Evaluation of Sustainable Water Demand in a Coastal Environment using WEAP Model

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Abstract

Ogun river basin, located in southwestern Nigeria, is one of the major river basins under the management of Ogun-Oshun River Basin Development Authority. Different water uses, including domestic, commercial, industrial and agricultural takes place within the basin. As population and economic activities increase, water demand also increases, which makes it imperative for water resources planners to take into account the consequent water demand challenges. In this study, Water Evaluation and Planning (WEAP) model is used to evaluate the impacts of possible water demands on the water resources of Ogun river basin up to the year 2020. Two scenarios were simulated: the first concerns the previous and current accounts of water demand in the basin from 2006 to 2011 while the second simulates the future water demand in the basin from 2012 to 2020. The water demand utilization, unmet demand, demand site coverage, supply delivered, stream flows and water storage were analysed for each scenario by integrating various hydrological components, such as hydrological year cycles, precipitation and dams. Each scenario also made key assumptions with respect to the gross domestic product, population growth rate, irrigation efficiency and complementary sources of water. The results of the model for the previous and current scenarios indicate that the water demand for domestic, commercial, industrial and agricultural uses are 4.7×10^9 m^3, 9.5×10^8 m^3, 6.8×10^8 m^3 and 3.4×10^4 m^3 respectively while the corresponding values for the total water demand, supply required and supply delivered are 6.7×10^9 m^3, 7.7×10^9 m^3 and 3.6×10^9 m^3, thereby making the unmet total water demand to be 4.1×10^9 m^3. The model prediction for the years 2012-2020 indicates that the water demand for domestic uses will be the highest at 5.3×10^{10} m^3. The demand from commercial, industrial and agricultural uses are 1.1×10^{10}, 2.5×10^9 and 1.4×10^9 m^3 respectively. The total water demand, supply required and supply delivered are 6.8×10^{10} m^3 , 7.9×10^{10} m^3 and 10×10^9 m^3 respectively resulting in unmet total water demand of 6.9×10^{10} m^3, at an average annual rate of 7.7×10^9 m^3. The Ogun River therefore, may not be able to satisfy the future water demand of water users in the basin. To reduce unmet demand, waste water treatment, introduction of water meters to check wastage, building of new dams or increasing the capacities of existing ones, groundwater development, information dissemination and development of manpower in the field of water resources are recommended.

Keywords: WEAP model, water demand, water supply, Ogun River basin, water uses

Introduction

Water is a vital resource for every human activity. Water makes life possible. Without it, life and civilization cannot develop or survive. Water forms the largest part of most living matter and is vital to man just as air and food are (Ayoade, 2003). The management and maintenance of water is thus very important (Fiorilloa, 2007).

The accelerating growth of human population, the rapid advances made in industry and agriculture have resulted in a rapidly increasing use of water by man, to the extent that the availability of water as well as the control of excessive water has become a critical factor in the development of every regions of the world (Williams, 2010). Over the decades, water supply management has proved to be insufficient to deal with strong competition for water with growing per capital water use, increasing population, urbanization pollution and storages (Wang Xiao – Jun et al, 2009). Also, the need for domestic, industrial and agricultural water supply is growing, but the absence of demand management strategies means that the increase in demand will likely outstrip the available supply, hence water scarcity (UNESCO, 2006).

The issue of water scarcity in the world and its implication on development of new political and economic relations among countries may result to crisis in the future. The management of water resources as a common resource would require trade-off among countries and water users (Yang and Zehnder, 2007). The need therefore to device means by which available water can be consumed and allocated among the various uses is pertinent.

Ogun river basin is one the five major river basins under the management of Ogun-Osun River Basin Development Authority (ORBDA) and it lies within the coastal environment. Due to the potential of Ogun river basin as a major source of water supply, this study developed a plan that will allow for the sustainable and rational utilization, conservation and management of available water resources within Ogun river basin using Water Evaluation and Planning (WEAP) Model. The study also determined the future water demand for various uses, proffered alternative strategies for water conservation through storage mechanism that will meet water demand within the basin.

The Study Area

Ogun river basin is one of the 5 major basins under the management of Ogun Oshun River Basin Development Authority. Others are Yewa, Sasa, Oshun, and Ona basins. Different water users i.e. domestic, commercial, industrial and agricultural activities, are present in the basin. Ogun River rises in the Iganran Hills (503 m) east of Shaki in the northwestern part of Oyo State and flows southwards for approximately 410 km, before discharging into Lagos lagoon. The river's main tributary, Oyan, which rises to the west of Shaki incorporates, Ofiki and Opeki rivers. The Ikere Gorge dam is situated on the Ogun River, 8 km east of Iseyin in Oyo state. The basin lies between latitudes 6^o 33 and 8^o 58 N and between longitudes 2^o 40 and 4^o 10. The total area is about 23,700 km^2 (Figure 1).

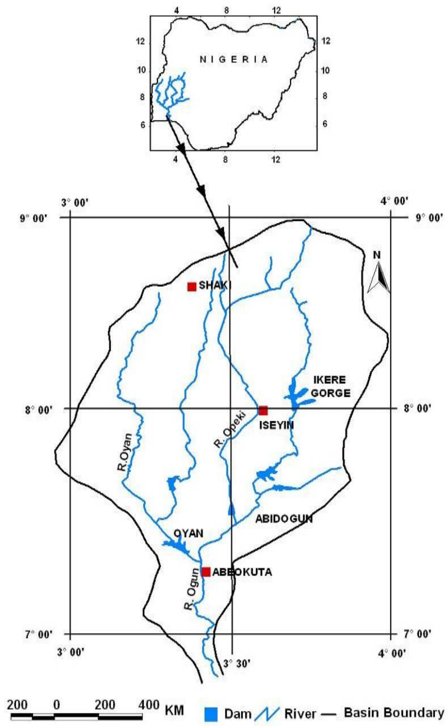

Figure 1: The Ogun River Drainage Basin

Methodology

Ogun river basin faces freshwater management challenges, some of which include allocation of limited water resources, inadequate environmental quality monitoring, and policies for sustainable water use. The evaluation process considered the identified issues as well as both hydrologic and institutional aspects in the assessment of water demand within the basin. The investigated water demand includes water consumption for human needs, agriculture (irrigation), and industries.

WEAP software was used to evaluate the future water demands in Ogun-Oshun River Basin. A full range of water development and management options were evaluated, which takes account of multiple and competing uses of water systems. In the WEAP, the typical scenario modeling effort consists of three steps. First, a Current Account year, which is chosen to serve as the base year of the model; second, a Reference scenario that is established from the Current Account to simulate likely evolution of the system without intervention; and third "what-if" scenarios created to alter the "Reference Scenario" and evaluate the effects of changes in policies and/or technologies. The data used in modeling for current accounts, ranges from 2006 to 2020 (Tables 1 and 2). In the allocation of the available resources therefore, a number of options were tested by developing several scenarios from where future water demands are projected.

Geographical information system (GIS) tool was used to configure the system and geo-reference the area of study. Primary and secondary data on water supply and demand for domestic, industrial, commercial were obtained from Ogun State Water Corporation. Irrigation water requirement, reservoir capacity, location and operation rules, gauge heights, river head flows and climatic data, such as rainfall and temperature, were obtained from Ogun Osun River Basin Development Authority and the Meteorological Station at the Federal University of Agriculture, Abeokuta. Population data for Ogun River Basin was obtained from National Population Commission.

Key assumptions were made; these are the user defined parameters employed throughout the WEAP model. The assumptions are:

- Level of GDP growth;
- Population growth rate;
- Level of technological irrigation efficiency;
- Other complimentary source of water usage.

The use of key assumptions enables a faster set up of the current situation, the scenarios, and simplifies changes in the characteristics of reservoirs and demand sites.

WEAP model is structured in a way that the water resources system is represented in terms of river, groundwater, reservoirs withdrawals, transmission and wastewater treatment facilities, ecosystem requirements, and return flow. Other representations include flow requirements, runoff river hydrology, water demand sites and pollution (Sieber et al, 2005). The model also consists of five main views, namely Schematic, Data, Results, Overviews and Notes.

The schematic view, which is the study area and other polygon parameter were created using a GIS based tools, where raster files were imported to the system as a background for schematic layers. Drag and drop method was used to create objects such as demand nodes, reservoir, transmission link and return flow, which were positioned within the study area. Streams in the area were also redrawn by using the interactive drag and drop button on the WEAP model (Figure 2).

The current account (baseline) year represent the basic definition of the water system as it currently exists. The year 2006 was selected as the starting year for all scenarios due to data availability for water demand, supply, irrigation and hydrological information such as inflow and rainfall. The WEAP software takes into account water demand for all demand sites, which include domestic, commercial, industrial and agriculture (middle and lower Ogun irrigation project). Two main parameters were identified; the Annual Activity Levels and Annual Water Use Rate.

The annual activity/demand level represents the amount of water required by each demand. Losses, reuse and efficiency are accounted for separately. Water consumption was calculated by multiplying the overall level of activity by a water use rate. Activity levels are used in WEAP's demand analysis as a measure of social and economic activity. WEAP multiplies activity levels down each chain of branches to get the total activity. The Annual Water Use Rate is not the total amount used but it is the average annual water consumption per unit of activity.

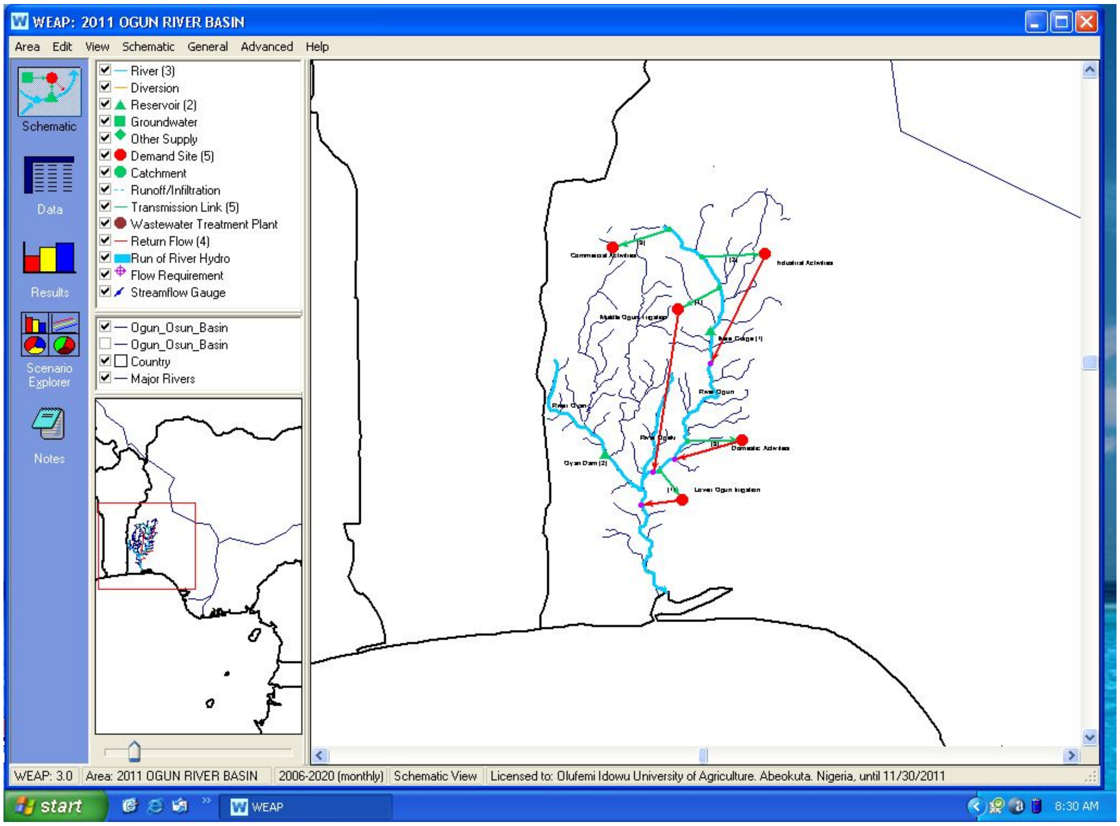

Figure 2: The Schematic Map of Ogun River Basin as at 2011 produced from the GIS raster layer

Table 1: Past data used to calculate resources demand for the period (2006 - 2020)

Reference Account:	**2006-2011**
Population:	**2485182 persons**

Demand sites:	**Industrial**	**Commercial**	**Domestic**	**Middle Ogun**	**Lower Ogun irrigation**
Annual activity (10^6 m^3)	48.227	16.29	12.22	325.68	369.1
Annual water rate (%)	1.59	4.71	30.88	46.32	40.87

Source: Ogun State Water Corporation, 2011

The average of the annual inflow of the river head flows for rivers Ogun, Opeki, and Oyan from 2006-2011 were determined as presented in Table 2. The minimum and maximum values were taken as a very dry and very wet year respectively, while the normal year was the mid point between the very dry and the normal. This was used in the model to accommodate future changes in hydrological patterns. Maximum and minimum water storage data and the net evaporation values for Oyan and Ikere Gorge dams were obtained to account for the difference between evaporation and precipitation on the reservoir surface.

Table 2: Average Monthly River flows ($m^3 s^{-1}$)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River Ogun	0.53	0.52	0.38	1.16	0.36	1.63	4.08	64.44	132.86	136.70	37.78	2.35
River Opeki	9.17	8.28	10.03	17.49	26.79	24.00	46.52	77.52	87.69	64.32	26.73	9.68
River Oyan	0.65	0.46	0.78	0.41	2.34	2.37	7.40	8.11	13.32	8.41	8.90	0.82

Source: Ogun – Osun River Basin Development Authority, 2011

Current Account of the water system was first created. Based on a variety of economic, demographic, hydrological and technological trends, the "Reference" projection was established. Then a policy scenario was developed with alternative assumptions about future development. The scenario can address a broad range of ''what if" questions such as: what if population growth and economic development patterns changes?, what if reservoir operating rules are altered?, what if new sources of water pollution are added?, what if a water – recycling program is implemented?, what if a more efficient irrigation technique is implemented?, what if ecosystem requirements are tightened?, what if various demand management strategies is implemented?, and what if climate change alters the hydrology? These scenarios are viewed simultaneously in the results for easy comparison of their effects on the water system. The results were accessed and every model output was displayed in the next software chapter while the overview allows accessibility of key indicators in the model. Notes were eventually added to the model for documentation of the key assumptions.

Results and Discussion

The reference scenario covers 2012 – 2020 in this study and it is the base scenario that uses the actual data to help in understanding the best estimates about the studied period. The objective of a reference scenario is to help planner and water resources manager understand what could occur if current trend continues and to understand the real situation. Reference scenarios can also be useful for identifying where knowledge is weak, analyze likely trends and where more information needs to be collected. Also, it is important for designing contingency plans where there is a lot of risk and uncertainty. In this study, the reference scenario replicates real situation and the result for projected water demand is shown in Table 3.

The amount of water available for future use among the various demand sites is shown in Table 3. Water demand for various demand sites vary according to water use rate. As the population within the basin increases, water demand for demand site also increases. For instance, the demand for domestic activities is $5.3 \times 10^{10} m^3$, which is the largest amount. On the other hand, middle and lower Ogun irrigation have marginal increment in water demand due to low level of irrigation practice within the area. Thus, for the months of July to December, irrigation at lower and middle Ogun region has almost 100% demand site coverage (Table 4). Excess water is available to meet up water use rate during the period due to small irrigated farmland, high precipitation, and minimal technological improvement in the agricultural activities within the basin. In addition, the demand site coverage between the period of March and April was due to seasonal variability of rainfall. Commercial, domestic and industrial activity has 99.9% water demands from the month of February to May because the onset of rainfall, which begins around March/April, coincides with when the river has minimum water flow.

Table 3: Projected yearly water demand (10^6 m^3) for year 2012-2020

	2012	2013	2014	2015	2016	2017	2018	2019	2020	SUM
Commercial Activities	353.6	456.1	588.4	759.1	979.2	1,263.2	1,629.5	2,102.0	2,711.6	10,842.6
Domestic Activities	1,736.9	2,240.2	2,889.3	3,726.5	4,806.2	6,198.8	7,994.9	10,311.5	13,299.2	53,203.6
Industrial Activities	172.9	193.8	216.4	240.7	266.9	295.2	325.6	358.3	393.5	2,463.3
Lower Ogun Irrigation	57.0	64.7	72.5	80.6	88.8	97.3	105.9	114.7	123.8	805.3
Middle Ogun Irrigation	40.1	44.7	49.4	54.2	59.1	64.2	69.3	74.6	80.0	535.6
Sum	2,360.5	2,999.5	3,816.0	4,861.0	6,200.3	7,918.6	10,125.2	12,961.1	16,608.1	67,850.4

Source: WEAP model Author's Computation, 2011

Table 4: Monthly water supply coverage in percentage for various water uses

	January	February	March	April	May	June	July	August	September	October	November	December
Commercial Activities	4.1	0	0	0	0	17.8	68.7	61.3	35.2	75.9	34.2	20.3
Domestic Activities	4.1	0	0	0	0	17.8	68.7	61.3	35.2	75.9	34.2	20.3
Industrial Activities	50.2	0	0	0	0	58.3	100	100	100	100	100	99.5
Lower Ogun Irrigation	99.9	98.4	96.8	95.2	94.4	99.1	100	100	100	100	100	100
Middle Ogun Irrigation	99.9	72.9	30.7	41.1	94.4	99.1	100	100	100	100	100	100

Source: WEAP model Author's Computation, 2011

The annual water supply requirement for domestic, commercial and industrial activities are 6.3 x $10^{10}$$m^3$, 1.2 x $10^{10}$$m^3$ and 2.6 x 10^9 m^3 respectively (Table 5). The result also shows steady annual increase due to the gradual increase in population growth within the basin (Table 6). Middle and lower Ogun Irrigation project shows slight or no increase in supply requirement over the extended period of time with 6.0 x10^8 m^3 and 1.0 x 10^9 m^3 respectively (Figure 3). The lower amount of water demand utilization within the use category is due to the level of technological improvement and irrigation efficiency. But the amounts of supply delivered in the month of January to May are reduced drastically due to little or no river flow during the period. Thus both middle and lower Ogun irrigation project has 61.7% reliability, industrial activities 56.7%, while commercial and domestic activities have 13.9% each (Figure 4). The values are attributable to the differences in the annual water use rate.

Table 5: Annual water supply requirement (10^6 m^3) for various uses from 2012-2020

	2012	2013	2014	2015	2016	2017	2018	2019	2020	SUM
Commercial Activities	392.9	506.8	653.8	843.4	1,088.0	1,403.5	1,810.5	2,335.6	3,012.9	12,047.4
Domestic Activities	2,043.4	2,635.5	3,399.2	4,384.1	5,654.4	7,292.7	9,405.8	12,131.1	15,646.1	62,592.4
Industrial Activities	182.0	204.0	227.7	253.4	281	310.7	342.7	377.2	414.2	2,592.9
Lower Ogun Irrigation	71.3	80.9	90.7	100.7	111.0	121.6	132.4	143.4	154.7	1,006.7
Middle Ogun Irrigation	47.2	52.6	58.1	63.8	69.6	75.5	81.6	87.8	94.1	630.1
Sum	2,736.8	3,479.8	4,429.5	5,645.4	7,203.9	9,204.1	11,773.0	15,075.1	19,322.0	78,869.5

Source: WEAP model Author's Computation, 2011

Table 6: Projected water supply ($10^6 m^3$) for the year 2012-2020

	2012	2013	2014	2015	2016	2017	2018	2019	2020	SUM
Commercial Activities	117.5	129.7	136.1	134.4	132.1	129.3	126.2	121.6	117.8	1,144.7
Domestic Activities	611.3	674.5	707.7	698.4	686.6	671.7	655.5	631.9	611.6	5,949.0
Industrial Activities	116.4	127.6	131.6	134.8	142.9	156.6	172.8	190.1	205.7	1,378.5
Lower Ogun Irrigation	70.5	79.9	89.5	99.3	109.2	119.3	129.5	139.8	150.2	987.1
idle Ogun Irrigation	40.8	44.9	49.1	53.3	57.4	61.9	66.3	70.7	75.1	519.5
Sum	956.5	1,056.6	1,113.9	1,120.1	1,128.2	1,138.8	1,150.2	1,154.2	1,160.3	9,978.8

Source: WEAP model Author's Computation, 2011

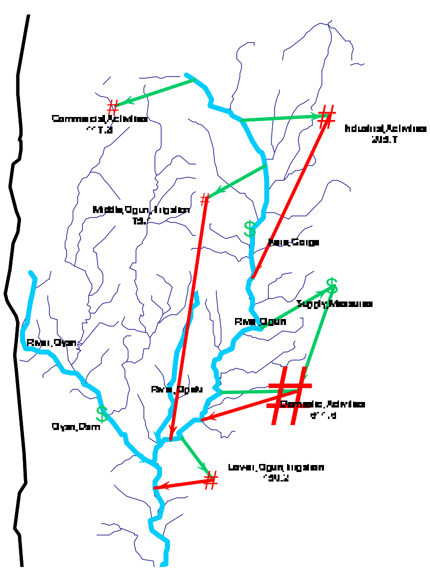

Figure 3: Schematic illustration of supply delivered

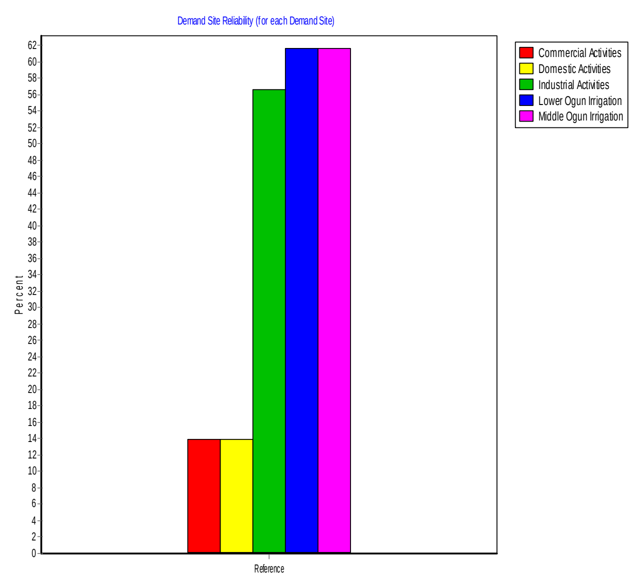

Figure 4: Demand site reliability for various water uses

Unmet Water Demand

As a result of water supply requirement and that which is demanded, a large shortfall is experienced among the various water uses (Table 7 and Figure 5). The model is able to simulate the results and show seasonality and variation between years. Figure 5 shows the unmet demand at the different demand sites. The Figure shows that the unmet demands occur from February to May during the onset of rainfall, and towards November to December during the cessation of rainfall with a mark variation in domestic water use. The annual unmet demand for domestic, commercial and industrial activities are 5.7 x 10^{10} m^3, 1.1 x 10^{10} m^3 and 1.2 x 10^9 m^3 respectively (Table 7). In addition to the seasonal rainfall distribution pattern (i.e. dry & wet season) that affects water availability within Ogun basin. Increase in population and GDP growth rate, which increases the standard of living of the people invariably increases water use rate within the basin. On the other hand, middle and lower Ogun irrigation project has sufficient water supply hence the absence of unmet demand, which makes water available for other uses.

Table 7: Variation in yearly unmet water demand (10^6 m^3) for various uses (2012-2020)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	SUM
Commercial Activities	275.4	377.1	517.7	709.0	955.9	1,274.2	1,684.3	2,213.9	2,895.1	10,902.7
Domestic Activities	1,432.2	1,961.1	2,691.5	3,685.6	4,967.8	6,621.1	8,750.3	11,499.3	15,034.5	56,643.4
Industrial Activities	65.5	76.4	96.2	118.6	138.1	154.1	170.0	187.0	208.6	1,214.4
Lower Ogun Irrigation	0.8	1	1.2	1.5	1.8	2.3	2.9	3.6	4.5	19.6
Middle Ogun Irrigation	6.4	7.6	9	10.5	12.1	13.6	15.3	17	19	110.6
Sum	1,780.2	2,423.2	3,315.6	4,525.2	6,075.7	8,065.3	10,622.8	13,920.9	18,161.7	68,890.7

Source: WEAP model Author's Computation, 2011

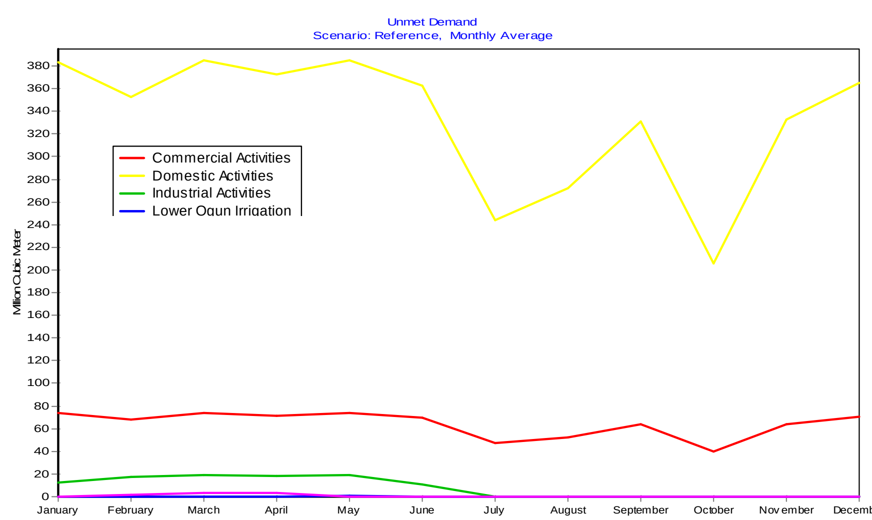

Figure 5: Monthly average unmet demand for various water uses in $10^6 m^3$

Application of Water Year Method Scenario (2006-2011)

The Water Year Method allows the usage of historical data in a simplified form that explores the effects of future changes in hydrological patterns. The method is a useful tool in testing hypothetical event and helps to understand and explore in simple ways the sensitivity to climatic change. The fractions are derived from historical flows by statistical analysis. The years are first grouped into five sets and then their variation from the norm is computed to reach the coefficient. The years are sorted from lowest to highest for 2006 to 2020 for the average annual inflow. The results of the scenario help to supplement the previous simulated method. In the end the coefficient is computed as the average divided by the normal water year average.

The most important parameter in the water year method is the coefficient for the water year definition, which includes 0.7, 0.8, 1, 1.3 and 1.45 for very dry, dry, normal, wet, and very wet respectively. The water year definition specifies how much more or less water flows into the system in that year relative to a normal water year. Figure 6 shows some level of water hydrology (head flow), which has greater implications for Rivers Ogun and Opeki in that order. The variation is due partly to climatic change and largely to hydrological pattern affecting the trend of water variation. It should be noted that the amount of water demand differences will be significant in the short run as the variation tends to compensate for the losses from year to year. In the long run however, the effect tends to be visible. The stream flow for all the three rivers in the month of October has been very high, indicating that the monthly average precipitation values are very high during the months of July to October, thereby increasing the volume of stream flow for the period (Figures 7 and 8).

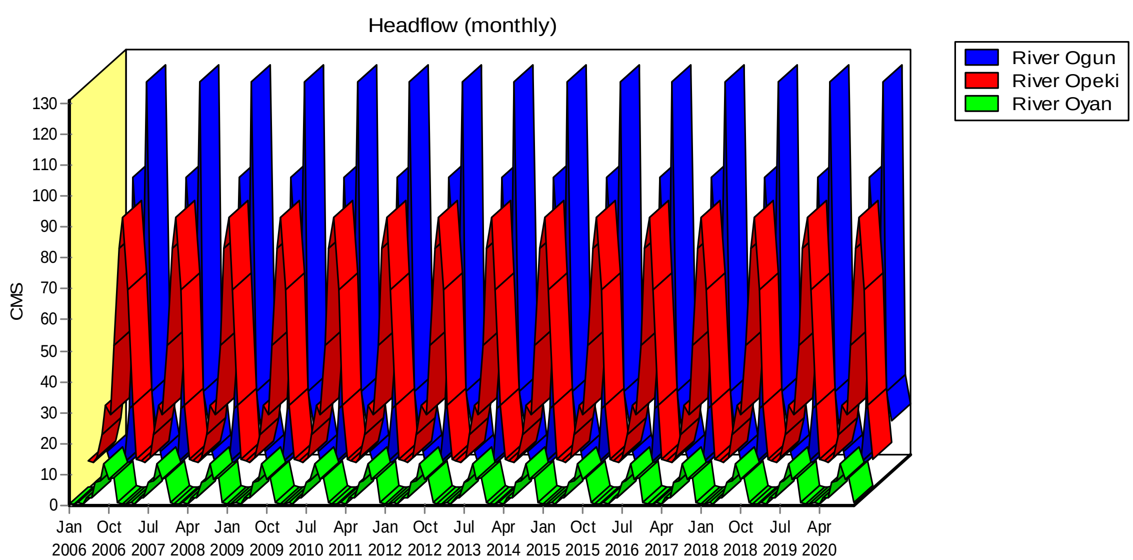

Figure 6: Annual river flow $m^3 s^{-1}$ for the year 2006-2020

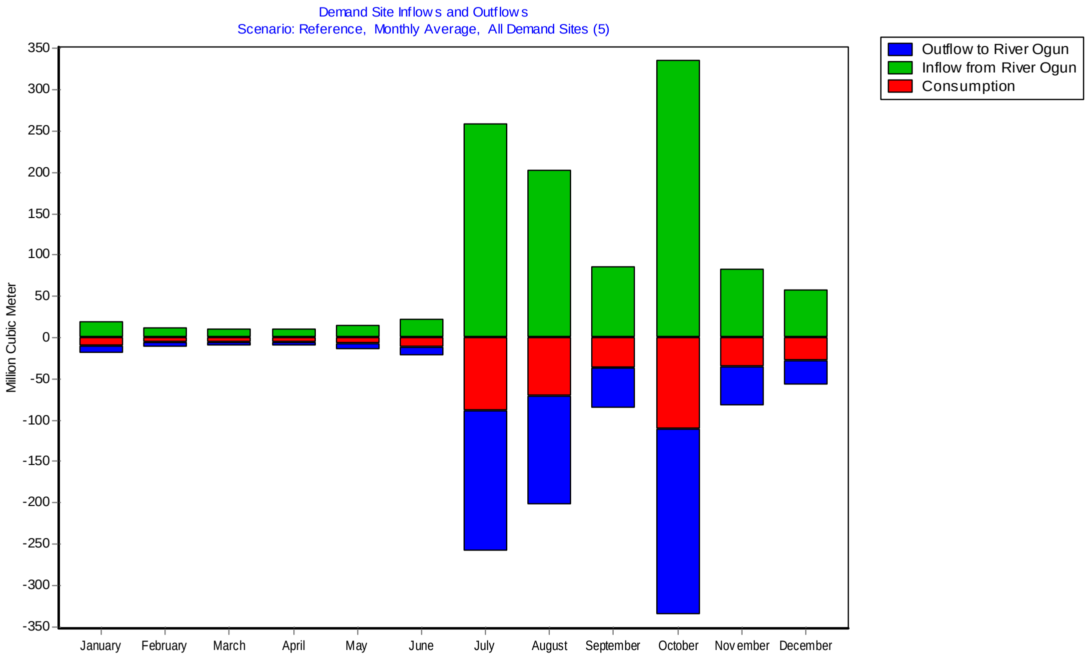

Figure 7: Monthly inflows and outflows of River Ogun and rate of consumption in 10^6 m^3

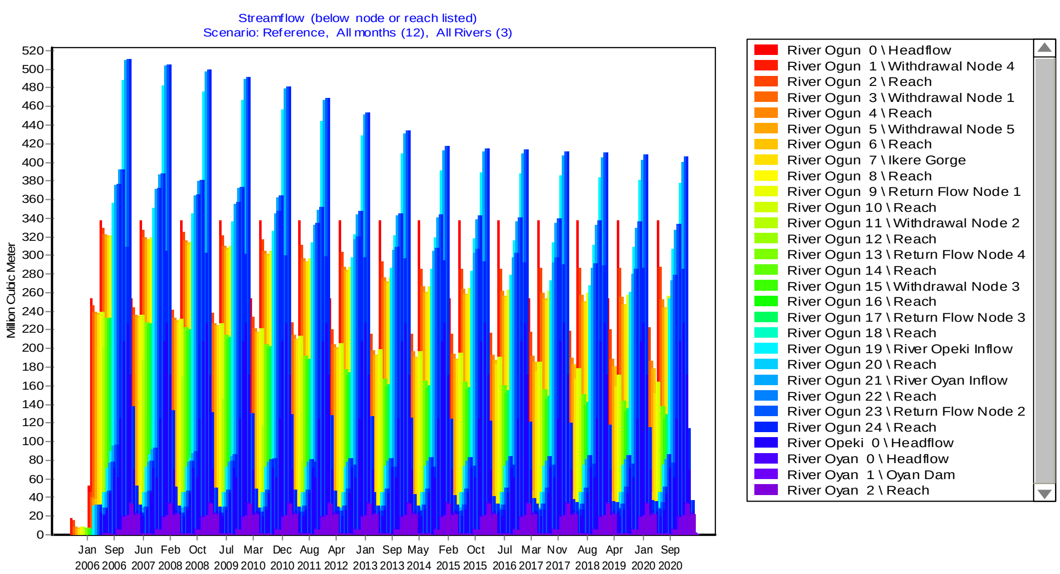

Figure 8: Annual stream flow in 10^6 m^3 for the year 2006-2020

Also in Figure 8, the inflow of water in the month of September for river Opeki and Oyan head flow are 2.27 X 10^8 m^3 and 3.45 X 10^7 m^3 respectively. In the month of October, the head flow of river Ogun is 3.37 X 10^8 m^3. Discharges from both rivers Opeki and Oyan into river Ogun is responsible for the observed increase in Ogun river flow. The increase is also attributable to the rainfall distribution pattern in the basin. Rainfall values are expectedly high during raining season, thereby increasing the volume of stream flow for the period. Figure 8 equally depicts more outflows from the areas due to high runoff generated by peak water level.

Table 8 further summarizes the derivation of unmet water demand as follows:

Required standard Unmet Water Demand:-
Delivered Supply – Required Supply = (9,978.8 – 78,865.5) = - 68,890.7 = **- 6.89 X 10^{10}m^3**

Present Unmet Water Demand:-
Delivered Supply – Water Demand = (9,978.8 – 67,850.4) = - 57,871.6 = **- 5.79 X 10^{10}m^3**

Table 8: Summary of various components as computed by WEAP Model for year 2012-2020

	Water Demand	Water Required	Water Delivered	Unmet Water Demand
Commercial Activities	10,842.6	12,047.4	1,144.7	10,902.7
Domestic Activities	53,203.6	62,592.4	5,949.0	56,643.4
Industrial Activities	2,463.3	2,592.9	1,378.5	1,214.4
Middle Ogun Irrigation	805.3	1,006.7	987.1	19.6
Lower Ogun Irrigation	535.6	630.1	519.5	110.6
SUM	67,850.4	78,869.5	9,978.8	68,890.7

NB: The Negative sign shows lack of water or unmet water demand; Source: WEAP Model Computation, 2011

Conclusions

Water resources are finite, while demands are increasing dramatically, driven by relentless growth of human activity in recent decades. River Ogun, Opeki and Oyan are vital source of freshwater for economic activities that include agricultural, industrial and commercial purposes. From the evaluation carried out in this study, the reservoirs do not suffer from water shortage.

The study revealed that the main consumption in Ogun river basin is the domestic demand, followed by commercial and industrial demand. For agricultural use, the middle and lower Ogun irrigation project have low level of water demand because irrigation practices, though still at infancy stage within the basin, is efficient and there is some level of technological improvement. The low level of water demanded from the river also in part depend on the availability of other complimentary water sources such as self supply boreholes and hand dug wells in urban areas, and self supply wells and streams in rural areas.

The WEAP simulation for the reference scenario from year 2012 to 2020 are 6.79 X 10^{10} m^3, 7.89 X 10^{10} m^3 and 9.98 10^9 m^3 for water demand, required supply and delivered supply respectively. Using the standard water per capita of 90 litres per person per day, the unmet water demand is 6.89 X 10^{10} m^3. Given the present water utilization status quo i.e. using below the standard water per capita use as stipulated by the United Nations, the unmet water demand stands at 5.79 X 10^{10}m^3.

The monthly unmet demand for the various demand sites is pronounced between the months of March and June, and the effect is also noticed during August rainfall break and towards the month of December. The middle and lower Ogun irrigation project however have little or no unmet demand for the reported periods.

This study shows decline in the projected water supply for domestic and commercial activities from year 2014 to 2020, invariably resulting to rise in the unmet demand. There is also variation in the water delivered, attributable to the projected hydrological pattern within the basin. The implication of the projected scenario gives concern for water availability in the nearest future. There is therefore the need to be proactive in tackling the challenges of unmet water demand to avoid impending water crisis. Appropriate solutions should include but not limited to setting up of water metering systems, expansion of existing reservoirs, coupled with proper water resources monitoring through data acquisition. The above findings will no doubt help relevant authorities in making adequate provision for future water utilization.

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