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Effect of Climate Change on Water Balance of Lower Ogun River Basin

[1*]Eruola A. O., [1]Ufeogbune G. C., [2]Eruola A. A., [1]Idowu O. A., [1]Oluwasanya G. O. and [1]Ede V. A.

[1]Federal University of Agriculture, Abeokuta, Nigeria.
[2]Yaba College of Technology, Lagos, Nigeria.

*Corresponding author: E-mail - layosky@yahoo.com, Phone - 08057354226

Abstract

The lower Ogun River is highly vulnerable to climate change due to its geographic location at the southern edge of western Nigeria and water management planners are facing considerable uncertainties on future demand and availability of water. This study was carried out to investigate the effect of climate change on water balance of lower Ogun River basin. The procedure of Ayoade (1976) water balance bookkeeping model was followed in computation. The temperature and water balance components were compared using descriptive statistics. The result showed that climate change influences the water balance components: rainfall, evapotranspiration, runoff and change in storage. Recurrent dry spells were encountered in the years 1988, 1990, 1998, 2006 and 2009. However, in the recent years increasing rainfall amount have been observed to cause flood that displaces most inhabitance of the lower basin area. Rainfall variability, land degradation and desertification are some of the factors that may also contribute to variation in the component of the hydrologic cycle in the river basin. The recurrent dry spells and flood encountered in the basin represented a particularly trying episode for the area, with massive losses of agricultural production and its consequence on human lives and domestic economies. Thus, climate change may become a great obstacle to the achievement of the Millennium Development Goals (MDGs) to which the Government of Nigeria is committed.

Key words: Climate, water balance, basin, Ogun, aridity

Introduction

Water management planners are facing considerable uncertainties on future demand and availability of water. This uncertainty has been attributed to climate change and its potential hydrological effects. The increasing concentration of greenhouse gases in the atmosphere according to Second Assessment of the Intergovernmental Panel on Climate Change (IPCC. 1996) is likely to cause an increase in global average temperature. The impact of climate change scientific assessment model suggested that global average temperature may increase between 1.5^{O}C and 4.5^{O}C, with the best estimates of 2.0^{O}C in the next century with the doubling of CO_2 concentration in the atmosphere (Houghton et al. 1996). This increasing temperature will lead to a more vigorous hydrological cycle, with changes in precipitation and evapotranspiration rates regionally variable (Houghton et al. 1996). These changes will in turn affect water availability and runoff and consequently the discharge regime of rivers. This is more so that rainfall is characterized by seasonal variability and unpredictable distribution in the tropics particularly in Nigeria (Bello, 1997). The potential effects on discharge extreme that determine the design of water management regulations and structures are of particular concern (Akintola , 2001); since changes in extremes may be larger than changes in average figures, climate change may potentially have major consequences on the use and management of dams and other water bodies at large (Adejuwon, 2004). Regarding the potentially large socio-economic impacts, it has become recognized that climate induced changes in the water regime of dam and their effects should be factored into water management (Deressa *et al*., 2005). Research over the last few decades has devoted a lot of efforts on the development of useful technologies in response to the various constraints and stresses facing water resources management and planning. Observational evidence from all continents and most oceans shows that many natural systems are also being affected by anthropogenic climate changes (Reinsborough, 2003). Adaptation to climate change is, consequently, of urgent importance. The impacts will certainly vary considerably from region to region and even from basin to basin, causing serious challenges for water resources management (Mendelsohn and Dinar, 2003). This study therefore examines the effect of climate change on water balance of lower Ogun River basin.

Materials and Methods

Water Balance was computed using Thornthwaite's water balance bookkeeping model following the procedure of Ayoade (1976). The procedure involves the determination of

i. The mean monthly precipitation (rainfall) (P).
ii. Monthly calculated values of potential evapotranspiration (PE)
iii. Difference between precipitation and potential evapotranspiration (P - P.E) - Negative values means the amount by which precipitation fails to satisfy water need of vegetation, while a positive value means the amount of excess water available for soil and groundwater recharge.
iv. Accumulated Potential Water Deficit (ACPWD) – This is the sum of negative values of P - P.E.
v. Storage (ST) – This value was read from appropriate table of soil moisture retention with values corresponding to the obtained value of accumulated potential water deficit. The soil moisture retention table of 250mm was used since it was assumed that the study area is highly forested.
vi. Change in storage (ΔST_n) was obtained as follows:

$$\Delta ST_n = ST_n - ST_{n-1} \quad (1)$$

where ΔST_n = change in storage for month n,
ST_n = moisture storage for month n, and
ST_{n-1} = moisture storage for proceeding month.

vii. Actual evapotranspiration (A.E) was obtained as follows:
If $P \geq P.E$ then $A.E = P.E$
If $P < P.E$ then $A.E = P - \Delta ST_n$, hence $A.E < P.E$
viii. The water deficit (D) was obtained from $D = P.E - A.E$
ix. Water surplus (S) where the soil is at field capacity is given as:

$$S = (P - P.E) - \Delta ST_n \quad (2)$$

x. When computing the monthly runoff (Q) it was assumed that following Thornthwaite and Mather (1957) only 50% of the surplus water was available for runoff in a given month actually runs off, the other 50% is retained in the study area and made available for the runoff the following month.

Monthly meteorological data covering a period of 30 years (1981 - 2010) for lower Ogun River was used as required for climate change study. The data used includes wind speed (m/s), mean temperature (o C), rainfall (mm), relative humidity (%), and sunshine hours (hours). The PE was estimated using Penman approach. Abeokuta, Ijebu-Ode and Lagos were selected for this study because of their locations in the lower part of the Ogun River basin and the consistency in the availability of meteorological records for considerable length in the station. Other required variables, of which measured values were not available but were estimated using meteorological table (Shaw, 1994) for the estimation of PE were radiation received at the top of the atmosphere (Ra) in mm/day, daily maximum possible sunshine duration (N), mean saturated vapour pressure (ed), Blackbody radiation (σTK4) in mm of water weighting factor for effect of temperature and altitude (w). Data were also subjected to descriptive statistic to determine the relationship among temperature and the components of water balance.

Description of the Study Area

Ogun River basin lies within latitude $6^{O}33'$-9^{O}'N and longitudes $2^{O}40'$-$3^{O}45'$ E in the rain forest zone of Nigeria covering a total area of 23,700km^2 (Figure 1). The climate is influenced by cooling, rainfall- bearing southwest monsoon blowing from the hot Atlantic Ocean and dry season by the continental North Easterly harmattan winds from the Sahara desert. The area is located within a region characterized by bimodal rainfall pattern (commences in March and is plentiful in July and September, with a short dry spell in August). The long dry period extends from November to March. The basin area is characterized by strong climatic variations and an irregular rainfall that ranges between 1250 and 1400mm with coefficients of variation ranging from 15 to 30 percent (Fox and Rockström, 2003; CILSS, 2004) and mean annual air temperature of about 30^{O}C in the basin area and environs. The topography of the basin reflects the contrast between the hummocky terrain underlain by the crystalline rocks north of Abeokuta, with its compact drainage pattern, and thickly forested undulating hills and swampy lowlands of the sediments to the south (Martins, 1987). Agriculture is predominantly rain-fed. Climate variability therefore poses one of the biggest obstacles to the achievement of food security and poverty reduction in the region.

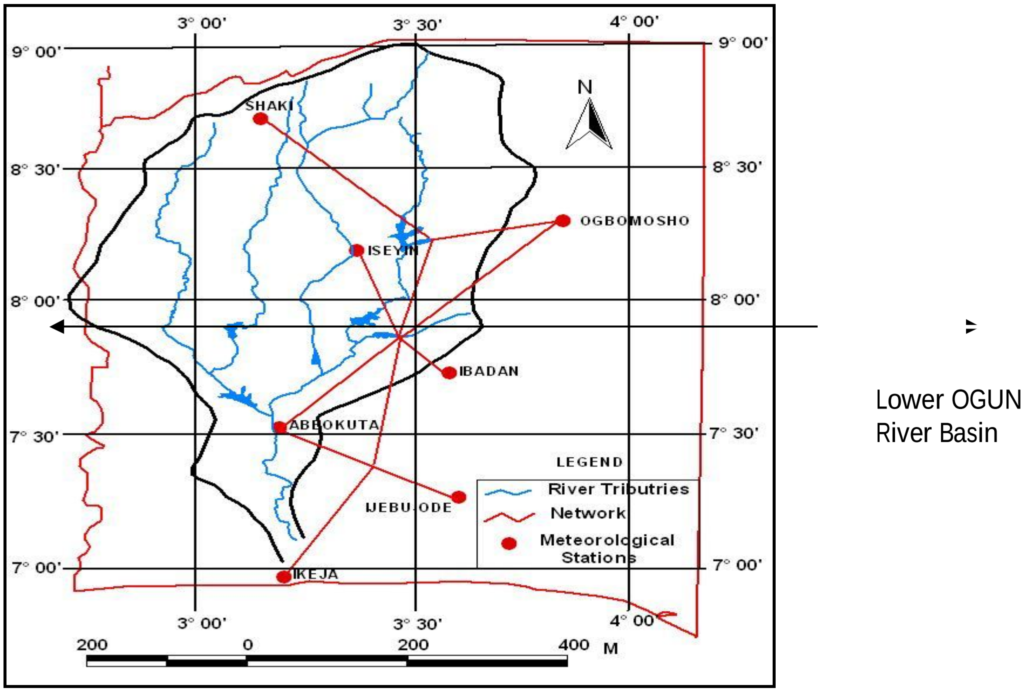

Fig. 1: Map showing the Ogun River basin area in Nigeria.

Results and Discussion

Climate variability poses one of the biggest obstacles to water resources management and the achievement of food security and poverty reduction in the basin area. In the last three decades, the river basin experienced annual mean variation in Temperature with the highest range in 1990 - 1999 (27.5 - 29.0^{O}C), followed by 2000 - 2010 (27.0 - 29.0^{O}C) then 1981 - 1989 (26.5 - 29^{O}C). Six major drought years including 1982, 1987, 1994, 2002 and 2006 were experienced and the long period of sustained declining rainfall (the 'desiccation') that spanned most of the 1990s and continued with some interruptions into the 2000s (Figure 2). The desiccation was a dramatic episode for the Ogun River basin. The annual rainfall values of 700 mm of 2006 was the lowest recorded in the last three decades, but severe dry spells of annual rainfall values of 800 mm also occurred in 1982 and 1987.

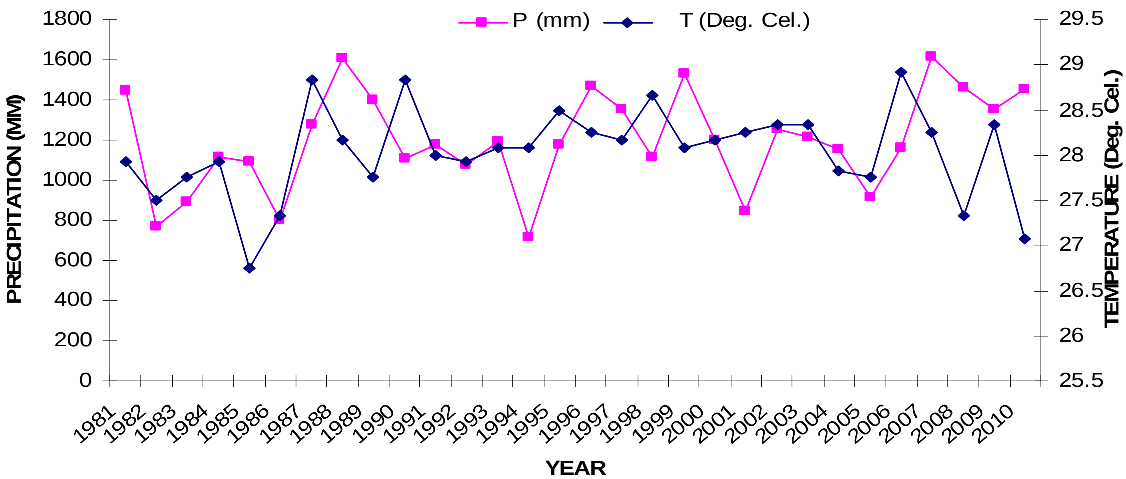

Fig. 2: Graph showing precipitation and temperature for Abeokuta (1981 - 2010)

There is now scientific consensus that the global climate is changing. Global mean temperature increased by 0.6 degree C in the last century, with the hottest years ever in record occurring after 1990. This is as evident in the temperature variation pattern observed in the graphs. Warming of the world climate has been linked to a higher concentration of greenhouse gases (GHGs) in the atmosphere, the consequences of which can be manifested in the higher frequency of extremes such as floods, droughts and cyclones. The lower Ogun River basin has had its fair share of changes. While rainfall variability is a major characteristic of the river basin, the first half of the 1990's and 2000's has witnessed a dramatic reduction in mean annual rainfall at the lower part of the basin as illustrated by Figure 2.

The downward trend of rainfall during the first half of the 1990's affected the lower part of basin with tragic consequences it had on its people and economies, was a wakeup call to the rural communities, whose economies, are heavily based on agriculture and livestock. The prolonged aridity further stretched the very little resources of these basin areas, with devastating consequences such as hunger and malnutrition, deterioration of soil and water resources, desertification and widespread misery.

Arid conditions are likely to be exacerbated in the years where an increase in precipitation is predicted because of a higher evapotranspiration regime due to higher temperatures as it is the case in 1988, 1990, 1998, 2006 and 2009 (Figures 3 & 6). Extremes in the form of aridity and floods will be more frequent, putting an additional pressure on already stressed systems.

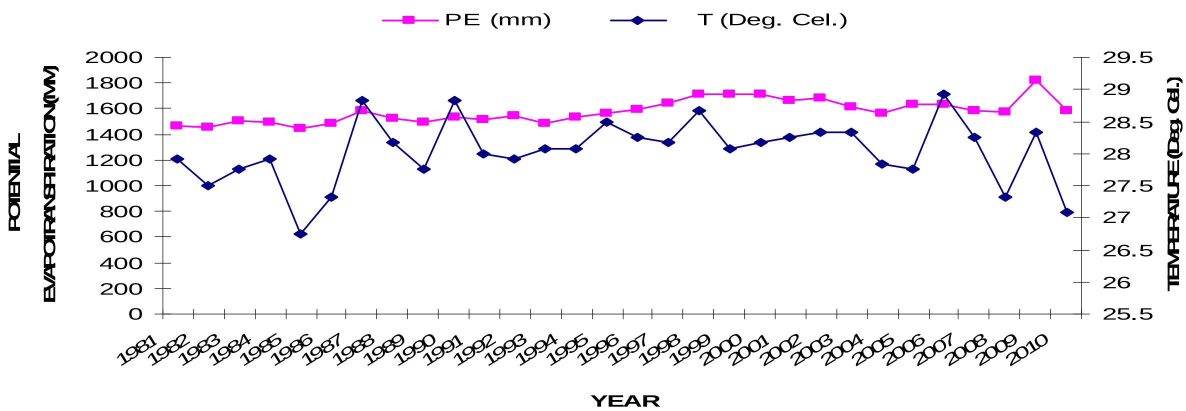

Fig. 3: Graph showing potential evapotranspiration and temperature for Abeokuta (1981 – 2010)

The change in storage (soil moisture storage and ground water storage) rises in the years where higher evapotranspiration regime occurred due to higher temperatures as it is the case in 1988, 1990, 1998, 2006 and 2009 (Fig. 4 & 6). This might be as a result of soil and water conservation practices that reduce runoff through improved infiltration capacity and soil transmission characteristics. This implies that deforestation along the lower Ogun basin has not totally turned the area into a derived savanna.

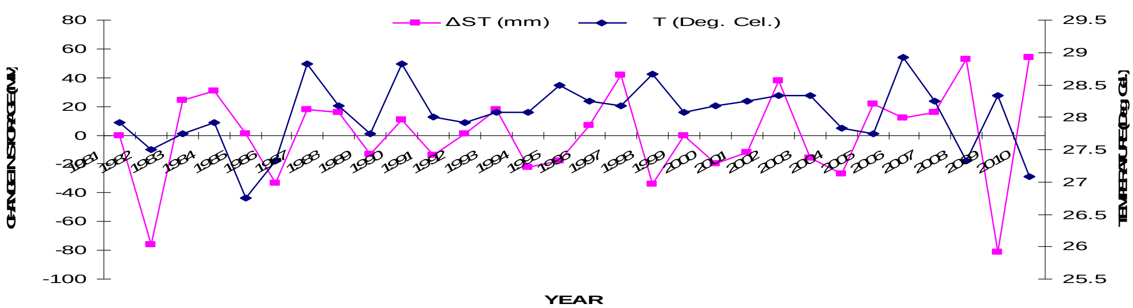

Fig. 4: Graph showing change in storage and temperature for Abeokuta (1981 – 2010)

The discharge (runoff) is also on the decline in the years where higher evapotranspiration regime occurred due to higher temperatures as it is the case in 1988, 1990, 1998, 2006 and 2009 (Fig. 4 & 6).

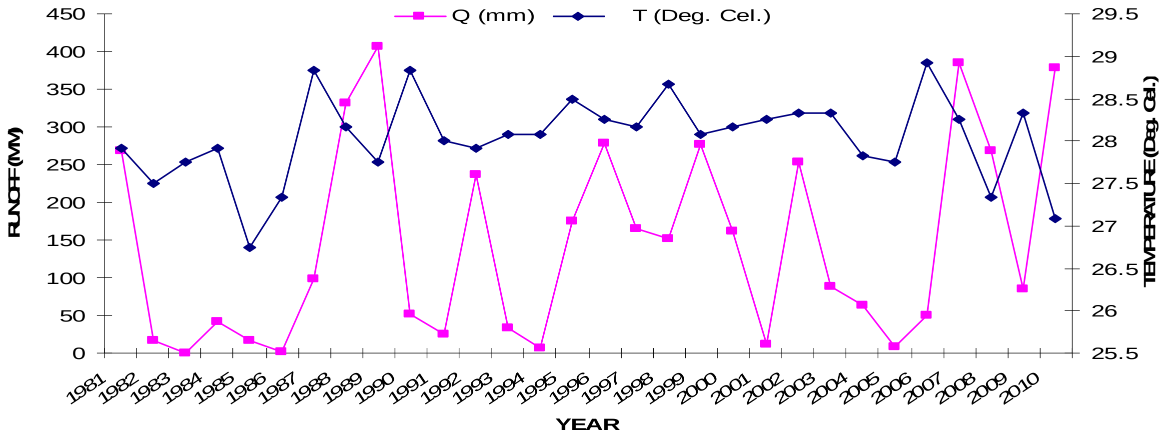

Fig. 5: Graph showing runoff and temperature for Abeokuta (1981 – 2010)

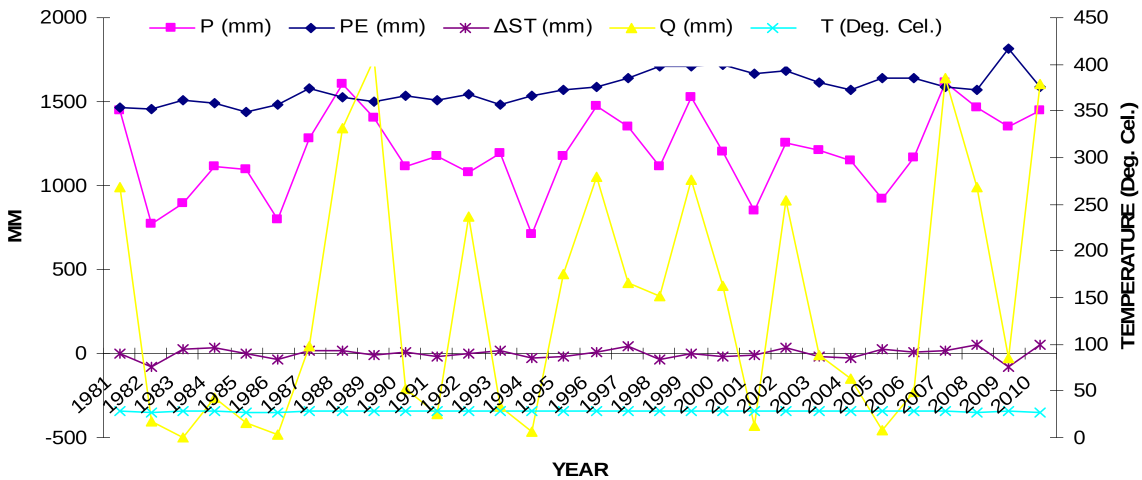

Fig. 6: Graph showing water balance components and temperature for Abeokuta (1981 – 2010)

Conclusion and Recommendation

Rainfall variability is a major driver of vulnerability in the basin. However, blaming the 'environmental crisis' on low and irregular annual rainfall alone would amount to a sheer oversimplification and misunderstanding of the basin dynamics. Climate is nothing but one element in a complex combination of processes that has made water resources management, agriculture and livestock farming highly unproductive. Over the last three decades, the combined effects of population growth, land degradation (deforestation, continuous cropping and overgrazing), reduced and erratic rainfall, lack of coherent environmental policies and misplaced development priorities, have contributed to transform a large proportion of the basin into barren land, resulting in the deterioration of the soil and water resources. The intertwined processes of land degradation and desertification, which have prevailed in the basin over the last few decades, are nothing more than the embodiment of a degenerative process that started several decades back.

The dry years of the 1982, 1987, 1994, 2002 and 2006 were not necessarily the cause, but certainly the culmination, of this environmental crisis. Even if the components of water balance and rainfall in particular have come back to near-normal and food security improved in recent years, the lower part of the Ogun River basin remains an environmentally sensitive region and climate change is likely to exacerbate the vulnerability of its ecological and socio-economic systems.

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