.53 with a standard deviation of 0.12. The coefficient of variance was 0.05. The trend analysis of summer (JJA) AET indicated a

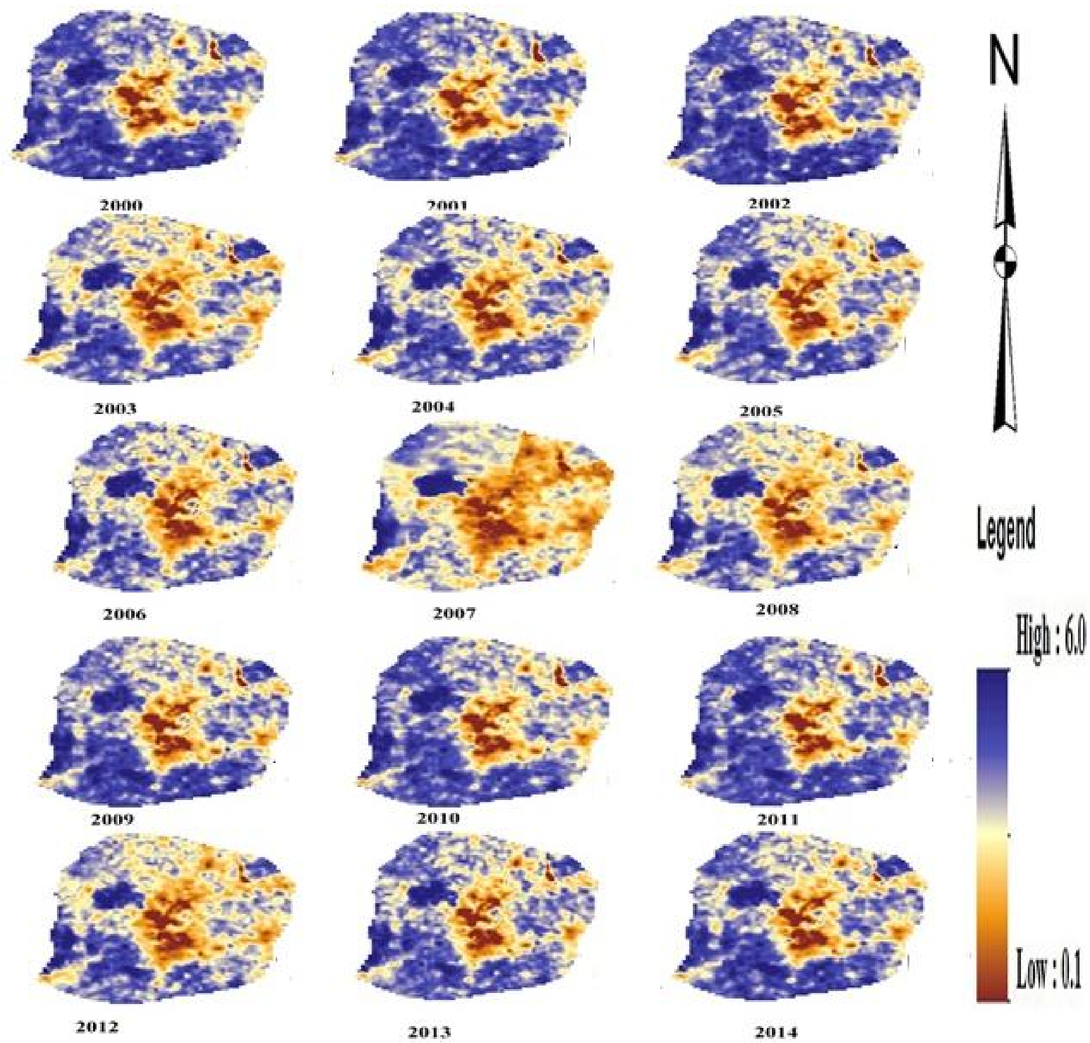

Fig. 4. Spatio-temporal variation of winter (DJF) AET of Lower River Kaduna Catchment

negative trend in lower river Kaduna catchment. The spatio temporal distributions of summer (JJA) were generated (Fig. 6). The result revealed that it has an increasing spatial pattern towards the surrounding part of the catchment. The Afaka forest reserved situated in the North West part shows distinguished high AET. Also, the northern and the eastern part of the catchment had a medium range of AET whereas in the south part of study area indicated high AET.

Fig. 2E showed that 2014 had the highest autumn (SON) AET value followed by 2011, 2008 and 2004. Similar AET value was observed in the year 2002, 2005 and 2010. 2007 had the lowest autumn (SON) AET value. Table 1 showed that autumn (SON) has the highest overall mean value of about 4.03 with a standard deviation of 0.12. The coefficient of variance is about 3%. The trend analysis of autumn (SON) AET revealed a positive trend in lower river Kaduna catchment area. The spatio-temporal distribution of autumn (son) AET is not the same for all the year. In Fig.7 revealed that the central, as well as the Kangimi dam in the northeast part of the catchment, has the lower value. The northern part of the catchment had a medium range value. Southern part and Afaka forest reserved in the northwest part of catchment had the highest value of autumn (SON) AET.

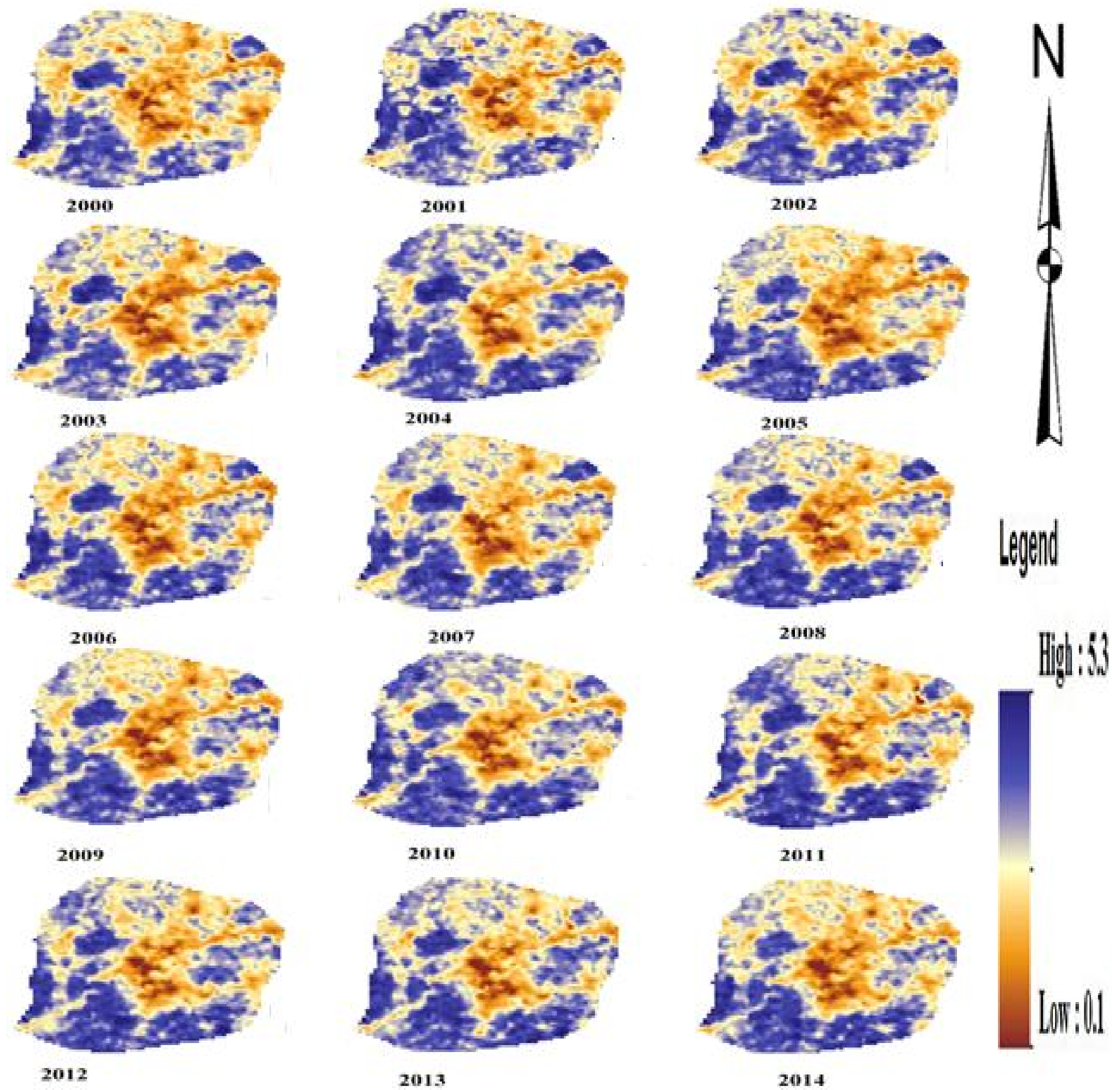

Fig. 5. Spatio-Temporal variation of Spring (MAM) AET of Lower River Kaduna Catchment

3.3 Discussion

It noted that during winter the water requirement by the plant was high. This can beclosely associated with characteristics of vegetation in the catchment [12]. The results also revealed that high AET variability was observed during winter and spring which can be attributed to the response of climatic condition during this period [12]. These are the periods where dry climate is experienced in the catchment. The increase of the amount of water required by vegetation was observed during autumn while during the summer there was a fluctuation of water required for the vegetation. The autumn can be associated with the full canopy of vegetation. This implied that the vegetation has fully grown. The later (summer) can be attributed to the rainfall variability in the catchment.

The negative temporal trend of annual and winter AET indicated the decrease of water requirement over time in lower river Kaduna catchment. This result of the decrease of AET might be related to the temporal absence of vegetation as observed in the catchment. It can clearly said that the evapotranspiration rate from plants mighty have exceed the evaporation from lakes, built up area and bare land, similar to the results of [24], It has been well established by experience and experiments that the rate of water loss from a bare soil, built up area and water bodies are less than from vegetated cover [24]. This is similar to what was observed in this study. Therefore, without a complete vegetative cover, the actual water loss rate is less. Besides driven essentially by climatic factors, the AET is also constrained by the amount of available water when the complicated influences of vegetation and soil are ignored [21]. These results provided a large number of possible uses for average water losses from land surfaces. Some examples are flood forecasting, climatic indices, assessment of the agricultural potential, and other water related problems in agriculture [24]. In nature, however, limited soil moisture frequently reduces the amount of water lost from land surfaces [24]. As a crop canopy develops, the ratio of transpiration to evapotranspiration increases, until most of the evapotranspiration comes from transpiration, and soil evaporation is a minor component.

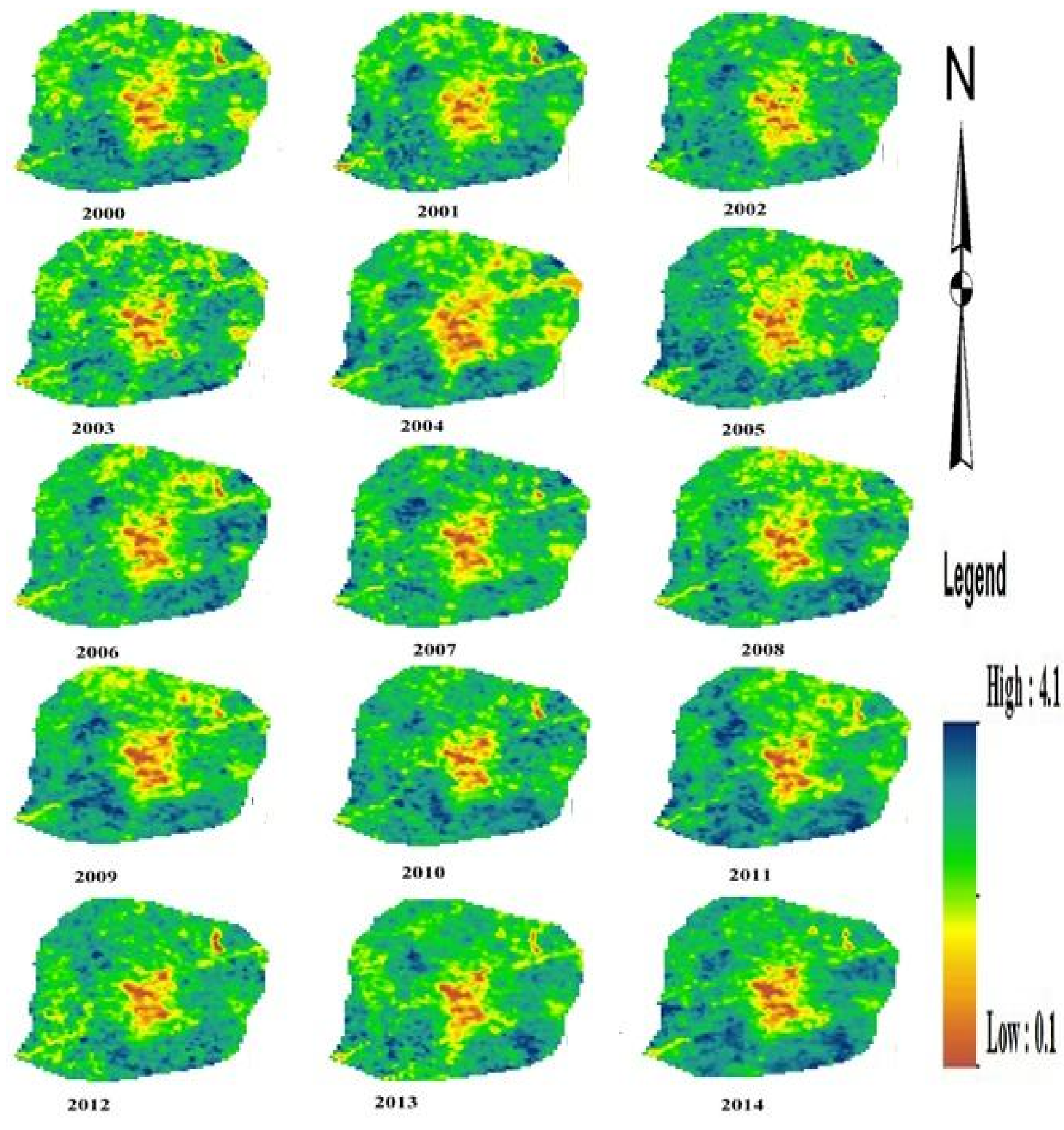

Fig. 6. Spatio-temporal variation of summer (JJA) AET of Lower River Kaduna Catchment

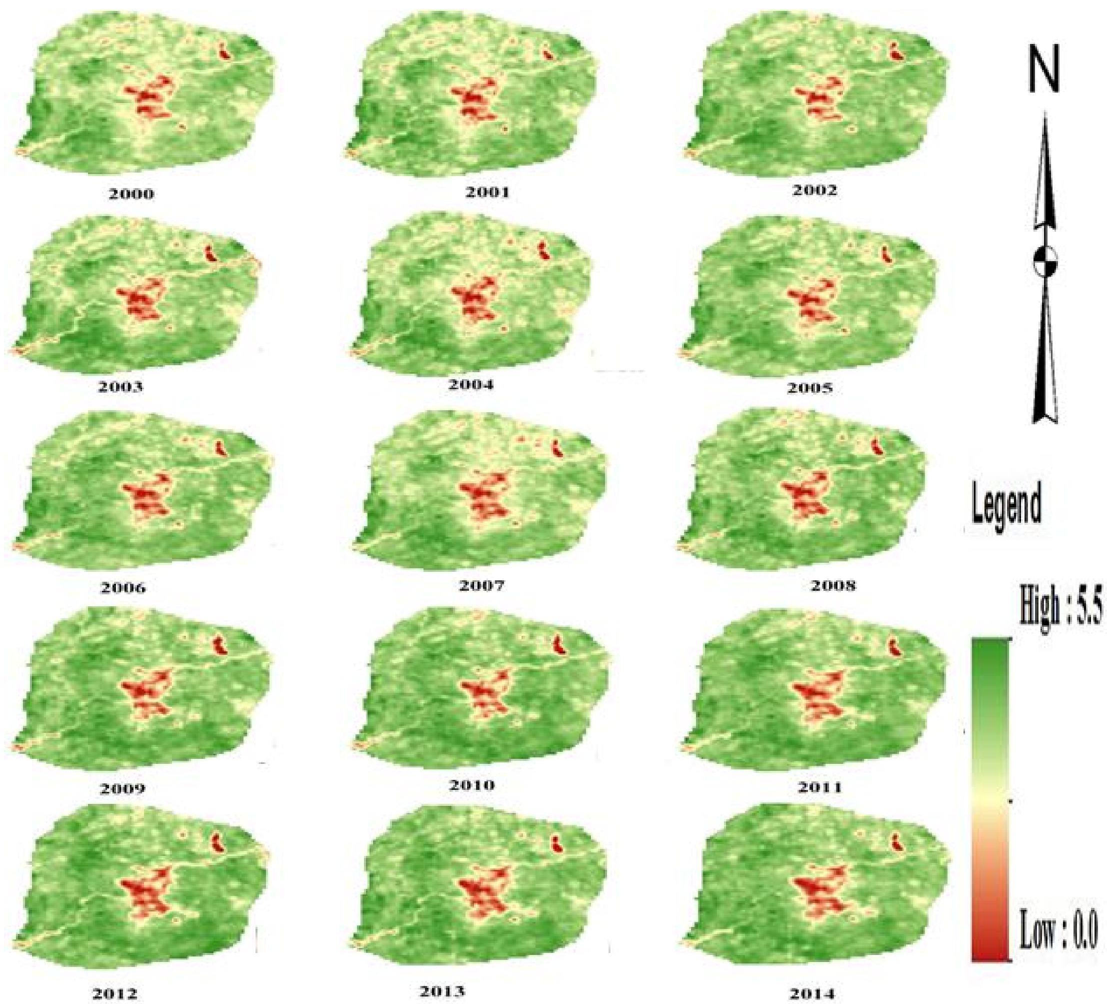

Fig. 7. Spatio-temporal variation of autumn (SON) AET of Lower River Kaduna Catchment

4. CONCLUSION

The estimated AET, showed a variation from one season to another as well as from one land use to another. The result revealed that the more the area is forested the high the amount of water required to sustain the area. These can infer that the influenced mechanism of spatial variation of AET is climate and vegetation in the lower river Kaduna catchment area. On this basis, climate and vegetation collectively controlled the spatial patterns of AET hence shaped the spatio-temporal patterns of AET in lower river Kaduna catchment area. Therefore, it is possible for utilization of remote sensing (RS) and geographical information system (GIS) tools in providing solution for integrated water resources management problems, especially water balance and irrigation water, through estimation of ET and crop water requirement in the study area.

ACKNOWLEDGEMENT

We sincerely thank NiMet Kaduna for providing meteorological data and Land Processes Distributed Active Archive Center (LP DAAC), NASA for providing free access to MODIS dataset. We also thank the reviewers for their invaluable comments and useful suggestions. We declare that the manuscript has not been published in any journal or other publication enterprises.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Dunn S, Mackay R. Spatial variation in evapotranspiration and the influence of land use on catchment hydrology. Journal of Hydrology. 1995;171:49-73.
2. Oguntunde PG, Olufayo AA. Impact of weather parameters on some models for predicting potential evapotranspiration. West Indian Journal of Engineering. 1999; 22(1):1-10.
3. Othoman A, Flores C, Jinno K, Tsutsumil A. Comparison of several reference evapotranspiration methods for Itoshima Peninsula Area, Fukuoka, Japan. Memoirs of the Faculty of Engineering. 2006;66(1): 1-14.
4. Oluwaseun AI, Philip GO, Ayorinde AO. Evaluation of four ET models for IITA stations in Ibadan, Onne and Kano, Nigeria. Journal of Environment and Earth Science. 2014;4(5):89-97.
5. Ramirez B, Harmsen W. Water vapour flux in agro ecosystems: Methods and models review. In L. Labedski, Evapotranspiration. INTECH Open Access Publisher. 2011;3-48.
6. Shahid S. Impacts of climate change on irrigation water demand in Northwestern Bangladesh. Climatic Change. 2011;105(3-4):433–453.
7. Nurul NA, Sobri H, Shamsuddin S. Comparison of different methods in estimating potential evapotranspiration at Muda Irrigation Scheme of Malaysia. Journal of Agriculture and Rural Development in the Tropics and Subtropics. 2012;115(2):77–85.
8. Mohammadian, Mohsen, Ramin Arfania, Hossein Sahour. Evaluation of SEBS algorithm for estimation of daily evapotranspiration using landsat-8 dataset in a Semi-Arid Region of Central Iran. Open Journal of Geology. 2017; 7.03:335.
9. Allen RG, Pereira SL, Raes D, Smith M. Crop evapotranspiration-guidelines for computing crop water requirements. FAO Irrigation and Drainage. 1998;56.
10. Peter EA. An assessment of rainfall and temperature variations in selected stations in parts of Northern Nigeria. Unpublished PhD thesis, University of Jos.; 2012.
11. Deloitte AW. Draft report on IBP rural water supply study. Lagos: Deloitte West and Central Africa, Deloitte Touche Tohmatsu; 2006.
12. Daniel Aimaje Attah. Climate variability and its impact on water resources of lower kaduna river catchment Nigeria. Unpublished Phd Thesis, ABU Zaria. 2013; 1-189.
13. Saleh Y, Badr AM, Elbanna F, Shahata A. agricultural land-use change and disappearance of farmland in Kaduna Metropolis Nigeria. Science World Journal. 2014;9(1):1-7.
14. Liu WX, Li XD, Shen ZG, Wang DC, Wai OW, Li SY. Multivariate statistical study of heavy metal enrichment in sediments of the Pearl River Estuary. Environmental Pollution. 2003;51:377-388.
15. Maina MM, Amin MS, Aimrun W, Asha TS. Evaluation of different ET calculation methods: A case study in Kano State, Nigeria. Philipp Agric Scientist. 2012; 58(2):394–399.
16. Omonijo AG. Rainfall amount and numbers of rainy days in Kaduna, Northern Nigeria-implication on crop production. International Conference on Agricultural, Ecological and Medical Sciences. 2014; 3(4):6-12.
17. Bamgboye OA. Brief on the field trip to kaduna water supply system; Background Reference Session 19 Field Trip; TOT-IWRM 2004 Program; 2004.
18. Ndabula C. Assessment of land use/landover changes in Kaduna Metropolitan area using remote sensing and geographic information system techniques. Unpublished Msc Thesis, Abu Zaria. 2006;137.
19. El-Shirbeny MA, Ali AM, Badra MA, Bauomy EM. Assessment of wheat crop coefficient using remote sensing techniques. World Research Journal of Agricultural Sciences. 2014a;1(2):12-17.
20. El-Shirbeny MA, Aboelghar MA, Arafat SM, El-Gindy AG. Assessment of the mutual impact between climate and vegetation cover using NOAA-AVHRR and Landsat data in Egypt. Arabian Journal of Geosciences. 2014b;7(4):1287-1296.
21. Ge G. Changes of evapotranspiration and water cycle in China during the past decades. Chalmers Reproservice Gothenburg; 2010.
22. Farg E, Arafat SM, Abd El-Wahed MS, El-Gindy AM. Estimation of evapotranspiration ETc and crop coefficient Kc of wheat, in South Nile Delta of Egypt Using integrated FAO-56 approach and remote sensing data. The

Egyptian Journal of Remote Sensing and Space Sciences. 2012;15:83–89.
23. Singh SK, Sujay D, Nishith D. Estimation of crop evapotranspiration of cotton using remote sensing technique. International Journal of Environmental Engineering and Management. 2013;4(5):523-528.
24. Joe RE. Pan evaporation, potential and actual evapotranspiration. Journal of Applied Meteorology. 1967;6:482-488.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/20181