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Application of MIKE SHE software for estimation of groundwater recharge in Ogun and Oshun basins, southwestern Nigeria

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Abstract

MIKE SHE software was used to estimate recharge into the aquifers of Ogun and Oshun Basins. Abeokuta within the Ogun Basin and Oshogbo in the Oshun Basin are sub-divided vertically into two components: atmosphere, and unsaturated zone. The atmosphere zone comprises of rainfall and potential evapotranspiration, while the unsaturated zones, comprises of the Basement Complex and Sedimentary rock. Daily records from two rainfall stations, Oshogbo station (2008–2011) and Abeokuta station (2010–2014) water years were obtained for simulation of groundwater recharge processes using MIKE SHE model. The simulation results showed that daily groundwater recharge is influenced by rainfall and ranges from 0 mm·day^{-1} in January when there was an insufficient rainfall in the two stations to 10.89 mm·day^{-1} in Abeokuta and 29.85 mm·day^{-1} in Oshogbo in the month of August when the soils had attained field capacity. The study found out that there are more daily groundwater recharge in Oshun basin compared to that of Ogun basin. This was alluded to more rainfall and less evapotranspiration recorded at Oshun basin as compared to Ogun basin coupled with the sedimentary soil which allows more movement of water into the aquifer of the basin. It is recommended MIKE SHE model should be used to estimate recharge in other basins in Nigeria and Africa for quick and effective daily recharge calculations to permit better and scientific decision making in these areas.

Key words: *groundwater recharge, hydrological parameters, meteorological parameters, MIKE SHE model, Ogun basin, Oshun basin*

INTRODUCTION

The need to estimating groundwater recharge into the aquifer of a basin is to achieve quantification of water reaching the water table for water resources planning purposes. Groundwater remain a viable source of water supply to many populace in the world. There has been great concern on access, quality and use of technology on the surface water especially in the developing where the demands on the water supply has risen due to increase population. The groundwater, with relative quality and access, therefore needs to be evaluated regularly to ascertain rate of its replenishment, flow and quality for policy and development purposes [DE VRIES, SIMMERS 2002; LEWIS, WALKER 2002; SCANLON, COOK 2002].

In this study area, there are established agencies that manages river basins such as the eleven River Basins Authorities across Nigeria and Nigeria Hydrological Agency that predict and forecast the likelihood of flooding from the basins. There are also State Water Corporations that make use of water from these basins for water supply. These agencies depend on accurate estimate of groundwater recharge and have failed to accurately measure the rate and amount of groundwater recharging the aquifers in their respective regions, thereby making proper planning impossible. Equally, this aspect of research has witnessed limited effort from researchers and scientists, especially within this study area. Few researchers, such as IDOWU and MARTINS [2007] and OGUNKOYA [2000] had worked on estimating recharges in some catchments in South-West of Nigeria using hydrograph analysis and water balance methods.

OKE *et al*. [2015] and OKE *et al*. [2016] equally used soil budget analysis, empirical analysis, water table fluctuation and hydrograph analysis in evaluating groundwater in some of the basins using monthly meteorological and hydrological data. However, the incessant issues of flooding, drought and overexploitation of groundwater for domestic and industrial uses make daily recharge estimation necessary for easy planning and quick decision making.

One of the methods that can be used, not only for estimating daily recharge, but to forecast future groundwater changes, is hydrological modelling technique [DE VRIES, SIMMERS 2002; SCANLON, COOK 2002]. Consequently, several models were developed and utilized to estimate groundwater recharge, such as Soil and Water Assessment Tool (SWAT) model [USDA-ARS 2014]; MODFLOW and MODPATH [MONDAL, SINGH 2009] and MIKE SHE [DHI 2007]. Various researchers had utilized these models to solve many hydrological challenges. For instance, [LUBCZYNSKI, GURWIN 2005] used MODFLOW model to examine the inconsistency of recharge in Spain. SMERDON *et al.* [2009] used MIKE SHE to estimate evapotranspiration and recharge for northern Okanagan basin in British Columbia. Also, SHAMUYARIRA [2017] used MIKE SHE to determine the recharge and groundwater potential in Mhinga Area, South Africa. This study presents the result of the use of MIKE SHE model in estimating groundwater recharge in Ogun and Oshun basins which has not been done before in the study area.

STUDY MATERIAL AND METHODS

GENERAL INFORMATION

In line with the recommendations of LERNER *et al.* [1990], and COMBALICER *et al.* [2008] on methods useful to carryout recharge estimation in humid regions, which include but not limited to empirical method, soil budgets, hydrograph analysis, hydrological modelling, tracer method, this study used hydrological modelling – MIKE SHE to evaluate groundwater recharge in the Ogun and the Oshun basins. MIKE SHE hydrological model was used to estimate recharge in the Ogun and the Oshun basins, southwestern Nigeria.

In this study, both the Abeokuta within the Ogun basin and Oshogbo within the Oshun basin are sub-divided vertically into two components: atmosphere, and unsaturated zone. In the atmosphere component, climatic parameters considered were rainfall and potential evapotranspiration. In the case of the unsaturated zone, the two geologic formations in the study area – basement complex and sedimentary rock were considered. Daily rainfall data were collected from two major synoptic stations in the study area – Abeokuta and Oshogbo. They are four years for Oshogbo (2008–2011) water year and five years for Abeokuta (2010–2014) water year. These rainfall data were used for estimation of groundwater recharge using MIKE SHE model. However, monthly rainfall and evaporation data were collected for Abeokuta, Ikeja, Oshogbo and Ijebu Ode synoptic stations. The study areas – Ogun basin and Oshun basin, are described separately in the sections that follow to reveal their characteristics.

OGUN BASIN

The basin is located at latitudes 6°33' N and 8°58' N, and longitudes 2°28' E and 4°8' E (Fig. 1) in southwestern Nigeria. It occupies a total area of about 24,096 km^2 covering three states in Nigeria: Ogun, Lagos, and Oyo States. About 2% (400 km^2) of the basin falls within Lagos State, about 20% of the basin (4,700 km^2) falls within Ogun State, while the remaining 78% (13,600 km^2) falls within the boundary of Oyo State. The Ogun River originates from Iganran Hills (el. 503 m a.s.l.) located on the eastern side of Saki, in Oyo State [OORBDA 1982a]. It flows southwards for a distance of 307.31 km and empties into the Atlantic Ocean. The main tributary of the Ogun River is the Oyan River. The Oyan River rises from the western side of Saki and stretches up to 189.07 km. The Ofiki and Opeki Rivers are major tributaries of the Oyan and the Ogun Rivers, respectively. The total length of the Ofiki River is 157.12 km while that of Opeki length is 70 km.

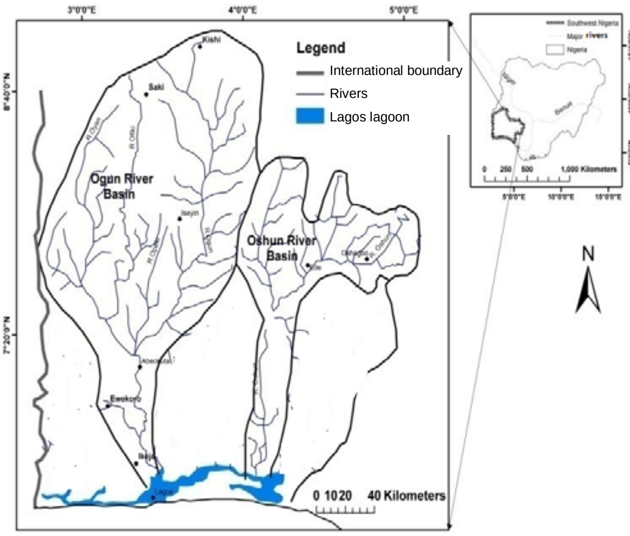

Fig. 1. Drainages of Ogun and Oshun basins; source: OKE *et al*. [2015] modified

The topography in the North ranges in elevation from 370 m to the highest point at 495 m (Fig. 2), located to the West of Saki. In terms of rock types, sedimentary rocks are found in the southern section while remaining sections are composed of crystalline rocks of the basement complex (Fig. 3). The land use map (Fig. 4) shows that the dominant land use is intensive row crops and minor grazing. The soil groups for the Ogun River basin, based on the Harmonized World Soil Database (HWSD) are the Arenosols, Leptosols, Lixisols, Vertisols and Nitisols [FAO 2009] (Fig. 5).

OSHUN BASIN

Oshun basin lies to the East of the Ogun River basin, on latitudes 6°30'–8°20' N and longitudes 3°57'–5°10' N (Fig. 1). The Oshun basin occupies about 9,741 km^2 out of which 107 km^2 (1.1%) falls within Lagos State, 1,203 km^2 (12%) falls within Ogun State, while 8,390 km^2 (86.13%) falls within the boundary of Oyo State. The Oshun River

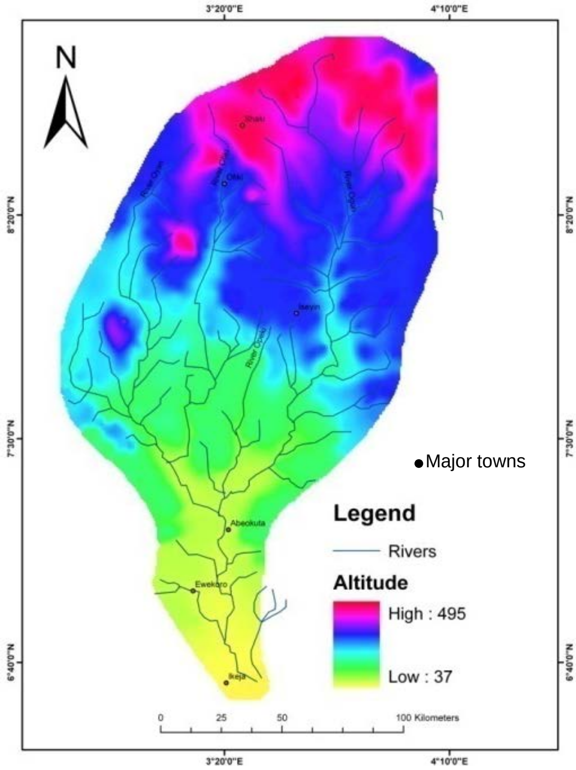

Fig. 2. Elevation map of Ogun basin; source: own elaboration

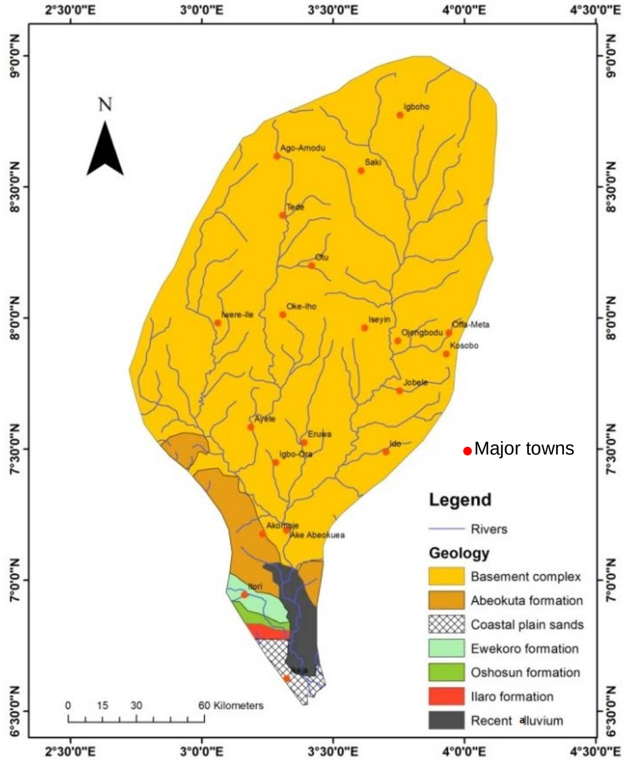

Fig. 3. Geological map of Ogun basin; source: own elaboration

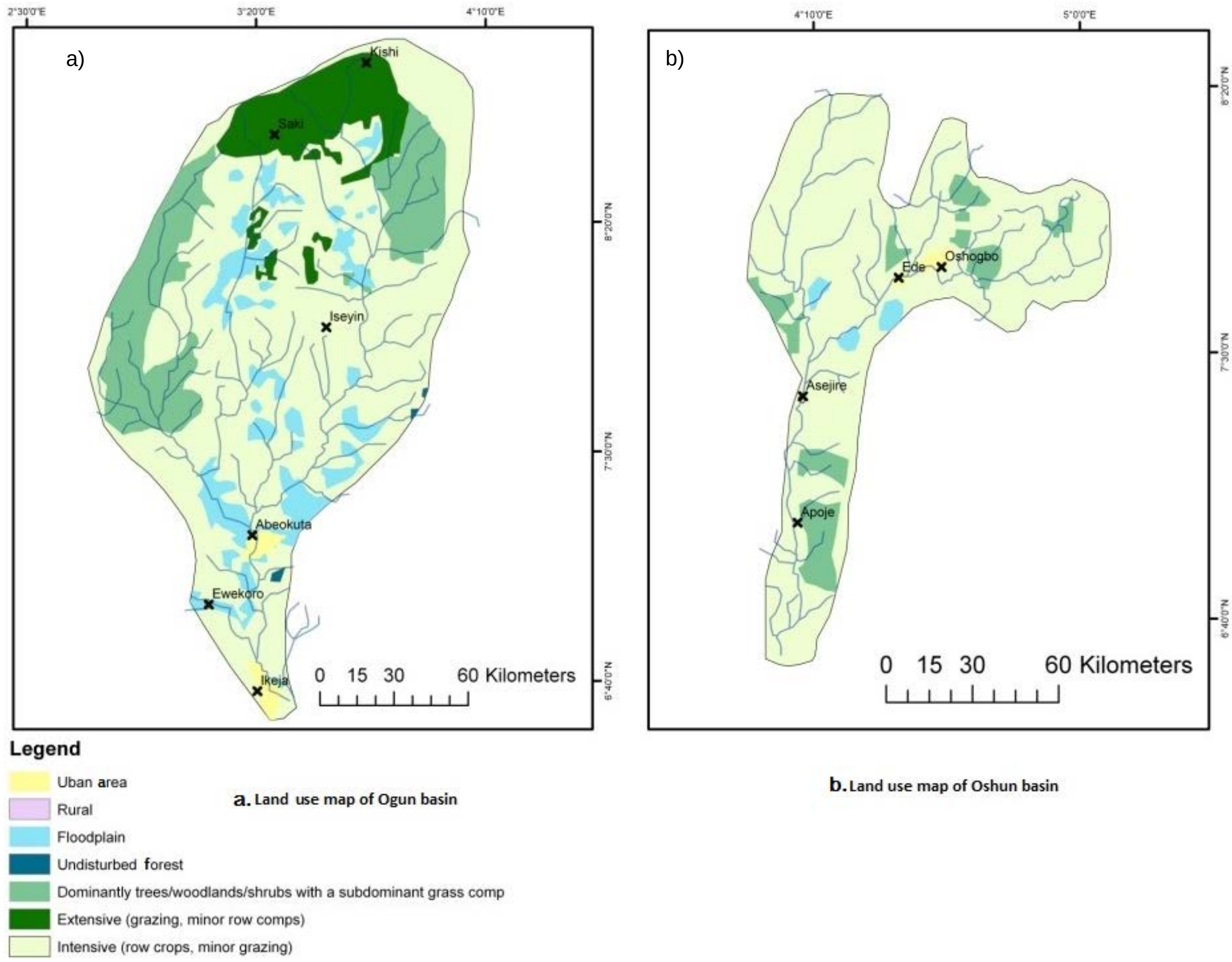

Fig. 4. Land use of analysed basin: a) Ogun basin, b) Oshun basin; source: own elaboration

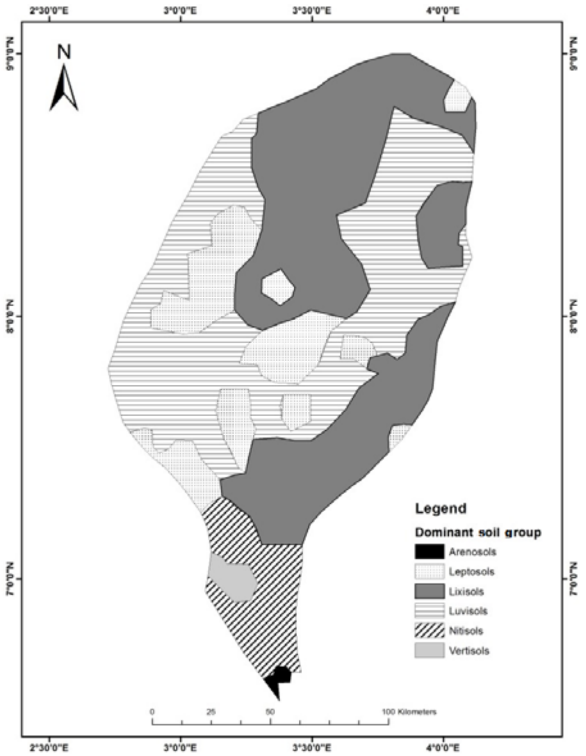

Fig. 5. Dominant soils in the Ogun basin; source: own elaboration

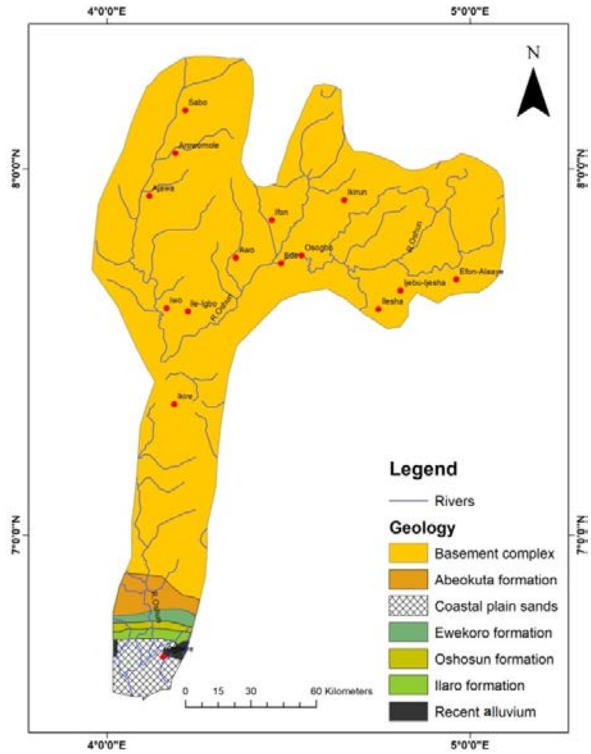

Fig. 7. Geological map of the Oshun basin; source: own elaboration

rises from the ridges of Oke-Mesi ridge located on the margin between Oyo and Ondo States and flows through Oshogbo and Ede and then southwards to enter the Lagoon via Ijebu Ode-Epe area of Lagos State [OORBDA 1982b].

The topography of Oshun River is such that the elevation rises from 41 m in the South to about 624 m in North (Fig. 6).

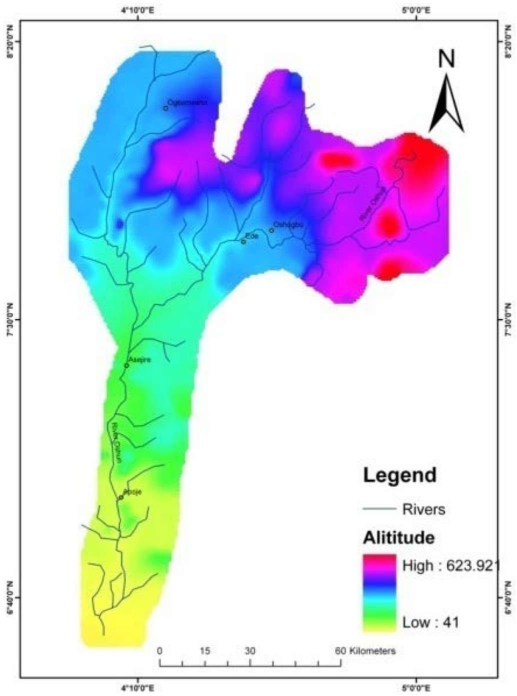

Fig. 6. Elevation map of Oshun basin (with black dot referring to major towns in the basin); source: own elaboration

In terms of geological types, it shares the same with Ogun River with sedimentary rocks found in the southern section and the remaining sections composed of crystalline rocks of the basement complex (Fig. 7).

The dominant land use (Fig. 4b) is intensive row crops, minor grazing – meaning agricultural activities and urbanization effect. In terms of soil group, the only soil group in Oshun basin that is different from Ogun basin is Luvisols, characterised by the presence of eluvial (Ae) horizons and illuvial (Bt) of silicate clay dominance [LAVKULICH, AROCENA 2011] – Figure 8.

THE MIKE SHE MODEL

The MIKE SHE software is organized around the set-up data tree, which consists of display, simulation specification, model domain and grid, climate. The model display controls the map overlays and the size of the map view in the rest of the dialogues. Since the Ogun and Oshun basins were run separately, the coordinate extent of the basins were read into the model from two separate polygon shape files from Arc GIS. The simulation specification dialogue is the key dialogue in the programme, as key options could be selected for each of the components included in the simulation. The unsaturated flow (UZ) and evapotranspiration modelled using the gravity module, are checked on for this model.

This defines the model area, which include the horizontal extent used in the model for the saturated groundwater flow. The catchment area of Ogun and Oshun were defined by polygon shape files from Arc GIS. Bearing in mind that the shape file is a non-gridded data, the following grid dimensions were set:

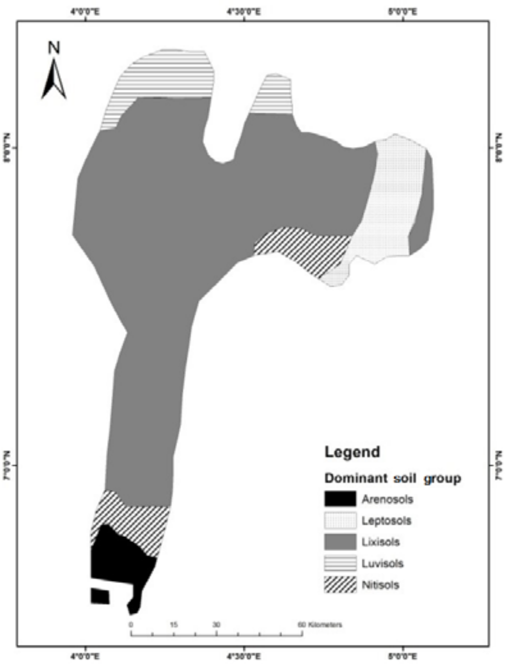

Fig. 8. Dominant soil group in the Oshun basin; source: own elaboration

Cells in the X direction, NX = 200; cells in the Y direction, NY = 200; size of cell = 0.001 m; rotation = 0; origin (X0, Y0) = 2.7181, 6.4665 (Ogun basin) and 3.9616, 6.5474 (Oshun basin);
Map projection type = Non-UTM.

The Graphics User Interface (GUI) automatically ascribes 1 to the internal cells and 2 to the boundary cells. In MIKE SHE, the upper boundary of the model is defined by the topography. Consequently, Digital Elevation Map (DEM) was used to define the topography of the Ogun and the Oshun River basins using point data and shape files. The bilinear interpolation method was selected for this option, while a search radius of 0.1 m (two times the cell size) was inputted into the model. The climate dialogue of the model consists of precipitation and evapotranspiration rate. A time-series grid file was created to represent the daily rainfall and evapotranspiration distribution of the two rainfall stations. The evaporimeter data was multiplied with pan factor of 0.90 [ADEFOLALU 1998] to obtain the evapotranspiration (*ETp*) rate for Abeokuta and Oshogbo synoptic stations. For the vegetation, leaf area index (*LAI*) was given a value of 1 and depth to roots (Root) was assumed to be 500 mm [CANADELL *et al.* 1996].

Based on USGS classification on soil textural characteristics, clay soil was dominant in the study areas of Abeokuta and Oshogbo [FAO 2009] while the following assumptions were incorporated into the model: effective saturation of 75 mm, bulk density of 1700.000 kg·m^{-3}. Based on VAN GENUCHTEN [1980], the hydraulic conductivity characteristics are assumed as follows: α = 0.0051 cm^{-1} and shape factor of 0.5.

ANNUAL RAINFALL DISTRIBUTIONS

The annual rainfall distribution for the four synoptic stations in the basins are statistically presented in (Tab. 1). In the table, Ikeja station has a mean annual rainfall for the 28 years to be 1482.72 mm, with maximum and minimum value of 2007.7 mm and 860.8 mm in 2002/2003, and 1983/1984 respectively. The mean annual rainfall for Abeokuta is 1193.0 mm, with maximum and minimum values of 1876.4 mm and 753.7 mm in 1982/1983 and 2007/2008 respectively. The mean annual rainfall of 1354.21 mm was experienced by Oshogbo, while the maximum and minimum values were recorded as 1765.5 mm and 1066.7 mm in the years 1985/1986 and 1983/1984 respectively. At Ijebu Ode synoptic station, maximum annual rainfall of 1968.6 mm was recorded for the hydrologic year 1996/1997 while a minimum value of 1337.38 mm recorded for 1998/1999. The mean value of 1625.9 mm was recorded for the 22 years of record in Ijebu-Ode. The low standard deviation observed in Ijebu-Ode shows that the variation of the observed rainfall from the normal or mean is lower when compared to other locations (Tab. 1), suggesting that annually more rainfall occurs in Ijebu-Ode.

Moreover, the recorded rainfall of about twelve years were above the normal rainfall of 1482.7 mm, which indicates that 12 wet years was experienced within the 28 years of study; and 10 dry years was also experienced in Ikeja. Table 1 shows that the annual rainfall distribution in Abeokuta differs to Ikeja in that 10 wet years were above the rainfall of 1193.0 mm, while about 13 years of dry years were experienced within the period of study. In Oshogbo, 13 years of wet years were experienced; while the remaining 11 years are dry. However, despite the larger mean rainfall in Ijebu-Ode there were 14 dry years, while 8 were wet years. It was observed that more rainfall is experienced in Ikeja and Ijebu-Ode, perhaps because of its closeness to the Atlantic Ocean. This indicates that the monthly rainfall increases northward of the Ogun and Oshun basins.

Table 1. Descriptive statistics of rainfall in synoptic stations of the study area

Station	Years	Duration	Mean (mm)	*SD* (mm)	Maximum (mm·year^{-1})	Minimum (mm·year^{-1})
Ikeja	1982/1983 – 2010/2011	28	1 482.72	278.79	2 007.7 (2002/2003)	850.8 (1983/1984)
Abeokuta	1981/1982 – 2010/2011	29	1 193.00	263.48	1 876.4 (1982/1983)	753.7 (2007/2008)
Oshogbo	1982/1983 – 2009/2010	28	1 354.21	172.93	1 765.5 (1985/1986)	1 066.7 (1883/1984)
Ijebu-Ode	1990/1991 – 2011/2012	22	1 623.48	167.13	1 968.6 (1996/1997)	1 337.4 (1998/1999)

Explanations: *SD* = standard deviation. In brackets are given hydrological years.
Source: own study.

Table 2. Annual evapotranspiration at Ikeja, Abeokuta, Oshogbo and Ijebu Ode stations

Stations	Years	Duration	Mean (mm)	*SD* (mm)	Maximum (mm·year^{-1})	Minimum (mm·year^{-1})
Ikeja	1982/1983–2010/2011	28	1 444.08	218.44	1 826.80 (2010/2011)	1 123.05 (1993/1994)
Abeokuta	1981/1982–2010/2011	29	1 463.62	241.08	2 089.17 (1997/1998)	1 043.75 (2008/2009)
Oshogbo	1982/1983–2009/2010	28	1 258.61	190.98	1 715.55 (1981/1982)	991.96 (1992/1993)
Ijebu-Ode	1990/1991–2011/2012	22	1 361.68	35.31	1 434.12 (2005/2006)	1 306.76 (2006/2007)

Explanations: *SD* = standard deviation. In brackets are given hydrological years.
Source: own study.

ANNUAL POTENTIAL EVAPOTRANSPIRATION

The annual potential evapotranspiration (*PET*) of the basins were estimated using the Penman–Monteith equation. Climatic data, comprising temperature, relative humidity, wind speed, and sunshine hour were incorporated into Penman–Monteith equation in an Excel sheet to obtain the *ETp*.

The average monthly evapotranspiration general increases from the beginning of the wet season in April to the end of November. However, there is a sharp reduction in the months of December and January. The average monthly evapotranspiration estimated for Ikeja and Abeokuta is higher in the Ogun basin than Ijebu-Ode and Oshogbo in the Oshun basin. The implication is that more water will be available for recharge in Oshun River basin than Ogun River basin, more so that more rainfall occur annually at Ijebu Ode basin.

RESULTS AND DISCUSSIONS

For Ogun and Oshun basins area, MIKE SHE model was used to estimate groundwater recharge. After supplying daily rainfall, potential evapotranspiration, and soil characteristics of the study areas, the MIKE SHE numeric model gave daily estimations of groundwater recharge to the saturated zone in each of rainfall stations (Fig. 9). The daily recharge in Abeokuta and Oshogbo ranges from 0 mm·day^{-1} in January when there were insufficient rainfalls to 10.89 mm·day^{-1} in Abeokuta and 29.85 mm·day^{-1} in Oshogbo in month of August when the soils had reached field capacity. The result from the model indicate that the daily recharge in Abeokuta decreases from 0.9 mm·day^{-1} in June to zero at the end of December, followed by another rise from zero to 1.44 mm·day^{-1} in February 2011. The groundwater recharge to the saturated zone in the upper part of the Oshun River basin follows a similar pattern. However, the daily recharge decreases from 0.91 mm·day^{-1} in the month of June, to 0 mm·day^{-1} in November before it rises again from December to March 2011. This result agrees with what was obtained by OKE *et al.* [2016] at Ogun basin but using different methods – water table fluctuation and soil moisture method. According to OKE *et al.* [2016], groundwater recharge result obtained using water table fluctuation was 0.8 to 4.3 mm·year^{-1}, while for soil moisture balance recharge was 0.0 to 23.3 mm·year^{-1} in the year 2010–2011. Also, SHAMUYARIRA [2017] gave a similar result 0 mm·year^{-1} to 2.75 mm·year^{-1} using MIKE SHE model at Mhinga, a sedimentary rock succession area of South Africa, between December 2009 and January 2010.

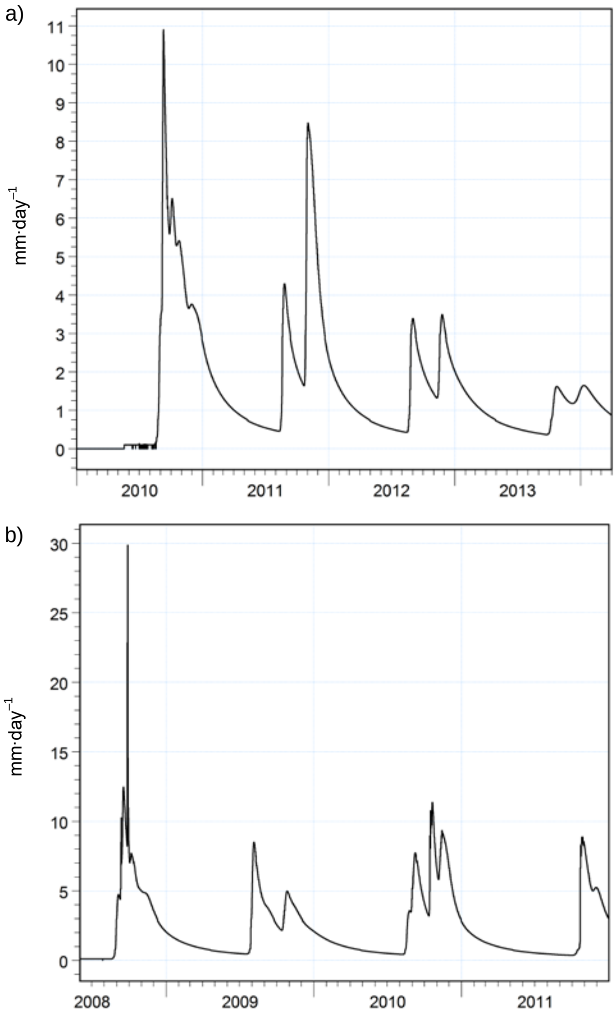

Fig. 9. Daily groundwater recharge obtained by MIKE SHE model for two stations: a) Abeokuta, b) Oshogbo; source: own study

The results obtained agree with the work of SHARP [2010] in which it was concluded that recharge rates may vary spatially and temporally. It also agrees with REESE and RISSER [2010] assertion that the amount of recharge in humid regions like Nigeria could be high due to large amount of rainfall, infiltration, and less influences of evapotranspiration because of vegetative cover.

CONCLUSIONS

The statistical analysis of rainfall data indicate that there are more rainfall in southern part of Oshun and Ogun basins than in the northern upper part of the basins. This has been adduced to the closeness to the Atlantic Ocean as well as the presence of sedimentary soil which are aiding high rainfall in that area. Even at the upper parts, more rainfall are recorded in Oshogbo synoptic station (Oshun basin) than Abeokuta synoptic station (Ogun basin). Also, more evapotranspiration are recorded in Ikeja (Ogun basin) than Ijebu Ode (Oshun basin). Equally, more evapotranspiration are recorded in Abeokuta (Ogun basin) than Oshogbo (Oshun basin). These have an impact on water availability at Oshun basin than Ogun basin. However, more evapotranspiration in Ogun basin is an indication of high anthropogenic activities. This impact has not been captured extensively in this study, whereas it deserve to be look into as further research, to establish the scientific position of impact of anthropogenic activities on groundwater recharge in the study area. Generally, the simulations of groundwater recharges of Abeokuta and Oshogbo using MIKE SHE showed that daily groundwater recharge ranges from 0 mm·day^{-1} in January when there was an insufficient rainfall to 10.89 mm·day^{-1} in Abeokuta and 29.85 mm·day^{-1} in Oshogbo in the month of August when the soils had attained field capacity.

Comparatively, more daily groundwater recharge were recorded in Ogun basin (highest 10.80 mm·day^{-1} and lowest 0.01 mm·day^{-1}) than Oshun basin (highest 10.20 mm·day^{-1} and lowest 0.1 mm·day^{-1}) in the hydrologic year 2010. However, there was a variation in the daily groundwater recharge with Oshun basin having more recharge (highest 9.00 mm·day^{-1} and lowest 0.1 mm·day^{-1}) than Ogun basin (highest 8.4 mm·day^{-1} and lowest 0.4 mm·day^{-1}) in the hydrologic year 2011. This indicate that groundwater recharge in the Ogun and Oshun basins is greatly influenced by rainfall, high infiltration, and less influences of evapotranspiration due to vegetative cover common in the area. The fluctuation in the daily recharge is further an indicator of the dynamic nature of the recharge system in the study area, which therefore necessitated that more attention should be paid to groundwater recharge monitoring for effective water resources decision making in these areas.

However, the study establish that MIKE SHE model can be used to estimate daily groundwater recharge in these basins and other basins in Nigeria and Africa. It could provide quick and effective daily recharge calculations for scientific decision making in these areas. Consequently, especially to achieve availability of daily meteorological and hydrological data, more automated synoptic and water level measuring stations across the length and breadth of the basin areas should be provided. This data generated should be made available and accessible to hydrologists and water managers in relevant agencies for the day to day water monitoring, planning, forecast and warning in case of extremes.

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