Determination of an Annual Groundwater Recharge and Demand in Oke-Ero LGA, Kwara State, Nigeria

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Abstract- Efficient groundwater management, water consumption rate and quantitative determination of the amount of rainfall that recharges groundwater naturally is essential for a place like Oke-Ero LGA where the people in Oke-Ero depend mainly on groundwater as the only source of water supply. In this work, an attempt has been made to evaluate the amount of rainfall that recharges aquifers using Krishna model with a view to knowing the groundwater potential of the area and determine the water consumption rate. This study established that Oke-Ero LGA has 65.7 million cubic meters (MCM) groundwater potential annually, from the survey output the average daily water demand in Oke-Ero is 75 l/c/d. The total water demands across the LGA based on 2016 population estimate is 2.11 MCM/year with anticipated increase of 4.34 MCM/year by 2040 and expected water demand increase rate of 3.2% annually. This work has ascertained that the available water is sufficient to take care of the water demand of the people in Oke-Ero LGA and it also shows that there is more water for other activities such as industrial purposes.

Keywords- Groundwater potential, Groundwater recharge, Oke-Ero LGA, Water demand

1 INTRODUCTION

The main challenges in the world today are planning and management of water resource with an increase in water demand. For the demand of various users to be met, ample attentions have to be drawn on the thorough planning, effective distribution and use of other sources of water (surface water, ground water, and rainfall) is essential to maximize the outcome economic returns to limited water resources and, also, protect the destructible ecosystem (Oke *et al* 2014). It is not possible to think of any natural resource that supports human needs and economic development than water and it is the main source of fresh water availability on earth (Ravindran, 2012).

The physical reality of life can only be explained by water; the existence of human depends on it and thus is the most vital resource supplied by earth systems (Robert, 2007). During dry season when drinking water is not readily available, people can cover a long distance in search of it for their various house consumption. This is because water is regarded as life, since water is being drinking and utilize in various ways. The great increase in industrial, agricultural and domestic activities in recent years has resulted to increase in demand for potable water to meet the increasing demand for water (Adewale, 2017).

Groundwater has always been considered most suitable for this growing demand due to its chemical composition, lower level of contamination, easy exploration and wider distribution (Arulbalaji *et al, 2019*). The interaction of climatic, geological, hydrological and ecological factors is the one that resulted to variation in occurrence of groundwater at different locations on earth; it was not a matter of chance (Akinwumiju *et al*, 2016). Arkoprovo *et al*. (2012), said that "groundwater exploration is essentially a hydro-geological and geophysical inference operation and is dependent on the good interpretation of the hydrological indicators and evidences".

Groundwater exploration means searching or investigating the presence or absence of groundwater. Increasing demand on groundwater necessitated experts and researchers in the field of hydrological studies to look for more ways of groundwater exploration. In many parts of the world groundwater abstraction has exceeded safe yield, resulting in over exploitation and overstressing of the aquifer. Therefore, the quantum of available groundwater resource has to be assessed accurately for its optimum extraction and utilization (Meijirik, 2007). In view of the ever-increasing demand for groundwater, greater emphasis is now being placed on a planned and optimal utilization of this resource. Therefore, the present study aimed at determining the available recharge and correlates it with water demand in Oke-Ero, Kwara State, Nigeria.

1.1 STUDY AREA

Oke-Ero is one of the 16 Local Government Areas in Kwara State, its headquarters is in Iloffa with Latitude: 8°05'36.3"N and Longitude: 5°08'32.4"E. Other main towns in Oke Ero are Ekan-Nla, Ayedun, Idofin, Kajola, Ilale, Erin Mope others are Imode, Idofin Odo-Ase, Odo-owa and Egosi. Oke-Ero Local Government has a population of 56,970 at the 2006 census and area extent of 438 km², the population has since then grown steadily with a projection of 76,900 in 2016 by national population commission of Nigeria.

Oke-Ero has average annual temperature of 24.7°C with average rainfall of 1281 mm in a year. January is the driest month with 9 mm of precipitation, September usually has highest average precipitation of 237 mm with an average temperature of 27.0°C and March is the warmest month. August is the coldest month, with average temperatures of 22.6°C. (Bamidele, 2018).

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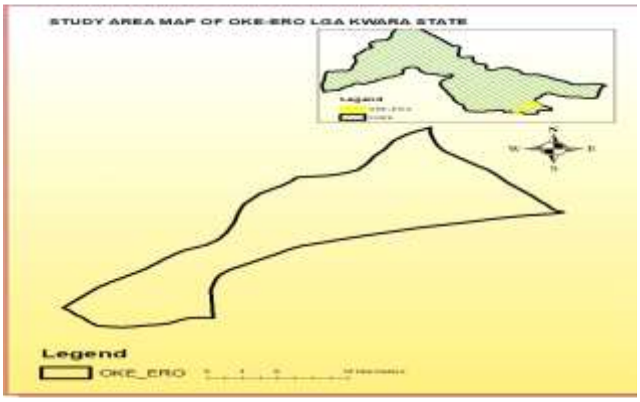

Fig. 1: Map showing Oke Ero LGA

2 METHODOLOGY

2.1 REQUIRED TOOLS AND DATA

A rainfall data, temperature, borehole yield and well depth were required, their category and source are listed in Table 1.

Table 1. Data required and their source

Data	Date	Source	Pertinence
Rainfall	1988-2017	LNRB Ilorin	Determination of net recharge
Temperature			Potential Evapotranspiration
Population	2006 & 2016	NPCN	Water demand/capital
Water usage	2019	Questionnaire	Water demand/capital/day

2.2 ESTIMATION OF GROUNDWATER POTENTIAL NET RECHARGE

The collected 30 years record of monthly rainfall was refined to annual values. The groundwater recharge was estimated using the empirical relationships established between recharge and rainfall developed by Krishna Rao in 1970 to determine the groundwater recharge in limited climatological areas.

The Krishna (1970) empirical equation is as expressed in equation 2. For areas where annual rainfall is between 1000-2000 mm/year

$$R = k(P - x) \quad (1)$$

Area with annual rainfall between 600-2000mm/year R is `given as;

$$R = 0.25(P - 400) \quad (2)$$

where R = Net recharge due to rainfall

P = Precipitation/Rainfall (both in mm)

2.3 POTENTIAL EVAPOTRANSPIRATION

The thirty years data on the monthly air temperature subjected into mean monthly. The annual mean monthly air temperature for each year as well as 30 year (1988-2017) mean air temperature utilized for the computation of potential evapotranspiration. Using the Thornthwaite Model of potential Evapotranspiration, the estimation of potential evapotranspiration was obtained for the area.

The different between Rainfall and Potential Evapotranspiration was calculated in order to have an idea of how much rainfall available for recharge. This is to give picture of groundwater potential since Rainfall and Potential evapotranspiration are key components of hydrological water balance. Potential evaporation is given by Thornthwaite (1948) as

$$\text{PET} = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_a}{I}\right)^{\alpha} \quad (3)$$

where PET= potential evapotranspiration (mm/month)

T_a= is the average daily temp. (°C if this is negative, use 0) of the month being calculated

N= is the number of days in the month being calculated

L= is the average day length (hours) of the month i.e. Hours between sunrise and sunset in the month

α = coefficient,

I= annual heat index, which depends on the 12monthly mean temperatureT_{ai}.

$$\alpha = (675 \times 10^{-9})\, I^3 - (771 \times 10^{-7}) I^2 + (179 \times 10^{-4}) I + 0.4924 \quad (4)$$

$$I = \sum_{i=1}^{12}\left(\frac{Tai}{5}\right)^{1.514} \quad (5)$$

2.4 WATER DEMAND INVESTIGATION

A questionnaire was prepared and distributed across Oke-Ero LGA for data acquisition on water demand/consumption using the survey device created. This survey was used to determine the amount of water consume by individual per day, 2006 population census figures and projected population up to 2040 were used to arrive at the domestic water demand of the area incorporating the germane documents that reflect consumption rate in various kinds of settlement. Thus other activities like agricultural related economic and loss at 15% and 5% were also considered respectively and added to the result of domestic demand. 2006 population figure was projected using geometrical method with growth rate of 3.05.

3 RESULTS AND DISCUSSIONS

3.1 GROUNDWATER POTENTIAL ESTIMATION

The groundwater recharge was calculated using empirical relationships stated in Equation 2, it was used to estimate annual recharge using the annual precipitation and the results were presented in Table 3. The groundwater potential available annually in the area was the product of the annual net recharge and the total area which gave 65,656,200 m^3/year. The summary of the results was presented in Table 2.

Table 2. Summary of Groundwater Potential Evaluation

Total Area (Km^2)	438
Average Annual Rainfall (mm/year)	1,258.1
Average GW recharges (mm/year)	149.9
Rainfall-recharge (%)	12.0
GW Potential (m^3/year)	65,656,200

The outcome of the average groundwater recharge estimated is close to the average value estimated in the JICA, 2014 master plan for the whole Niger central (HA-2) with the mean groundwater recharge of 132 mm/year which is akin to the result obtained in this research and the increment might be because the area in consideration is close to the western littoral (HA-6) with a value of 236 mm/year. It should be noted that the estimated available groundwater reserve is the amount of groundwater replenished yearly.

Rainfall net recharge is the major parameter in estimating groundwater potential. The result procured from the chosen model for each year from 1988 to 2017 varies from 136.9 mm/year to 166.0 mm/year. The highest and lowest result took place in 2011 and 2010 years respectively. The estimated value of 149.9 mm/year was the mean value of recharge used in this work. The maximum rainfall net recharge occurred a year after the minimum and both happened in the last ten years of the data used as shown in Table 3. This simply means that the lowest and the highest rainfall over the year 1988 to 2017 happened at the last ten years of the data used. The calculated average annual rainfall is 1,258.1 mm/year and the average annual rainfall that turns to recharge is 12% of the rain.

Table 3. Net recharge from rainfall data having the average of 149.9mm/year

Year	Rainfall (mm/year)	Recharge (mm/year)	Recharge as % Rainfall
1988	1270.6	152.4	12.0
1989	1244.6	147.8	11.9
1990	1194.8	139.1	11.6
1991	1278.1	153.7	12.0
1992	1285.8	155.0	12.1
1993	1264.9	151.4	12.0
1994	1273.2	152.8	12.0
1995	1241.6	147.3	11.9
1996	1253.6	149.4	11.9
1997	1185.3	137.5	11.6
1998	1289.4	155.7	12.1
1999	1249.7	148.8	11.9
2000	1229.5	145.2	11.8
2001	1263.4	151.1	12.0
2002	1299.3	157.4	12.1
2003	1226.0	144.6	11.8
2004	1239.8	147.0	11.9
2005	1258.7	150.3	11.9
2006	1281.3	154.2	12.0
2007	1289.9	155.7	12.1
2008	1255.1	149.6	11.9
2009	1260.6	150.6	12.0
2010	1182.5	136.9	11.6
2011	1348.3	166.0	12.3
2012	1193.5	138.9	11.6
2013	1241.5	147.3	11.9
2014	1287.3	155.3	12.1
2015	1272.6	152.7	12.0
2016	1244.8	147.8	11.9
2017	1308.7	159.0	12.2

Evapotranspiration is a very importance key process in hydrologic balance, therefore, in order to have a clear picture of net rainfall recharge that is available to replenish groundwater the potential Evapotranspiration (PET) was estimated. Thornthwaite model was used to estimate PET and the obtained PET values are very similar to the values from alignment charts solution of Thornthwaite's general equation (Thornthwaite 1948).

The variation in the result of annual PET values is from 1262.6 mm/year in 1995 to 1519.4 mm/year in 1993 while the variation in the result of annual rainfall is from 1182.5 mm/year in 2010 to 1348.3 mm/year in 2011, the result for all the years was presented in Figure 2. The rainfall distribution pattern is not too consistent as it reduced towards the north as shows in rainfall map. The value of the mean monthly PET over 30 years was calculated using the mean temperature. The values show that the highest PET occurred in March (185.7 mm/month) and lowest in August and December (121.7 mm/month). PET exceeds rainfall as it is the amount of evaporation that would occur if a sufficient water source were available not the actual Evapotranspiration.

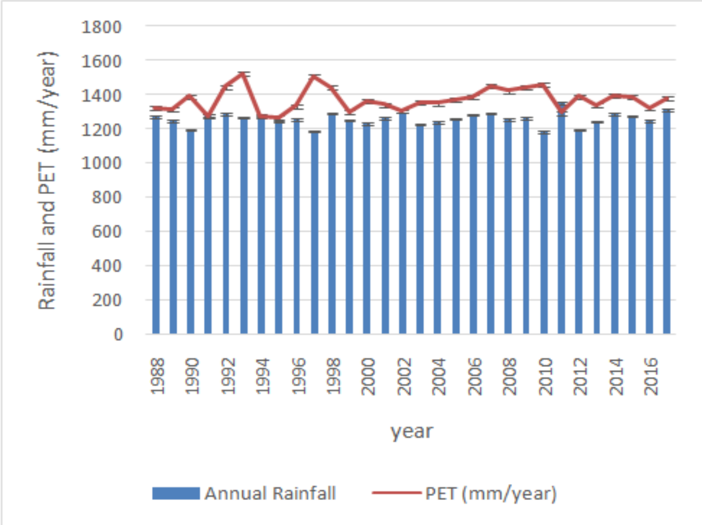

Fig. 2: Distribution patterns of PET and Rainfall

3.2 Water Demand for Oke-Ero LGA

Oke-Ero LGA was estimated to have a population of 56,970 in 2006 census figures with a projection of 76,900 in 2016 by national population commission of Nigeria and the population was projected in this work to 2040 using geometric population projection formula and 3.05% growth rate, the population was projected to be 158,226 in 2040 as presented in Table 4.

Table 4. Population Projection

Oke-Ero	Year	Population
Population census	2006	56,970
Projected Population	2016	76,935
	2020	86,760
	2025	100,823
	2030	117,156
	2035	136,156
	2040	158,226

From the survey output the average daily water demand in Oke-Ero is 2.5 gallons/capita/day which is the same as 62.5 liters/capital/day plus agricultural related economic activities and loss at 15% and 5% respectively which is equal to 75 l/c/d in total. Table 5 provided the water demand, total water demands across the LGA in year 2016 according to the population estimated was 2.11 MCM/year. This is anticipated to increase to 4.34 MCM/year by 2040 with anticipated 3.2% water demand increase rate every year.

The relationship between the annual water demand and annual water available for recharge was presented in Figure 3, from this result (because of low population) it can be ascertained that the available water is sufficient to take care of the water demand of the people in Oke-Ero LGA and it also shows that there is more water for other activities such as industrial purpose.

Table 5. Water demand

2006	W d {Pop06 xLcd06}	1.56 MCM/year
2016	W d {Pop16 x Lcd16}	2.11 MCM/year
2020	F w d {Pop20 x Lcd20}	2.38 MCM/year
2025	F w d {Pop25 x Lcd25}	2.76 MCM/year
2030	F w d {Pop30 x Lcd30}	3.21 MCM/year
2035	F w d {Pop35 x Lcd35}	3.73 MCM/year
2040	F w d {Pop40 X Lcd40}	4.34 MCM/year

where Wd=Water demand, Fwd=Future water demand, Pop=Population and Lcd = Liter/capital/day

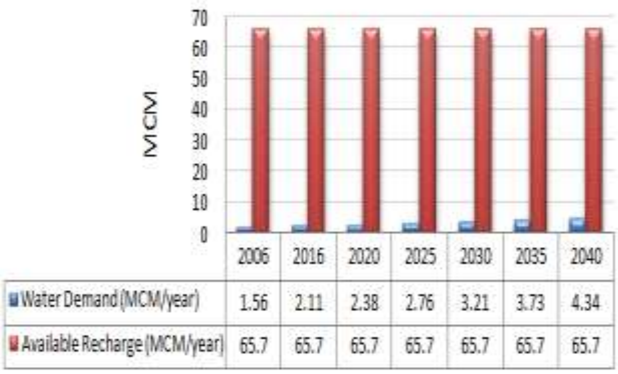

Fig. 3: Comparison of water demand and available recharge

4 Conclusion

Water consumption rate and quantitative determination of the amount of rainfall that recharges groundwater naturally is essential for a place like Oke-Ero LGA where they depend mainly on groundwater as only source of water supply. In this work, an attempt has been made to evaluate the amount of rainfall that turns to recharge using Krishna model with a view to know the groundwater potential of the area and determine the water consumption rate.

The result rainfall net recharge procured varies from 136.9 mm/year to 166.0 mm/year with estimated value of mean recharge of 149.9 mm/year and the calculated average annual rainfall is 1,258.1 mm/year having the average annual rainfall that turns to recharge is 12% of the rain. The value of the mean monthly PET over 30 years was calculated using the mean temperature and values show that the highest PET occurred in March (185.7 mm/month) and lowest in August and December (121.7 mm/month).This study established that Oke-Ero LGA has 65.7 million cubic meter (MCM) groundwater potential annually, estimated using available net recharge, evapo-transpiration and the total area.

From the survey output the average daily water demand in Oke-Ero is 75 l/c/d. The total water demands across the LGA based on 2016 population estimate is 2.11 MCM/year with expected increase of 4.34 MCM/year by 2040 and an expected water demand increase rate of 3.2% annually. The judicious utilization of groundwater resources coupled with proper water management is essential for ensuring groundwater sustainability. In this work, it can be ascertained that the available water is sufficient to take care of the water demand of the people in Oke-Ero LGA and it also shows that there is more water for other activities such as industrial purpose.

Further identification and measures of other detail assessment should be conducted periodically for monitoring, proper exploitation and alternative water sources like arresting rainwater from roof -top is recommended to capture ample of untapped rainfall.

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