LASU Journal of Environmental Sciences Vol 1, No. 1, June 2025
(https://www.lasujes.org.ng)

Water Accounting of the Ogun River Basin, Nigeria

[1] [2]Shakirudeen Odunuga / [3]Olubunmi Adegun / [4]Iyanu Olufiade & Gbolahan Badru

Abstract

The study applied the rapid water accounting plus (WA+) for the 2018 hydrological year to evaluate the water resources availability of the Ogun River Basin in Southwest Nigeria. Data from the Water Productivity (WaPOR) version 2.0 Level 1 open-access database was used for this study. Various tasks using QGIS, ArcGIS, Python, and Jupyter notebook computing were carried out. The results showed that the coefficient of correlation values of WaPOR 2.0 open access and NiMET precipitation data vary from 0.618 to 0.687. The basin's 2018 hydrological year annual precipitation was 16471mm yr^{-1}. *The total evapotranspiration was 13888 mm* yr^{-1}, *and surplus water of 150.85 mm* yr^{-1} *was generated. There are 12.7* km^{-3} yr^{-1} *of exploitable water supplies. The basin capacity grew by 1.4* km^3*/year, and the renewable water supplies are greater (14.14* km^3*/year). Gross inflow is 29.2* $km^{-3}yr^{-1}$, *total outflow and water utilized is 27.8 2* $km^{-3}yr^{-1}$, *and total water reserve shift is 1.4* $km^{-3}yr^{-1}$. *(Balance). Average annual water availability was 12.1* $km^{-3}yr^{-1}$, *of which 2.9% was controlled. On average, 0.1* $km^{-3}yr^{-1}$ *of Managed Water and Incremental ET were produced. The research suggests building medium-sized structures throughout the region to properly harness the surplus water for increased urban water supply and flood control.*

Keywords: ***evapotranspiration, land use, precipitation, water balance, water consumption***

---

[1] Dept. of Geographical and Environmental Education, Lagos State University of Education, Lagos, Nigeria. badrugs@lasued.edu.ng ORCID https://orcid.org/0000-0003-4020-6356

[2] Dept. of Geography, University of Lagos, Lagos, Nigeria. sodunuga@unilag.edu.ng. ORCID https://orcid.org/0000-0003-4307-9428. (Corresponding author)

[3] Dept. of Geography, University of Lagos, Lagos, Nigeria. Email: oadegun@unilag.edu.ng. ORCID https://orcid.org/0000-0003-2625-2110

[4] Dept. of Geography, University of Lagos, Lagos, Nigeria

Introduction

Water is a natural resource and the basis for the sustainable existence of life on earth as all biologically active creatures require water for survival. Apart from its benefits to humanity, it also serves a regulatory role in the climate system and is a critical factor in the sustainability of ecosystems and biodiversity (Bănăduc et al., 2022). Water is relatively abundant on earth, with the earth often referred to as a "blue planet". However, there is water scarcity (Oki and Kanae, 2006; Gleick and Cooley, 2021) and water stress (Liu et al., 2024) across space and time. Specifically, since the mid-nineteenth century, humanity has undergone a tremendous shift from an excess of water to a scarcity of clean and affordable water for drinking, sanitation, and food production (Rijsberman, 2006). Poverty, climate change, pollution, salinization, population growth, degradation of water-related ecosystems, and unsustainable management and funding of investments in water supply and sanitation, among other things, contribute to this lack of access (Adeaga, 2006; FAO, 2012).

As at 2009, the United Nations estimated that 1.2 billion people in more than 80 countries experienced water shortage and the figures expected to raise to 2.7 billion people by 2025. (Musie and Gonfa, 2023). According to UNEP (2021), Africa's per capita renewable freshwater supply might plummet by 80% by 2025, with Sub-Saharan Africa being the most susceptible region. This water shortage scenario will be exacerbated in Nigeria due to its massive population growth, which implies a continuous increase in the water demand.Consequently, every drop of water will need to be accounted for to meet the current and future water demand reality and challenges. However, to effectively manage water resources for sustainable development over geographical space and time, robust data and high-quality information must be available. This information should include the quantity of available water within the catchment, the demand by various users, knowledge of the impact of climate change on the water resource (Droogers et al., 2012) and a thorough understanding of the elements of the water balance across spatial and temporal dimensions.

The ground-based global hydro-meteorological observation network has been noted by Rodda (1998) to be steadily declining since the 1980s. In Nigeria, the density of the gauging network within the Eight Hydrological Areas (HA) is short of international standard prescription. As a result, data on water availability and usage that is needed for water accounting and budgeting by the River Basin Development Authorities is practically unavailable. Although there have been practical efforts by the Nigeria Meteorological Agency (NiMET) and the Nigeria Hydrological Services Agency (NIHSA) in recent years to improve the Meteorological and Gauging networks across the country, the density still needs to grow. Therefore, the need to adopt open-access satellite-based data sources to meet urgent water challenges and to complement the available ground-based data for decision-making becomes imperative.

Specifically, for the Ogun River under Ogun-Osun River Basin Development Authority (HA-VI), getting comprehensive data is challenging as flow measurements are only available at few locations, especially in the upper and mid-stream areas. Additionally, only a few stations have long-term, uninterrupted records of good-quality data providing only a glimpse of the available water resources. Information on groundwater and surface water abstractions is thus mainly unavailable since they are monitored only at selected places. Thus, integrating the data and information on water across sectors within the Ogun River basin remains complex. Furthermore, there is a need for data on the downstream section of the basin, as the old staff gauges for water level measurement have all been destroyed by flood and have not been replaced. The myriads of challenges currently bedeviling the basin calls for a better understanding of the hydrological processes to achieve sustainable water resources management. One of the ways of achieving this is through the water accounting approach. There are various methods of water accounting. These include flow accounting methods such as Food and Agricultural Organisation's [FAO] Aquastat, System of Environmental-Economic Accounting (SWEEA)-water, Australia's Water Accounting System and Depletion Accounting methods from other United Nations agencies such as the International Commission on Irrigation and Drainage [ICID], International Water Management Institute- Water Accounting [IWMI-WA] and Integrating for Healthcare - International Water Management Institute-Water Accounting [IHE-IWMI WA+] (Elmahdi, 2020).

For this study, the Water Accounting Plus (WA+) tool was used to assess the water resources availability in the Ogun River basin. The WA+ is an open-access basin-wide water accounting tool (FAO and IHE Delft, 2019) developed by IHE Delft in collaboration with FAO and IWMI. Since its development and introduction, the FAO and IHE Delft have applied the WA+ to assess the water resources conditions of several river basins in different parts of the world. For example, FAO and IHE Delft (2019) deployed the WA+ framework to investigate the water resources conditions (water availability, withdrawals, consumptive and non-consumptive use, services, and derived benefits) in the Litani River Basin in Lebanon for the period between 2010 and 2016. The study showed, amongst others, renewable water resources of 606.9M m^3 yr^{-1}., exploitable water resources of 664M m^3 yr^{-1}., and an estimated 800 m^{-3} cap yr^{-1}., water shortage. Similarly, FAO and IHE Delft (2020) utilized the WA+ methodology to account for the water resources of the Awash River Basin in Ethiopia. The results showed that for the 10-year study period, the estimated average exploitable water resources were 8.7 $km^{-3}yr^{-1}$ and the outflow to groundwater in the basin was 3.8 km^{-3} yr^{-1}. Due to the annual variability of available water resources and the increasing demand for water in the basin, the study recommended the implementation of strategies focused on improving water use efficiency and storage capacity. The results obtained for the Nile River Basin water accounting (FAO and IHE Delft, 2020) indicated a lesser gross inflow of 2,086 km^{-3} yr^{-1} when compared with an outflow of 2,164 km^{-3} yr^{-1}. The study also showed that the highest net water consumption is from bare or sparse vegetation cover. For the Niger River Basin, the results of the FAO and IHE Delft study indicated that the water budget for the study period is balanced with only an error margin of 1 percent. In addition, the study concluded that water resources in the basin are underutilized, signifying the potential for agricultural expansion.

Although the WA+ has been applied to major river basins in Africa, a literature search shows that apart from the Niger Basin, the WA+ has not been applied to other river basins in West Africa. In recognition of this, and the need to ensure sustainable water resource utilization in a highly populated and rapidly urbanizing basin such as the Ogun River Basin, this study adopted the WA+ framework. Specifically using remotely-sensed total water storage, the study compared WaPOR data with in situ observations, mapped net water generation and consumption, identified net consumers' land cover class, and assessed the derived basin scale water balance. This is with the aim of assessing the available water resources in the Ogun River Basin for the hydrological year under consideration.

Methodology

Study Area

Geographically, the Ogun River Basin, which is situated in Southwest Nigeria (Figure 1), is bound by coordinates 6° 33' N and 9° 'N and longitudes 2° 40'E and 3° 45'E. The basin covers four states (Lagos, Ogun, Oyo, and Kwara) in Nigeria (Odunuga & Ajayi, 2017). The basin has an estimated land area of 23,700 *km2* (Awomeso *et al.,* 2019). It is a seventh-order drainage that drains into the barrier lagoon coast complex (Odunuga et al., 2013).

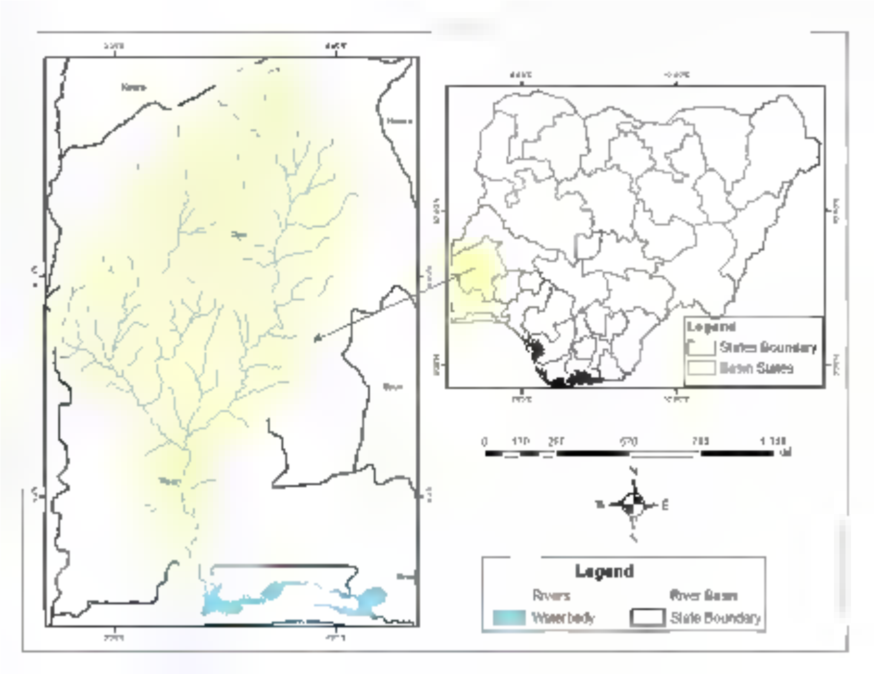

Fig. 1: Ogun River Basin in Southwestern Nigeria

The geology of the basin consists of a geological succession beginning with the Precambrian Basement, with the foliation and joints on these rocks regulating the river's path.

A minimum of seven months of rain are expected during the rainy season, which lasts from April to October or early November, and has a dry season from November to March. In the southern region, the mean yearly rainfall is between 1,020 mm and 1,520 mm, but less than 1,020 mm in the northern part. The weather data in the basin indicates that the warmest months are February and March when temperatures are high. (Odunuga and Ajayi, 2017).

The vegetation at the down and mid-stream parts of the watershed comprises swamps and tropical rainforests. At the same time, derived Savannah secondary forest regrowth due to years of human occupation (Ifabiyi, 2005) dominates the upstream area. The area is drained mainly by the

Ogun River and its major tributaries, including the Ofiki and Oyan rivers which contribute the most significant volume of water to the Ogun River basin. The relief is generally low, with the gradient in the north-south direction. The population is estimated at 21,862,598 people (NBS, 2017). Agriculture practices constitute a significant occupation within the basin, as new agricultural and processing hubs are springing up in Ogun and Oyo states.

Data and Methods

The data used for the water accounting of the basin was obtained from different sources (Table 1). Before using the WaPOR precipitation tool, the data was compared with in-situ rainfall data for the period 2009 to 2011. The Root Mean Square Error (RMSE), Bias, and Nash–Sutcliffe efficiency (NSE) tests validated the data.

Table 1: Data Source and Characteristics

Data	Resolution	Source	Date	Data Usage
Precipitation	250m	WaPOR database	2018	Water accounting plus (+)
Actual Evapotranspiration and Interception	250m	WaPOR database	2018	Water accounting plus (+)
Land Cover Classification	250m	WaPOR database	2018	Water accounting plus (+)
Reclassified of WaPOR Land Cover classification layer into WA+ classes		The World Database on Protected Areas and the Global Reservoir and Dam Database.		
Rainfall		NiMET (Ikeja, Abeokuta and Ibadan Stations)	2009-2018	Validation
Discharge and		OORBDA	2002-2012	Water accounting plus (+)

Stream Level		New Bridge, Abeokuta		
		Gravity Recovery and Climate Experiment (GRACE) data		
DEM	30m	USGS	2020	Elevation

For analysis of the data, the following approaches were used.

Water generation and consumption analysis

The WaPOR datasets for precipitation, actual evapotranspiration and interception, as well as landcover class were used to describe rainfall excess (water generation) and the lateral transport of water from water surplus to net water consumption per landcover class. The datasets were corrected in the QGIS software environment by multiplying the raster data by 0.1 using a raster calculator. Similarly, the water generation per landuse class was derived using Raster layer zonal statistics in the QGIS software environment.

Basin scale water balance

Due to the non-availability of some components of the catchment water balance such as inter-basin transfer and water discharge from the WaPOR database, additional data sources, including measured discharge and GRACE Total Water Storage Change data sources, were utilized. The available discharge and stream level data is for the 2002–2012 hydrological year. This data was, however, extended to the 2018 hydrological year using the Simple Moving Average (SMA) formula expressed as:

$$\text{SMA} = \frac{A_1 + A_2 + \dots + A_n}{n} \quad \dots\dots 1$$

Where:

A = Average in period n

n =Number of time periods (10 years)

The stage-discharge relationship is generally a single-valued relation for the majority of non-alluvial streams and rivers (Subramanya 2008) represented as;

$Q = K(G - a)^{n}$ 2

Q = stream discharge;
G = stream level;
a = constant representing the gauge reading corresponding to zero discharge;
K and n are the rating curve parameters.

The Excel solver, capable of optimizing linear and nonlinear equations by changing specified parameters, was applied to obtain optimum values of the rating curve parameters. In addition, the performance of the method for the parameter estimation was assessed concerning the relationship between the observed and the predicted discharges based on the Root Mean Square (RMSE) expressed as:

RMSE)= $\sqrt{\frac{\sum_{i=1}^{n}(Q_o^i - Q_p^i)^2}{N}}$ 3

Where:
Q_o is the observed discharge;
Q_p is the predicted discharge;

Total Water Storage Change

The Gravity Recovery and Climate Experiment (GRACE) was used to assess how much of the difference between P is due to change in the total water storage. GRACE is a dual-satellite mission continuously monitoring and mapping Earth's changing gravity field to estimate the total water storage anomalies (TWSA). The GSFC-v02.4-ICE6G solution (Luthcke et al., 2013) was used to validate the storage change in the water balance calculated using WaPOR data. Since the GRACE solution provides mean monthly TWSA and not the exact TWSA of the first and last days of the month, the change of storage ($\Delta S/\Delta t$) in a period was approximated using a second-order central difference as proposed by Biancamaria et al. (2019). The residual ($P - ET_a - Q_{out}$) was equated to the change of storage ($\Delta S/\Delta t$) following the simplified water balance equation (Biancamaria et al., 2019):

$$\frac{\Delta S}{\Delta t} = P - ET_a - Q_{out} \text{ ....} 4$$

WA+ Landuse categorization

The landuse map was based on the land cover layer (LCC) from the WaPOR database. However, it needs to be reclassified into the Water Accounting classes. First, the Managed Water Use class was reclassified from the 'Cropland, irrigated or underwater management' and 'Built-up' classes in the WaPOR LCC layer. Next, the Modified Land Use was reclassified from the Cropland, rainfed class in the WaPOR LCC layer. After that, the rest of the area, which includes 'Grassland,' 'Water bodies,' 'Tree cover: closed, evergreen broadleaved,' 'Tree cover: open, unknown type,' 'Tree cover: closed, deciduous broadleaved,' 'Tree cover: closed, unknown type,' 'Shrub or herbaceous cover, flooded,' 'Tree cover: open, deciduous broadleaved,' 'Shrubland,' were reclassified as Utilized Land Use class.

Pixel scale analysis

The WaterPix model was used for the pixel scale analysis. The model calculates the vertical soil water balance for each pixel. Rainfall ET (ET_{rain}) and incremental ET (ET_{incr}) are separated by keeping track of the soil moisture balance and determining if the ET is satisfied only from rainfall or stored in the soil moisture or if an additional source (supply) is required. Table 2 shows the main inputs into WaterPix, and Table 3 shows the outputs. Each parameter was calculated at the model resolution of 250m and available for monthly and annual time steps.

Table 2: Inputs of WaterPix model

Variable	Parameter	Source	Spatial	Temporal Resolution

			Resolution	
Precipitation	P	WaPOR	250 m	Daily
Actual Evapotranspiration	ETa	WaPOR	250 m	Monthly
Interception	I	WaPOR	250 m	Monthly
Landuse land cover	LULC	WaPOR	250 m	Yearly

Table 3: Outputs of the water balance model at pixel level

Variable	Calculation step	Definition
S	1	Soil Moisture
$\mathbf{Q_{sro}}$	1,4	Surface Runoff
R	1,4	Recharge
$\mathbf{ET_{rain}}$	2	Rainfall ET
$\mathbf{ET_{incr}}$	2	Incremental ET
$\mathbf{Q_{sup}}$	3	Supply

Python and Jupyter notebook software were used to collect and download data from the WaPOR database and to implement water balance variables equations (1-15) through scripts implemented in the python and Jupyter notebook software environment. The models and scripts for creating the water accounts and elaborating the reports are available on GitHub under the Water Accounting account (https://github.com/wateraccounting). The step-by-step follow-up of the computations is described below.

Step 1: Computation of soil moisture

The soil moisture ($S_{rain,t}$) is computed as the soil moisture storage at the end of the previous timestep ($S_{rain,t-1}$) plus the effective rainfall (P-I) minus recharge (R_{rain}) and surface runoff (Q_s):

$$S_{rain,t} = S_{rain,t-1} + P - I - Q_{sro,rain} \quad \ldots\ldots 5$$

Where the surface runoff ($Q_{sro,rain}$) is calculated using an adjusted version of the Soil Conservation Service runoff method. The adjusted version replaces the classical Curve Numbers by a dynamic soil moisture deficit term that better reflects the dry and wet seasons infiltration versus runoff behaviour (see Schaake et al., 1996; Choudhury & DiGirolamo, 1998). As the Curve Number method is developed for event-based runoff, we calculated $Q_{sro,rain}$ on daily basis, dividing the effective rainfall by the number of rainy days (n) and a calibration parameter f to account for the soil moisture variation due to drying up and filling within a month. The total surface runoff for a month is then multiplied by n:

$$Q_{sro,rain} = \begin{cases} 0 \; if \; P = 0 \\ \dfrac{\left(\frac{P-1}{n}\right)^2}{\frac{P-1}{n} + f\left(S_{sat} - S_{rain,t-1}\right)} * n \; if \; P \neq 0 \end{cases} \quad \ldots\ldots 6$$

Where the saturated soil moisture (S_{sat}) is calculated by multiplying the Saturated Water Content (θ_{SAT}) by the effective root depth (RD) for each land cover class estimated based on the effective root depth (Table 4) by Yang et al. (2016).

Table 4: Root depth values for each land cover class

WaPOR	Land cover class Root depth (mm)
Shrubland	370
Grassland	510
Cropland, rainfed	550
Cropland, irrigated or under water management	550
Fallow cropland	550
Built-up	370
Bare/sparse vegetation	370
Permanent snow/ice	0
Water bodies	0
Temporary water bodies	0

Shrub or herbaceous cover, flooded	0
Tree cover: closed, evergreen needle-leaved	1,800
Tree cover: closed, evergreen broad-leaved	3,140
Tree cover: closed, deciduous broad-leaved	1,070
Tree cover: closed, mixed type	2,000
Tree cover: closed, unknown type	2,000
Tree cover: open, evergreen needle-leaved	1,800
Tree cover: open, evergreen broad-leaved	3,140
Tree cover: open, deciduous needle-leaved	1,070
Tree cover: open, deciduous broad-leaved	1,070
Tree cover: open, mixed type	2,000
Tree cover: open, unknown type	2,000
Seawater	0

Step 2: Separation of ET_a into ET_{rain} and ET_{incr} and of update S

To compute the rainfall and incremental component of ET, ET_a was subtracted from$S_{rain,t}$. When $S_{rain,t}$ is insufficient for ET_a, the difference will be supplied by surface or groundwater uptake. The rainfall ET (ET_{rain}) becomes the amount that can be supplied by the soil moisture, whereas the difference will become incremental ET (ET_{incr}):

$$ET_{rain} = if\left(S_{rain,av} > ET_{a,}ET_{a,}S_{rain,av}\right) \tag{7}$$

$$ET_{incr} = ET_a - ET_{rain} \tag{8}$$

The new soil moisture storage then becomes:

$$S_{rain,t} = S_{rain,av} - ET_{rain} \tag{9}$$

Step 3: Estimation of Water Supply

The amount of water supplied to each pixel is a function of ET_{incr} and the so-called consumed fraction (f_c).

$$Q_{sup} = f\left(ET_{incr,}LU\right) = \frac{ET_{incr}}{f_c} \tag{10}$$

f_c is dependent on the land use class and was suggested to replace the classical irrigation efficiencies (Molden, 1997; Simons et al., 2016).

Step 4: Estimation of incremental soil moisture

Separate soil moisture storage is added to store Q_{sup} and calculate incremental recharge and runoff as follows:

$S_{incr,t} = S_{incrr,t-1} + Q_{supply} - ET_{incr} - R_{incr} - Q_{sro,incr}$ 11

And total soil moisture storage (St) becomes:

$S_t = S_{rain,t} + S_{incr,t}$ 12

Then the total recharge (R_t) was calculated as an exponential function of the soil moisture. Where the soil moisture is above the calibration parameter of the saturated content, the percolation will be computed using the following simple exponential function:S_t

$R_t = S_t * exp\left(-\frac{1}{S_t}\right)$..13

And the incremental recharge (R_{incr}) and the recharge from rainfall (R_{rain}) were computed as proportions of the incremental and rain soil moisture values.

The surface runoff is updated to account for the increase due to incremental surface

runoff from the supply

$$Q_{sro\ tot} = \begin{cases} 0\ if\ P = 0 \\ \frac{\left(\frac{P+Qsup-1}{n}\right)^2}{\frac{P+Qsup-1}{n} + f\left(S_{sat} - \left(S_{rain,t} + S_{incr}\right)\right)} * n\ if\ P \neq 0\ or\ Q_{sup} \neq 0 \end{cases} \text{.......}14$$

The incremental surface runoff ($Q_{sro,incr}$) was then computed as:

$Q_{sro,inr} = Q_{sro,tot} - Q_{sro,rain}$...15

Identification of rapid WA+ key performance indicators

A further analysis developed by Dost et al. (2013) in consultation with the

Land and Water Division of FAO was done to identify the Ogun River Basin's rapid WA+ key performance indicators:

The first set of indicators can be related to the Resource Base Sheet:

1. ET Fraction = ET_{tot} / (P +Q_{in}) (%)
2. Stationarity Index = ΔStorage / ET_{tot} (%)
3. Basin Closure = 1 - Outflow / (P +Q_{in}) (%)

The second set of indicators focuses on the actual amount of water that is currently being managed, or is available to be managed:

1. Available Water (AW) = Gross Inflow – Landscape ET – Reserved flow (km3 /year)
2. Managed Water (MW) = Incremental ET of Managed Water Use (km3 /year)
3. Managed Fraction = Managed Water / Available Water (%)

Results and Discussion

Current water resources availability

Precipitation (Rainfall)

The hydrological year typically starts in May and ends in October. The basin mean rainfall for 2018 varied between 2.8 mm month^{-1} to 239.1 mm month^{-1}, and the spatial variation of the mean annual precipitation varies between 1105.8 mm yr^{-1} and 1962.4 mm yr^{-1} across the pixel. It is observed that most of the rainfall falls in the southern region of the basin as depicted in figure 3, while lower amount rainfall was received in the northeastern part of the basin. The temporal variability of the average monthly WaPOR rainfall or precipitation (P) and spatial variability at the basin is as shown in figures 2 and 3, respectively. As also shown in figure 2, the peak monthly rainfall received during the hydrological year 2018 was in the month of September, which coincides with the period of the year when the second peak of the rainy is usually experienced.

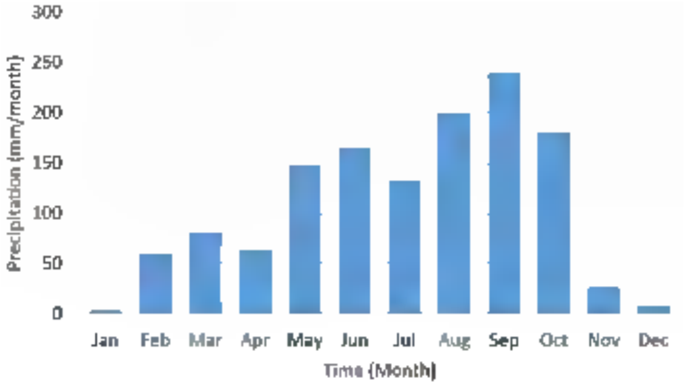

Fig. 2: *WaPOR monthly average precipitation (P) of 2018 hydrological year*

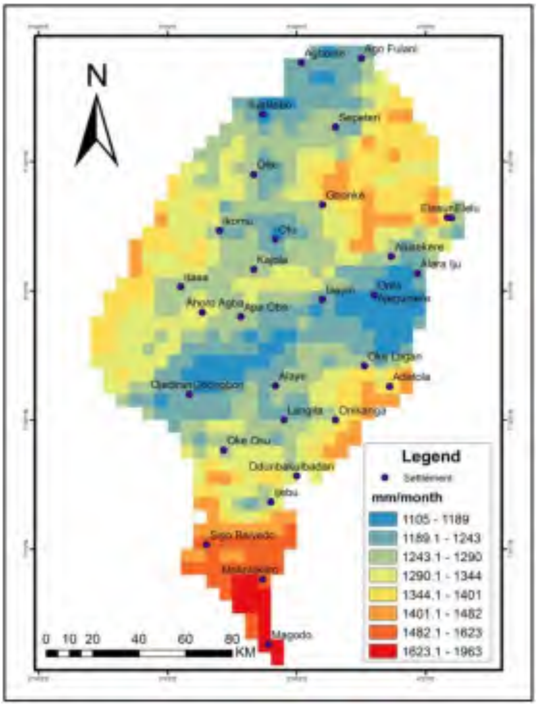

Fig. 3: *Spatial variation of WaPOR precipitation (P) of 2018 hydrological year*

Actual Evapotranspiration and Interception

The WaPOR evapotranspiration (ETa) layer estimates the total evapotranspiration, including its interception. The highest mean ETa value is

123.9 mm month^{-1} in November, and the lowest value is 71.274 mm month^{-1} in February, as shown in figure 4. The mean annual ETa over space varies between 306.8 mm/year to 1794.4 mm/year, as shown in figure 5.

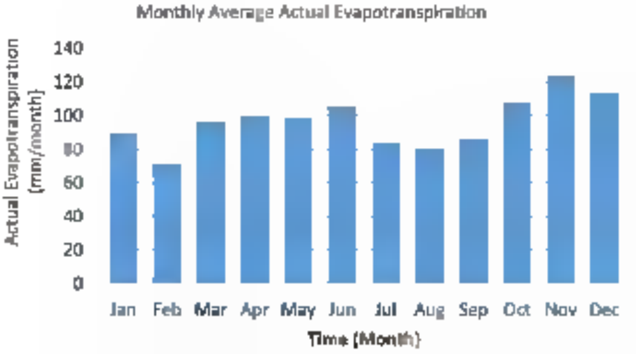

Fig. 4: ***WaPOR monthly average actual evapotranspiration (ET_a) of 2018 hydrological year***

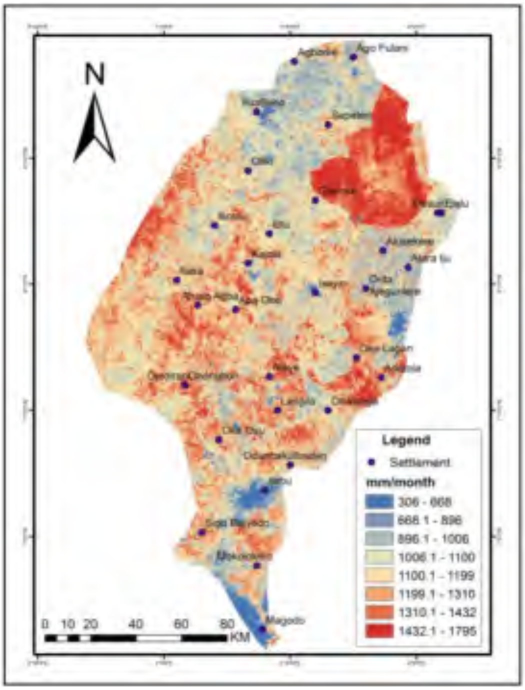

Fig. 5 ***Spatial variation of WaPOR actual evapotranspiration (ET_a) of 2018 hydrological year***

Land Use Land Cover Classes

According to the study's findings, there are twelve LULCs. These include built-up areas, shrubland, grassland, and rainfed cropland, irrigated or managed underwater. There are also water bodies, flooded shrub or grass vegetation, closed deciduous broadleaved trees, closed evergreen broadleaved trees, closed trees of unknown species, open deciduous broadleaved trees, and open trees of unknown species that make up the tree cover. Figure 6 shows the WaPOR database's land cover image for the year 2018.

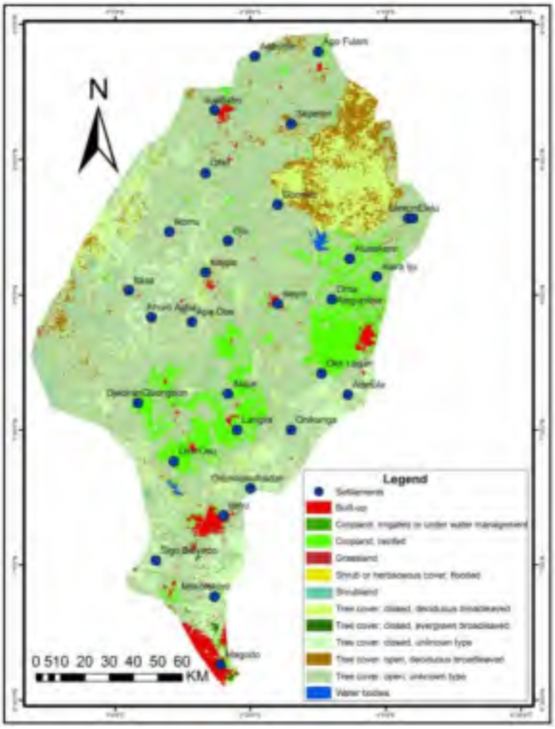

Fig. 6: ***Land cover classification of the Ogun River Basin***

As shown in Table 5, the waterbody had a spatial extent of 48.59 km^{-2}, which is 0.22% of the total extent of the study area. Built-up, Cropland rainfed, and Cropland irrigated or under water management occupied 459.35 km^{-2} (2.05%), 2301.77 km^{-2} (10.26%), and 25.22 km^{-2} (0.1%), respectively. Other LULC includes Grassland, which covers an area of 123.07 km^{-2} (0.55%). On the other hand, Shrubland and Shrub or herbaceous cover flooded covered an area of 295.65 km^{-2} and 34.37 km^{-2}, respectively, which accounted for about 1.32% and 0.15% of the total study area, respectively. Tree cover: closed, evergreen broadleaved, Tree cover: closed, deciduous broadleaved, Tree cover: closed, unknown type, Tree cover: open, deciduous broadleaved, and Tree cover: open, unknown type occupied about 42.39 km^{-2} (0.19%), 1838.27 km^{-2} (8.2%), 2534.8 km^{-2} (11.3%), 1207.68 km^{-2} (5.39%), 13515.63 km^{-2} (60.27%).

Table 5: Land cover class for the hydrological year 2018

S/N	LULC Class	Area km^{-2}	%
1	Water body	48.59	0.22
2	Built up	459.35	2.05
3	Cropland, rainfed	2301.77	10.26
4	Cropland, irrigated or under water management	25.22	0.1
5	Grassland	123.07	0.55
6	Shrubland	295.65	1.32
7	Shrub or herbaceous cover, flooded	34.37	0.15
8	Tree cover: open, unknown type	13515.63	60.27
9	Tree cover: closed, deciduous broadleaved	1838.27	8.2
10	Tree cover: open, deciduous broadleaved	1207.68	5.39
11	Tree cover: closed, unknown type	2534.8	11.3
12	Tree cover: closed, evergreen broadleaved	42.39	0.19
	Total	22426.79	100

Comparison between Observed and WaPOR Rainfall

The comparison results are shown in Figures 7, 9, and 11 for Ikeja, Abeokuta, and Ibadan stations, respectively. WaPOR underestimates the precipitation with a bias value of -0.079 mm month^{-1}, -0.162 mm month^{-1}, and -0.513 mm month^{-1} in Ikeja, Abeokuta, and Ibadan stations, respectively. Also, Figures 8, 10, and 12 show that the coefficient of correlation values between what NiMET observed and WaPOR precipitations data vary from 0.6711, 0.6184, and 0.687 for Ikeja, Abeokuta, and Ibadan stations, respectively. This shows a good agreement of monthly precipitation values from WaPOR and NiMET data for the three measurement locations. A comparison of this result with those of earlier studies revealed that the positive relationship between WaPOR and NIMET data in this study is relatively in tandem with those of Akinyemi et al. (2019).

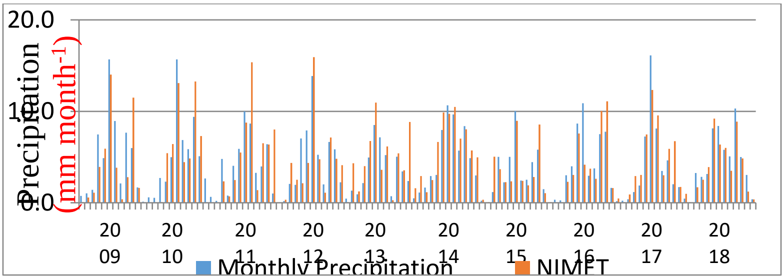

Fig. 7: ***Average monthly precipitation derived from WaPOR data compared with measurements from Ikeja stations between 2009 and 2018. R^2: 0.671 RMSE: 2.234 NSE: 0.653 BIAS: -0.079***

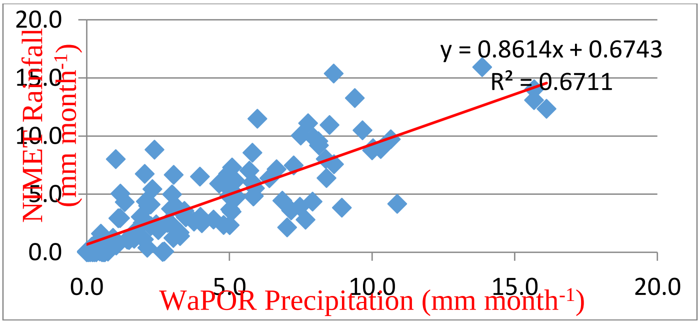

Fig. 8: ***Average monthly precipitation derived from WaPOR data compared with measurements from Ikeja stations between 2009 and 2018***

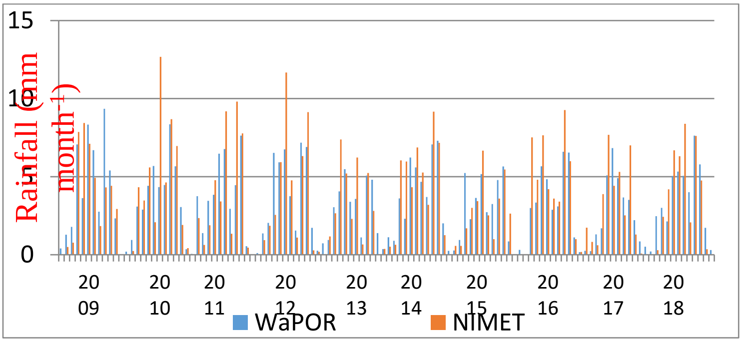

Fig. 9: *Average monthly precipitation derived from WaPOR data compared with measurements from Abeokuta stations between 2009 and 2018. R^2: 0.618 RMSE: 1.899 NSE: 0.616 BIAS: -0.162*

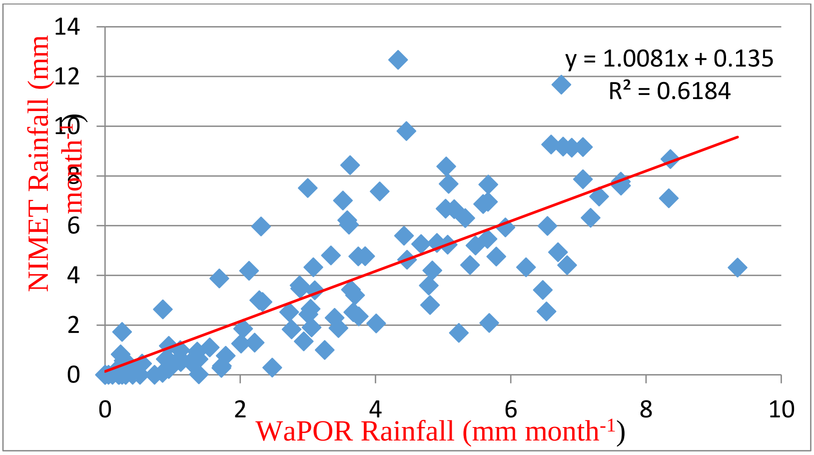

Fig. 10: *Average monthly precipitation derived from WaPOR data compared with measurements from Abeokuta stations between 2009 and 2018*

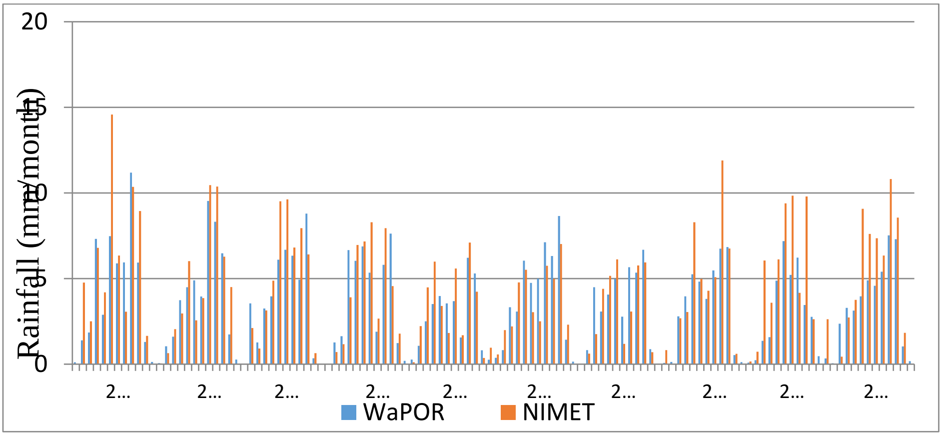

Fig. 11: ***Average monthly precipitation derived from WaPOR data compared with measurements from Ibadan stations between 2009 and 2018. R^2: 0.687 RMSE: 1.918 NSE: 0.663 BIAS: -0.513***

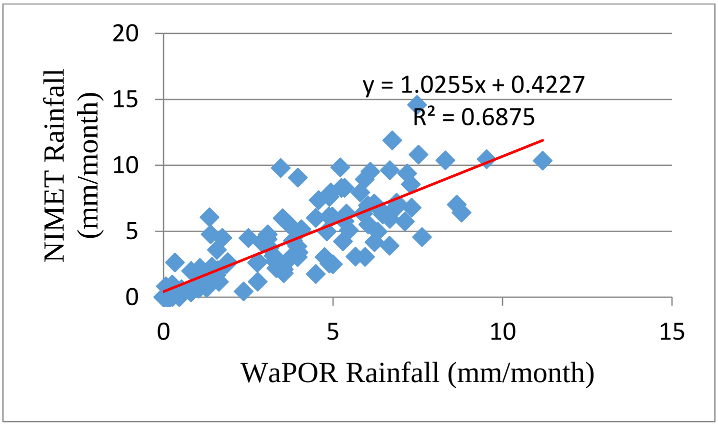

Fig. 12: ***Average monthly precipitation derived from WaPOR data compared with measurements from Ibadan stations between 2009 and 2018***

Water generation and consumption analysis

The actual evapotranspiration (ETa) values are related to the precipitation (P) for getting more insights into the balance between P and ETa. The spatial distribution of the yearly average rainfall excess (P-ETa) for the 2018 hydrological year is shown in Figure 13. The basin-wide long-term excess rainfall reports a positive value of 150.85 mm/year for 2018, as shown in Table

6. Based on the values from WaPOR data, this implies that, as a whole, the Ogun River basin generates surplus water. Surplus rainfall that is not consumed via evapotranspiration can generate surface runoff, interflow, drainage, groundwater recharge, seepage, and baseflow (Bastiaanssen et al., 2014). The result of the excess rainfall in this study is synonymous with various studies carried out in several other basins. For example, FAO and IHE Delft (2020) revealed that the Jordan basin comprehensive long-term excess rainfall from WaPOR data is 66 mm/year, with a positive value reported for all years between 2010 and 2018. Also, a study carried out by (FAO & IHE Delft, 2019) revealed that the Litani basin experienced an average yearly excess rainfall of 217 mm/year from 2010 to 2016 using WaPOR data.

Table 6: Total average annual precipitation (*P*) and actual evapotranspiration and interception (ET_a)

P (mm yr^{-1})	ET_a (mm yr^{-1})	P-ETa (mm yr^{-1})	P (km^{-3} yr^{-1})	ET_a (km^{-3} yr^{-1})	P- ET_a (km^{-3} yr^{-1})
1306.33	1155.48	150.85	29.3	25.9	3.3

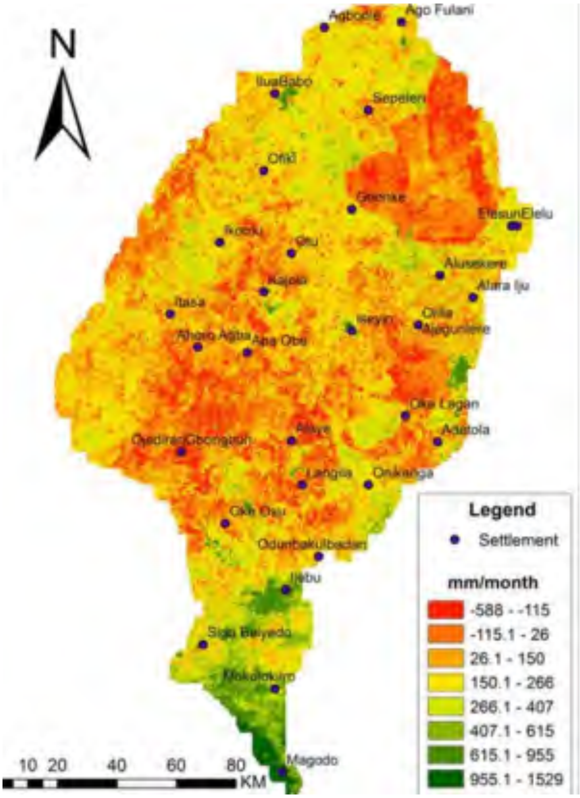

Fig. 13: ***Average difference between total precipitation and total actual evapotranspiration and interception (P – ET_a) for 2018 hydrological year***

The same calculation was done for each land cover class to identify net water generating and consuming land cover classes. Table 7 shows the mean values of P, ETa, and their difference per each land cover class. The built-up area is the most significant net water generator, giving P – ETa to be 828.6 mm yr^{-1}. This class's excess rainfall (P – ETa) is 61.9% of its precipitation (1339.01 mm yr^{-1}). Grassland, shrubs or herbaceous covers which were flooded are the second and third largest net water producers and generated 550.4 mm yr^{-1} and 500.5 mm yr^{-1}, respectively. Also, precipitation exceeds Eta in Tree cover: closed, evergreen broadleaved (391.6 mm yr^{-1}), Waterbodies (339.4 mm yr^{-1}), Tree cover: open, unknown type (218.9 mm yr^{-1}), Shrubland (99.09 mm yr^{-1}) and Tree cover: closed, unknown type (12.45 mm yr^{-1}). The biggest net water consumers are Cropland, irrigated or under water management (-295.3 mm/year), followed by the Tree cover: closed, deciduous broadleaved class (-33.2 mm yr^{-1}). Also, evapotranspiration exceeds precipitation in Cropland, rainfed, and Tree cover: open, deciduous broadleaf with -25.73 mm yr^{-1} and -3.25 mm yr^{-1} consumed, respectively.

This study reveals the P<ETa for the waterbody landcover class category, which disagrees with P>ETa found in other studies using either WaPOR or other remote sensing datasets. FAO and IHE Delft (2020), for example, revealed that waterbody is the most significant net water consumer (-1,157 M m^{-3} yr^{-1}), followed by the irrigated croplands class (-217 M m^{-3} yr^{-1}) in the Jordan River basin. FAO and IHE Delft (2020) also showed that the ETa exceeds P in water bodies in the highlands and lowlands in the Awash basin. In addition, Van Eekelen et al. (2015) revealed that the highest water consumer in the Incomati basin was open waters in 2013. This difference in the result of this study and the results from the FAO and IHE Delft (2020) can be attributed to the use of different WaPOR-level datasets. This study used the Level 1 WaPOR dataset, which is the continental level data available at 250m resolution as against the Level 2 WaPOR dataset for selected countries and basins data available at 100m resolution used by the studies used for comparison. However, in recent studies, the result agrees with FAO and IHE Delft (2020), where P<ETa for waterbody in the Nile River basin.

Table 7: Average P-ETa for each land cover class for hydrological year 2018

	Land Cover Class	Area km^{-2}	%	P (mm yr^{-1})	ETa (mm yr^{-1})	P km^{-3} yr^{-1})	ETa (km^{-3} yr^{-1})	P-ETa (mm yr^{-1})	P-ETa (km^{-3} yr^{-1})
1	Grassland	123.07	0.55	1535.88	1035.34	0.19	0.13	500.5	0.06
2	Built-up	459.35	2.05	1339.01	510.4	0.615	0.23	828.6	0.39
3	Cropland, irrigated or under water management	25.22	0.1	1183	1478.31	0.03	0.04	-295.3	-0.01
4	Water bodies	48.59	0.22	1459.4	1120	0.07	0.05	339.4	0.02
5	Tree cover: closed, evergreen broadleaved	42.39	0.19	1684.5	1292.91	0.07	0.05	391.6	0.02
6	Tree cover: open, unknown type	13515.6	60.27	1290.43	1071.53	17.4	14.5	218.9	2.9
7	Tree cover: closed, deciduous broadleaved	1838.27	8.2	1369.9	1403.1	2.52	2.58	-33.2	-0.1
8	Tree cover: closed, unknown type	2534.8	11.3	1347.85	1335.4	3.42	3.39	12.45	0.03
9	Cropland, rainfed	2301.77	10.26	1235.71	1261.44	2.84	2.9	-25.73	-0.1
10	Shrub or herbaceous cover, flooded	34.37	0.15	1403.7	853.27	0.05	0.03	550.4	0.02
11	Tree cover: open, deciduous broadleaved	1207.68	5.39	1339.87	1343.12	1.62	1.62	-3.25	0
12	Shrubland	295.65	1.32	1281.83	1182.74	0.38	0.35	99.09	0.03

Basin scale water balance

Discharge

Figure 14 shows that the average discharge of New Bridge Abeokuta station for the hydrological year 2018 is 110.4 m^{-3} s, while the minimum and maximum discharges are 15.64 m^{-3} s, and 271 m^{-3} s, respectively, were recorded. It should be noted that the reported data is for the mid-stream. Therefore, a higher discharge is expected downstream. Higher discharge downstream could result in increased velocity, leading to flooding and greater sediment transport downstream. Increased sediment transport could result in turbidity which can negatively affect aquatic life. Furthermore, higher discharge downstream implies increased water availability which could be beneficial for irrigation of crops cultivated on farmlands located downstream.

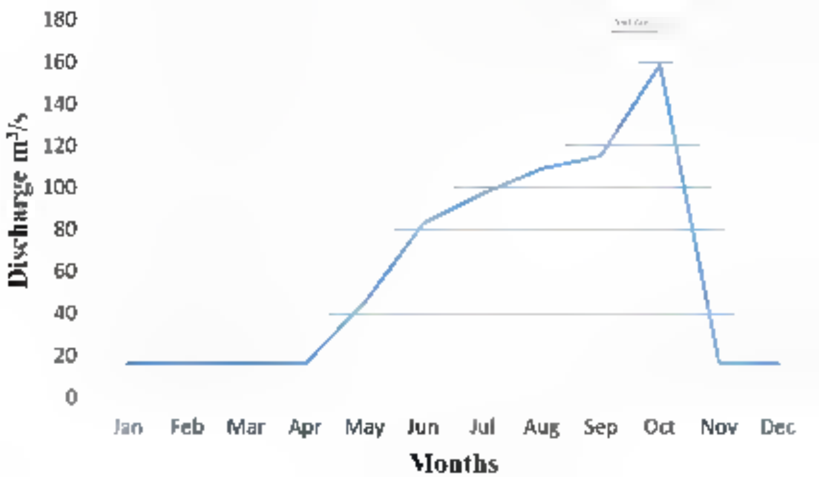

Fig. 14: New Bridge Abeokuta station discharge for 2018 hydrological year

GRACE total water storage change

Figure 14 depicts the negative longer-term pattern in storage shift (S) as seen by GRACE. For instance, from 2009 to 2016, the tendency of total water storage in equivalent water height for a number of GRACE solution grids, or mass concentration (also known as mascons), that span the Ogun River Basin was -12.9 mm yr^{-1}, or roughly -0.29 km^{-3} yr^{-1}. The GRACE numbers should be used with care because the basin only occupies one-third of the surface pixel. However, the temporal shifts offer a separate indication that groundwater supplies are being drained and that years like 2015 have sped up the process.

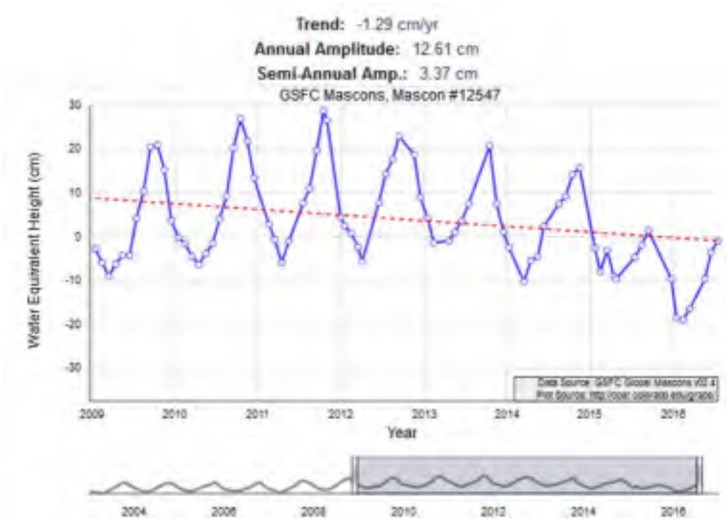

Fig. 15: ***Longer term trend of declining water storage in Ogun basin based on GRACE gravity measurements. Source: https://ccar.colorado.edu/grace/gsfc.html***

Figure 16 shows the GRACE data collected storage map versus WaPOR Level 1 data P - ETa - Qout. The overall storage shift (S) recorded by GRACE for the hydrological years does not match P - ETa - Qout. Table 8 depicts the imbalance of the WaPOR basin-wide water balance. From 2009 to 2016, there is an average bias of 9.89% (of precipitation) due to inexplicable basin overflow or errors in P and ETa or GRACE estimates. This finding is equivalent to the FAO and IHE Delft (2020) result, which showed that the error between P - ETa - Qout and S can be due to ambiguity in WaPOR P and ETa, discharge measurement, and/or GRACE TWSA solution in the Niger River region.

Table 8: The average total water storage change derived from WaPOR data and GRACE TWSA

Year	ΔS from WaPOR Water Balance (km^{-3} yr^{-1})	ΔS from GRACE (km^{-3} yr^{-1})	ΔS difference (km^{-3} year)	Error percentage (%Precipitation)
2009	7.27	0.79	6.48	20.68

Year	ΔS from WaPOR Water Balance (km^{-3} yr^{-1})	ΔS from GRACE (km^{-3} yr^{-1})	ΔS difference (km^{-3} year)	Error percentage (%Precipitation)
2010	3.12	1.45	1.67	5.55
2011	2.17	2.09	0.08	0.28
2012	7.84	0.19	7.65	26.58
2013	-0.02	1.08	-1.10	-5.14
2014	4.78	0.65	4.13	13.78
2015	-0.58	-1.17	0.59	2.58
2016	1.42	-2.54	3.96	14.78
Average	3.25	0.32	2.93	9.89

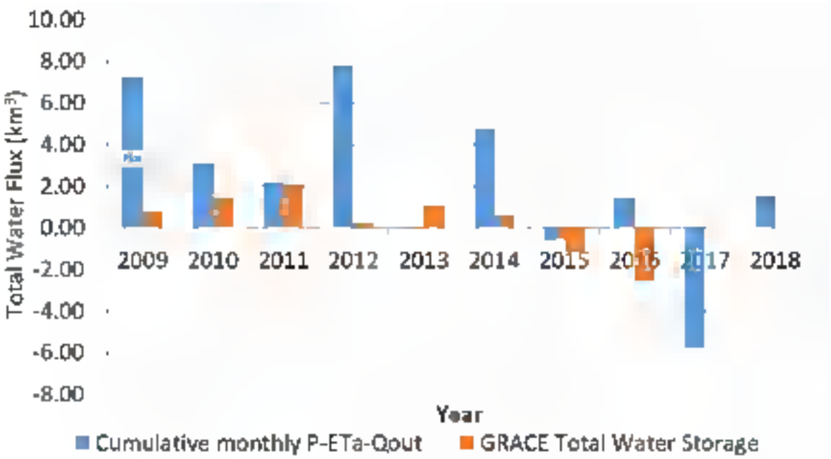

Fig. 16: Cumulative monthly difference of WaPOR P – ET$_a$ – Q$_{out}$ and GRACE TWSA for Ogun River Basin

WA+ Land Use categorization

Figure 17 shows the reclassified Land cover class into WA + category. It is seen that the main WA+ land use category in the basin is the Utilized Land Use which occupies 70% of the land area. This is followed by the Protected Land Use which occupies 18%, Modified Land Use which occupies (10%); and the Managed Water Use occupies 2 % of the total Ogun River basin Land cover. Also, the spatial pattern of the reclassified Land cover class into the WA + category is seen in Figure 18.

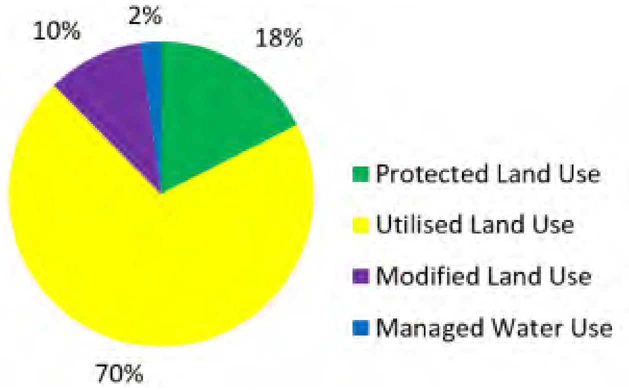

Fig. 17: ***WA+ Land Use category percentage of Ogun River Basin for 2018 hydrological year***

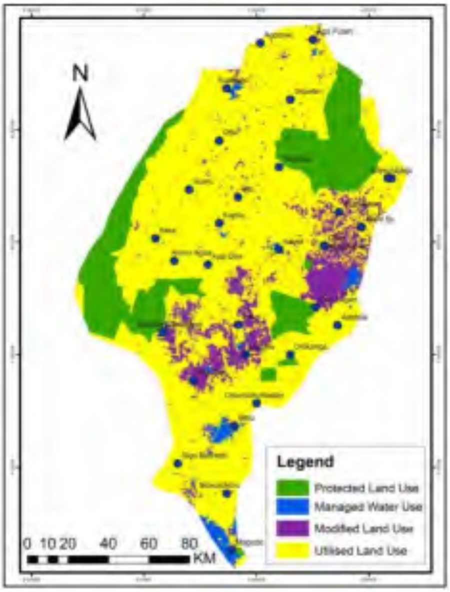

Fig. 18: ***Spatial pattern of WA+ Land Use category of of Ogun River Basin for 2018 hydrological year***

Pixel Scale Analysis

Separation of ET_a into ET_{rain} and ET_{incr}

Figure 19 displays the outcomes of the computation for ETrain and ETincr for the various land cover classifications. The percentages show how much ETrain and ETincr comprise the total precipitation. It demonstrates that irrigated or water-managed crops, confined deciduous broadleaved trees, rain-fed crops, and open deciduous broadleaved trees all have high additive ET. According to this method, 59% and 66% of ETa for plants come from ETincr. Similarly, the ETrain for crops that are rainfed, underwater, or both is 51% of the rainfall, and the ETincr is 74% of the rainfall.

The land cover groups with the highest incremental ET only encompass 23.95% of the basin. Only 51% of the ET in irrigated or water-managed crops comes from rainfall, with the remaining 74% from blue water. This 0.1% of the basin's territory has substantial ETincr. The built-up grassland, shrub or herbaceous cover, flooded water bodies, and shrubland cover categories produce most of the overflow in the region. Additionally, it is predicted that between 44% and 53% of total precipitation falls as ETrain in the cover groups of closed, evergreen broadleaved trees, open, unknown types of trees, and closed, unknown types of trees, which includes interception. This means that between 20 and 35% percolates or creates runoff.

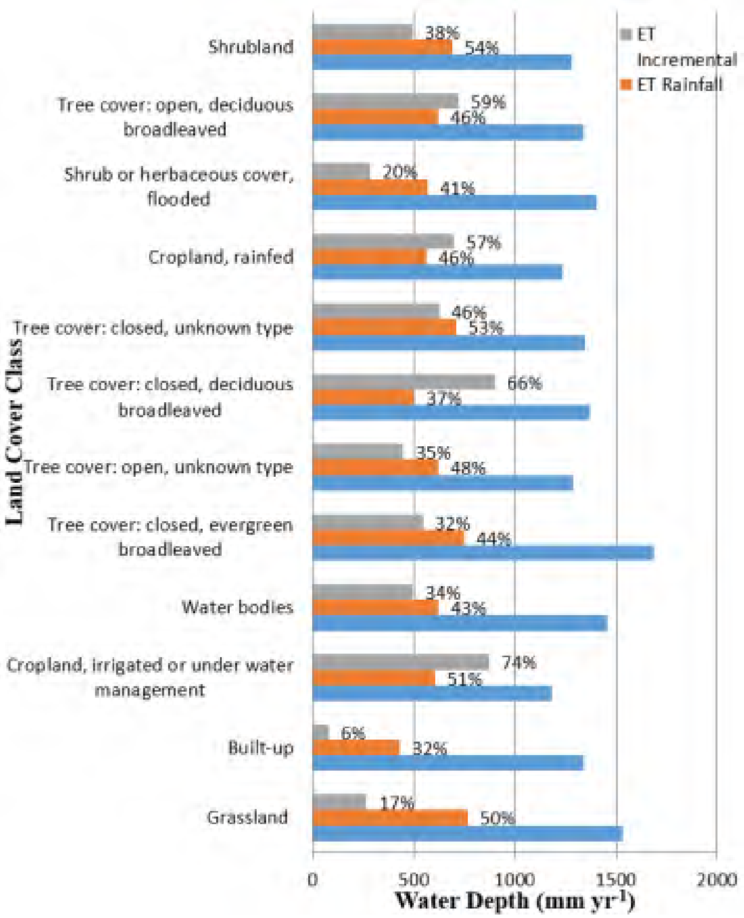

Fig. 19: Average Precipitation, ET_{rain} and ET_{incr} of each land cover class for the 2018 hydrological year

WA+ Sheet 1: Resource Base

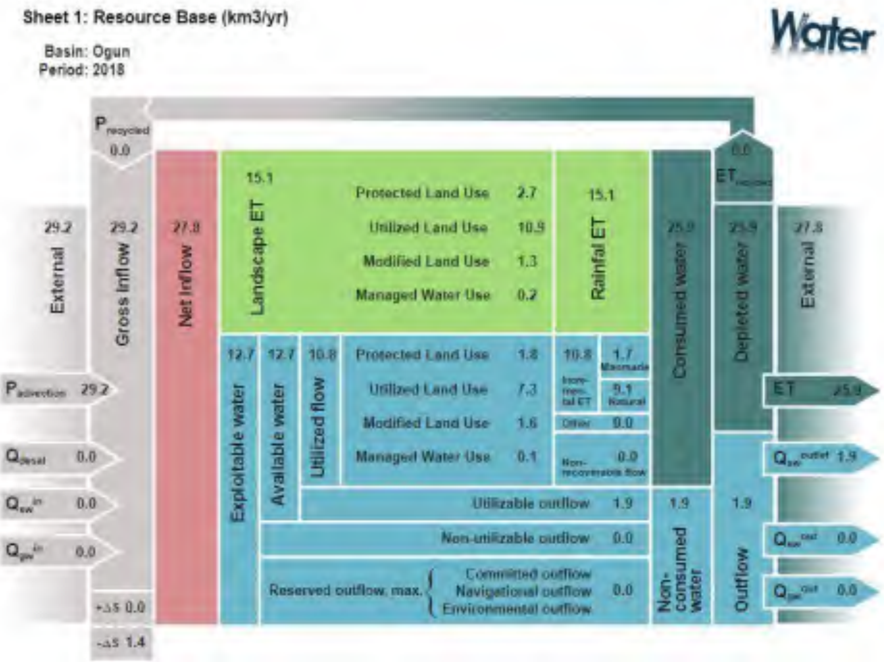

Fig. 20: ***WA+ Resource sheet for the Ogun River Basin containing average flow values for the 2018 hydrological year. Source: www.wateraccounting.org***

Figure 20 shows the WA+ resource bases sheet for the Ogun basin in the 2018 accounting year. The exploitable water resources in the Ogun basin are 12.7 km^{-3} yr^{-1}. However, the renewable water resources are higher (14.1 km^{-3} yr^{-1}) due to an increase in basin storage by 1.4 km^{-3} yr^{-1}. As a result, the gross inflow is 29.2 km^{-3} yr^{-1}, and the total outflow and consumed water is 27.8 km^{-3} yr^{-1}, which results in 1.4 km^{-3} yr^{-1} remaining as total water storage change (Balance).

The basin has an ungagged natural outlet, making it difficult to account for the entire surface water outlet of the basin. However, the study accounts for the discharge at one of the basin's hydrological stations (New Bridge Abeokuta) which is an average of about 1.9 km^{-3} yr^{-1}, and was used to represent the complete discharge from the basin for this study.

The utilized land use has the highest water consumption (10.9 km^{-3} yr^{-1} from ETrain and 7.3 km3/year ETincr), about 70% of the total ETa. The protected land use class of the basin consumes 2.7 km^{-3} yr^{-1} from ETrain and 1.8 km^{-3} yr^{-1} ETincr; the modified land use category consumes 1.3 km^{-3} yr^{-1} from ETrain and 1.6 km^{-3} yr^{-1} ETincr. The water consumption of the managed water use is 0.3 km^{-3} yr^{-1}. Therefore, it has the lowest water consumption of the total ETa to be 1%. Cropland irrigated or under water management covers 25.22 km^{-2}, about 0.1% of the Ogun River Basin area. The average incremental ET used by this land cover is 873.38 mm/year, which implies that about 0.02 km^{-3} yr^{-1} of the exploitable water is used for irrigation. The variation of the main fluxes in these sheets is shown in Figure 4.20. This result is similar to (FAO and IHE Delft, 2020) which revealed an increase in basin storage by 1.48 km^{-3} yr^{-1} in the 2017 hydrological year of the Jordan River basin.

Most (86%) of the ETincr's overall flow of 12.1 km^{-3} yr^{-1} (10.4 km^{-3} yr^{-1}) comes from natural withdrawals. The human outflows (1.7 km^{-3} yr^{-1}) constitute only about 14% of ETincr. Utilized Land Use (ULU), with 8.6 km^{-3} yr^{-1}, and Modified Land Use (MLU), with 1.6 km^{-3} yr^{-1}, receive the majority of the water resources that are accessible. Of the entire ETincr, Protected Land Use (PLU) utilizes only 1.8 km^{-3} yr^{-1}. Since this consumption happens organically and is hidden from water managers, it is rarely mentioned in plans for water allocation. However, the capillary rise and flood areas inundated by overflows and flash floods can account for the reality that indigenous use groups use blue water. According to FAO and IHE Delft (2020), groundwater-dependent habitats like bushland and forests would also access shallow reservoirs and block drainage movements.

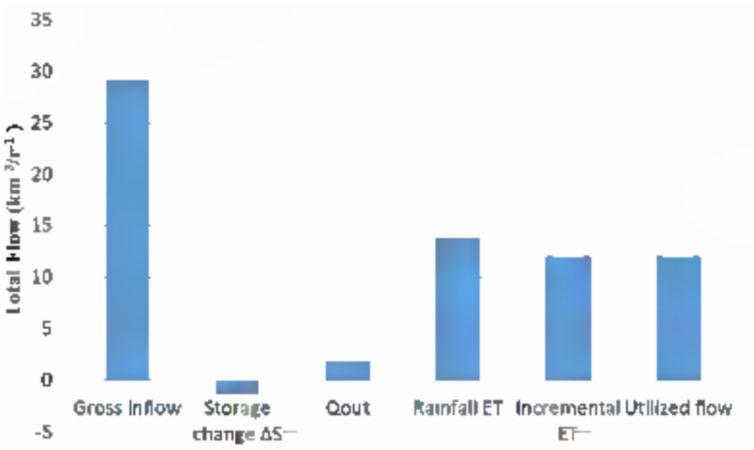

Fig. 21: Average water fluxes of Ogun River Basin for 2018 hydrological year

Rapid WA+ Key Performance Indicators of the River Basin System

Table 9 shows the key performance indicators. Again, we used WaPOR data to calculate the key indicators because there were differences between the storage change computed from WaPOR data, GRACE gravity readings and the storage change calculated from the annual water balance.

Table 9: WA+ Resource Sheet key indicators of Ogun River Basin for 2018 hydrological year

S/N	Performance Indicators	Value
1	ET Fraction (%)	88.6
2	Stationarity Index (%)	5.4
3	Basin Closure (%)	93.5
4	Available Water (AW) (km^{-3} yr^{-1})	3.4
5	Managed Water (MW) (km^{-3} yr^{-1})	0.1
6	Managed Fraction (%)	2.9

ET Fraction, Stationarity Index and Basin Closure

According to the key performance indicators in Table 9, the average ET fraction of the Ogun River Basin is 88.6%, showing that not all rainfall is utilized. Excess rainfall either adds to storage or causes an overflow from the area. As a result, the projected average stationarity score is 5.4%. The typical basin closure index is 93.5%, indicating that almost all water resources are utilized and stored. Only 6.5% of the basin's water is discharged.

Available Water, Managed Water and Managed Fraction

The actual quantity of water being managed or accessible for management is the emphasis of the second group of signs in Table 9. The average amount of water that is accessible is 3.4 km^{-3} yr^{-1}, of which only 2.9% is presently handled. The Managed Water, or the Incremental ET of Managed Water Use, is, on the other hand, typically 0.1 km^{-3} yr^{-1}. This implies that the Managed water use (Cropland, irrigated, or underwater management covers) significantly underutilizes water, adding to the excess water in the river region.

Conclusion

By using the WA+ framework to analyse the water balance, this research has reinforced the capacity of remote sensing methods in rapid water accounting. In particular, the WaPOR 2.0 Level 1 data quality evaluations revealed acceptable estimates of P and ETa at the basin size. They can aid in mapping the basin's overall spatial distribution and identifying regions of net water production and consumption. The spatial distribution of the disparity between P and ETa showed that P far outnumbers ETa. Cropland, irrigated or underwater management, and tree cover: closed, deciduous broadleaved, and Cropland rainfed as the most important water user in the basin. It is recommended that the 1.4 km^{-3} surplus water balance is an enormous potential that should be harnessed for a year-round agriculture through irrigation to increase agricultural productivity and food security in South Western Nigeria. This will reduce the food dependence of southwest Nigeria on other regions. Also, medium-sized dams should be constructed across the Ogun River basin to store water surplus, increase water availability in the face of water scarcity, and control the proliferation of boreholes. It is also recommended that the managed water use landcover class be expanded to efficiently reduce the possibility of a flood resulting from the water balance surplus.

REFERENCES

Adeaga, O. (2006). Multi-decadal variability of rainfall and water resources in Nigeria. *IAHS publication*, 308, 294.

Akinyemi, D. F., Ayanlade, O. S., Nwaezeigwe, J. O., and Ayanlade, A. (2019). A comparison of the accuracy of multi-satellite precipitation estimation and ground meteorological records over Southwestern Nigeria. *Remote Sensing in Earth Systems Sciences*, 1-12.

Awomeso, J., Taiwo, A., Idowu, O., Gbadebo, A. and Oyetunde, O. (2019). Assessment of water quality of Ogun River in southwestern Nigeria. IFE J. Sci., 21, 375.

Bănăduc, D., Simić, V., Cianfaglione, K., Barinova, S., Afanasyev,S., Öktener,

A., McCall, G., Simić, S., and Curtean-Bănăduc, A. (2022). Freshwater as a Sustainable Resource and Generator of Secondary Resources in the 21st Century: Stressors, Threats, Risks, Management and Protection Strategies, and Conservation Approaches. *International Journal of Environmental Research and Public Health,* 19(24): 16570. doi: 10.3390/ijerph192416570

Bastiaanssen, W. G. M., Karimi, P., Rebelo, L.-M., Duan, Z., Senay, G., Muttuwatte, L., and Smakhtin, V. (2014). Earth observation-based assessment of the water production and water consumption of Nile Basin Agro-Ecosystems, Remote Sensing, 6, 10306–10334.

Biancamaria, S., Mballo, M., Le Moigne, P., Pérez, J. M. S., Espitalier-Noël, G., Grusson, Y., and Sauvage, S. (2019). Total water storage variability from GRACE mission and hydrological models for a 50,000 km2 temperate watershed: the Garonne River basin (France). *Journal of Hydrology: Regional Studies, 24*, 100609.

Choudhury, B.J., and DiGirolamo, N.E. (1998). A biophysical process-based estimate of global land surface evaporation using satellite and ancillary data I. Model description and comparison with observations. *Journal of Hydrology, 205*(3-4), 164-185.

Dost, R., Obando, E.B., Bastiaanssen, W., and Hoogeveen, J. (2013). Water Accounting Plus (WA+) in the Awash River Basin. Coping with Water Scarcity – Developing National Water Audits Africa. https://www.wateraccounting.org/files/projects/awash_basin.pdf

Droogers, P., Immerzeel, W.W., Terink, W., Hoogeveen, J., Bierkens, M.F.P., and van Beek, L.P.H. (2012). Water Resources Trends in Middle East and North Africa towards 2050. Hydrology and Earth System Sciences, 16, 3101-3114. https://doi.org/10.5194/hess-16-3101-2012

Elmahdi, A. (2020). Guided paper: water accounting reporting system – WARS framework from concept to implementation for sustainable water management. *International Journal of Environmental Science and Natural Resources, 23 (4), 556118. DOI:10.19080/IJESRNR.2020.23.556118.*

FAO and IHE Delft. (2019). Water accounting in the Litani River Basin-remote for water productivity. Water accounting series. Rome.

FAO and IHE Delft. (2020). Water accounting in the Awash River Basin. FAO WaPOR water accounting reports. Rome.

FAO and IHE Delft. (2020). Water accounting in the Jordan River Basin. FAO WaPOR water accounting reports. Rome. https://doi.org/10.4060/c9918ien

FAO and IHE Delft. (2020). Water accounting in the Niger River Basin. FAO WaPOR water accounting reports. Rome. https://doi.org/10.4060/cb1274en

FAO and IHE Delft. (2020). Water accounting in the Nile River Basin. FAO WaPOR water accounting reports. Rome. https://doi.org/10.4060/c99895en

FAO. (2012). Coping with water scarcity: an action framework for agriculture and food security. FAO Water Report 38. Rome, Food and Agriculture Organization.

Gleick, P.H., and Cooley, H. (2021). Freshwater Scarcity. *The Annual Review of*

***Environment and Resources,* 46, 319 – 348. https://doi.org/10.1146/annurev-environ-012220101319**

Ifabiyi, I. P. (2005). Construction versus yield of deep wells in the regolith aquifer of Osun River basin, Nigeria. *Water Resources, 16*, 1-16.

Jones, H.A. and Hockey, R.D. (1964). The Geology of Part of Southwestern Nigeria Geol. Surv. Nigeria, Bull, 31, 101 p.

Luthcke, S. B., Sabaka T. J., Loomis B. D., Arendt A., McCarthy J.J., and Camp, J. (2013). Antarctica, Greenland and Gulf of Alaska land ice evolution from an iterated GRACE global mascon solution, J. Glaciol., 59(216), 613–631.

Mengyu L., Zhou, X., Huang, G., and Li, Y. (2024). The increasing water stress projected

for China could shift the agriculture and manufacturing industry geographically. *Communications Earth and Environment,* 5:396, 1-13. https://doi.org/10.1038/s43247-024-01560-y

Molden, D. (1997). Accounting for water use and productivity (No. 42). IWMI.

Musie, W., and Gonfa, G. (2023). Fresh water resource, scarcity, water salinity

challenges and possible remedies: A review. *Heliyon* 9, 1-18. https://doi.org/10.1016/j.heliyon.2023.e18685

National Bureau of Statistics NBC (2017). Demographic Statistics Bulletin 2017.

Odunuga, S. and Ajayi, O.S. (2017). Morphometric Changes of Ogun River Basin in South-West Nigeria. Benin Journal of Social Sciences, 23, 1-25.

Odunuga, S., Oyebande, L., and Omojola, A. S. (2012). Social-economic indicators and public perception on urban flooding in Lagos, Hydrology for Disaster Management: Special Publication of the Nigerian Association of Hydrological Sciences, NAHS, Abuja, 82–96, 2012.

Oki, T., and Kanae, S. (2006). Global hydrological cycles and world water resources. *Science*, *313*(5790), 1068-1072.

Rijsberman, F.R. (2006). Water Scarcity: Fact or Fiction? Agricultural Water Management, 80, 5-22. https://doi.org/10.1016/j.agwat.2005.07.001.

Rodda, J.C., (1998). Hydrological networks need improving! Proc. Int. Conf. on World Water Resources at the Beginning of the 21st Century, Paris, France, UNESCO.

Schaake, J.C., Koren, V.I., Duan, Q.Y., Mitchell, K. and Chen, F. (1996). Simple water balance model for estimating runoff at different spatial and temporal scales. *Journal of Geophysical Research – Atmospheres*, **101**(D3), 7461– 7475. Available from: https://doi.org/10.1029/95JD02892

Simons, G., Bastiaanssen, W., Ngo, L. A., Hain, C. R., Anderson, M., and Senay, G. (2016). Integrating global satellite-derived data products as a pre-analysis for hydrological modelling studies: a case study for the Red River Basin. *Remote Sensing*, *8*(4), 279.

UNEP (2021). Progress on IWRM: global indicator 6.5.1 updates and acceleration needs 2021.

Van Eekelen, M. W., Bastiaanssen, W. G., Jarmain, C., Jackson, B., Ferreira, F., Van der Zaag, P., and Luxemburg, W. M. J. (2015). A novel approach to estimate direct and indirect water withdrawals from satellite measurements: A case study from the Incomati basin. *Agriculture, Ecosystems & Environment*, *200*, 126-142.

Yang, Y., Donohue, R. J., and McVicar, T. R. (2016). Global estimation of effective plant rooting depth: Implications for hydrological modeling. *Water Resources Research*, *52*(10), 8260-8276.