

Article

Estimation of Groundwater Recharges Using Empirical Formulae in Odeda Local Government Area, Ogun State, Nigeria

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Abstract: Estimation and forecast of groundwater recharge and capacities of aquifers are essential issues in water resource investigation. In the current research, groundwater recharge and the recharge coefficient were determined through a case study using empirical methods applicable to the tropical zones. The related climatological data between January 1983 and December 2014 were collected in Ogun-Oshun River Basin Development Authority (OORBDA), Ogun State, Nigeria. The results showed that groundwater recharge was 194.7 mm per year, evapotranspiration was 1296.2 mm per year, and the recharge coefficient was 20.2% for the study area. The result showed that about 11% of rainfall infiltrated the aquifer, 73% was loss to evapotranspiration, and 36% ended up as run-off. Correlation between climatic parameters and groundwater recharge showed the highest correlation between recharge and rainfall. Temperature, humidity, solar radiation and evapotranspiration were at the 0.01 significance level, and the results of linear regressions proved that precipitation has a significant effect (with $R^2 = 0.983$) on estimated recharge.

Keywords: aquifer; evapotranspiration; groundwater recharge; recharge coefficient

1. Introduction

The search for water in arid and semi-arid regions are under increasing stress from the growing human population are the focus of many challenges due to its scarcity [1]. Groundwater, as a dynamic system, is located beneath the Earth surface. It moves under the control of many factors, which are studied in various fields of sciences such as hydrogeology, hydrology, and climatology [2]. Among the factors controlling the situation and fluctuation of groundwater, recharge is an important parameter that needs to be assessed more fully. Recharge occurring in small and large scales, spatially and temporally, is influenced by several factors, such as meteorology, soil characteristics, geology, surface cover, slope, and depth of the groundwater level [3–5]. Groundwater recharge estimation from precipitation is an integral part of hydrology and hydrogeology [6].

Although, precipitation is the most important source of groundwater recharge [7] the accuracy of currently attainable techniques for measuring recharge are not completely acceptable.

Comparative analysis of empirical formulae to estimate recharge which is a prerequisite for groundwater resource management was carried out [8]. Estimation of groundwater recharge was derived from rainfall data obtained from Ogun-Oshun River Basin Development Authority (OORBDA) using three empirical formulae, which include the empirical methods of [7,9,10]. The result revealed that the three formulae used give the same results, and they concluded that any of the formulae can be used for groundwater estimation. Additionally, the groundwater recharge was estimated and capacity of aquifers in Malaysia using empirical formulae [9] and obtained a recharge of 326.39 mm for the area [11].

Furthermore, there are indirect measurements of recharge due to the lack of universal standard methods. Nevertheless, a number of methods were the models and equations for determining the groundwater recharges can be classified into three groups: physical models, calculated from base flow; chemical models, measurements of water-soluble substances; and numerical models, using numeric methods, such as HELP, RORA, PULSE, PART, HYSEP, WEAP and WTF. Estimating the groundwater for various climates such as arid, semiarid, and tropical has its own advantages and disadvantages [12].

2. The Study Area

Odeda Local Government Area is located on the outskirts of Abeokuta, an ancient city in the southwestern part of Nigeria, extending from longitude 3.3899E to 3.47950E and latitude 7.1745N to 7.2300N. Abeokuta is located in Ogun state, Southwestern Nigeria, as shown in Figure 1.

The study area is characterized by a tropical climate with distinct wet and dry seasons. The wet season is associated with the relative prevalence of the Moist Maritime Southerly Monsoon from the Atlantic Ocean, while the dry season by the Continental North Easterly harmattan winds from the Sahara desert. The area is located within a region characterized by a bimodal rainfall pattern (commencing in March and is plentiful in July and September, with a short dry spell in August). The long dry season extends from November to March. The Annual rainfall ranges between 1400 and 1500 mm in Abeokuta and environs. The region is characterized by relatively high temperature with a mean annual air temperature being about 30 °C. The greatest variation in temperature is experienced

in July (25.7 °C) and in February (30.2 °C). Humidity is lowest (37%–54%) at the peak of dry season in February and highest at the peak of the rainy season between June and September (78%–85%).

The study area is underlain by basement complex, and the basement complex rocks of Nigeria are well-represented in the selected study areas of Ogun State. These rocks are of Precambrian to early Palaeozoic age and they extend from the northeastern part of the Ogun state running southwest and dipping towards the coast [13].

The basement complex metamorphic rocks are characterized by various folds, structures of various degrees of complexity, faults and foliation. These structural features have a predominant North-South or North-North-East-South-South-West (NNE-SSW) orientation which is particularly strong within the low grade metamorphic. The common metamorphic rocks encountered are gneiss, schist, quartzite and amphiboles. The study area is characterized by various rock types ranging from, granite granitic gneiss and pegmatite. The individual rocks have various hydro-geologic characteristics and belongs to the stable plate which was not subjected to intense tectonics in the past. Therefore, the underground faulting system is minimal and this has contributed to the problem of underground water occurrence in this area.

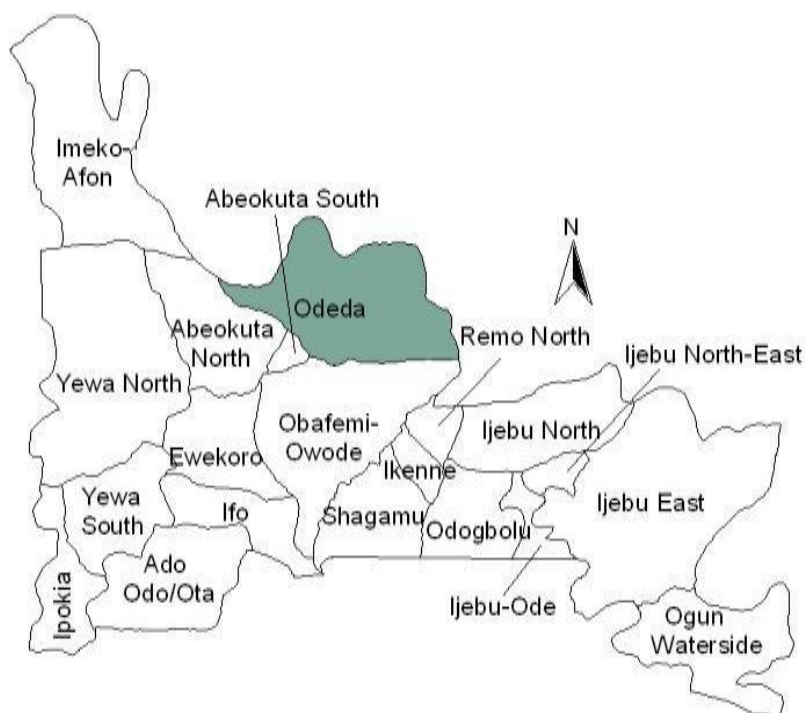


Figure 1. Location Map showing the study area.

3. Methodology

Owing the non-availability of meteorological stations in the study area, Ogun Osun River Basin Development Authority (OORBDA) meteorological station was used and parameters collected from OORBDA weather station were; minimum and maximum temperature, sunshine hour, relative humidity wind speed, and Rainfall.

Thirty two (32) years of weather parameters were collected from OORBDA weather station. These were used to calculate the recharge, evapotranspiration, recharge coefficient and run-off using empirical formulae.

The potential evapotranspiration (PE) was determined using CROPWAT version 8.0 based on FAO Penman-Monteith formula.

3.1. Evapotranspiration

Evapotranspiration is equal to the sum of evaporation and transpiration. It is a climatic index integrating the effect of air temperature, humidity, wind speed, and solar radiation. CROPWAT software version 8.0 was used to estimate evapotranspiration. The software is based on the FAO Penman-Monteith formula [14].

3.2. Estimation of Groundwater Recharge

Estimation of groundwater recharge of the study area was conducted using a modified version of [9] for tropical regions based on water level fluctuation and rainfall depth [14,15]. The equation is given as:

$$R = 1.35(P - 14)^{0.5} \quad (1)$$

where R is the net recharge due to precipitation in inches, and P is the precipitation in inches. These can be converted to millimeters (mm).

3.3. Recharge Coefficients

The value of the recharge coefficient is defined as the ratio of recharge to effective rainfall and is expressed in percentage [16] as:

$$R_{\text{coefficient}} = \frac{R}{P_e} \% \quad (2)$$

where R is the recharge and P_e is the effective rainfall.

3.4. Estimating Direct Runoff

Estimated runoff for water budget was developed by [13], and given as:

$$R_{\text{off}} = 0.85 \times P - 30.5 \quad (3)$$

where R_{off} is the direct runoff and P is the precipitation.

3.5. Co-Integration Analysis

The climatic data was analyzed using co-integration analysis. The analysis involves a unit root test performed on levels, the first difference and the second difference to determine whether the individual input series are stationary and exhibit similar statistical properties. It must be noted that regressing a non-stationary time series data over another non-stationary time series data gives a spurious or nonsense regression. To correct for this, a unit root test is performed [17].

A time series is stationary when $X(t_1), X(t_2), \dots, X(t_n)$ is the same as the joint distribution of any set of $X(t_{1+k}), X(t_{2+k}), \dots, X(t_{n+k})$, for all n and k .

$$Y_t = pY_{t-1} + U_t \quad (4)$$

where $P \leq 1$ and U is the white noise error.

If the estimated p is statistically equal to 1 when Y_t is regressed on Y_{t-1} , then Y_t is non-stationary; that is, has no unit root (I (0)).

The Augmented Dickey–Fuller (ADF) test was used to test for the stationarity of the data. The test consists of the following regression:

$$\Delta Y_\tau = \beta_1 + \beta_{2\tau} + \delta Y_{\tau-1} \alpha \sum_{\tau=1}^n \Delta Y_\tau + \varepsilon_\tau \quad (5)$$

where:

$$\varepsilon_\tau = \Delta Y_{t-1} = (Y_{t-1} - Y_{t-2}), \Delta Y_{t-2} = (Y_{t-2} - Y_{t-3}) \quad (6)$$

The Johansen procedure was used to test for the number of co-integration vectors in the model. The Johansen technique was used not only because it is vector auto-regressive-based but because it performs better in multivariate models [18]. If X_t and Y_t are then co-integrated, their short-run dynamics can be described by an error correction model (ECM). The theory states that if two variables, Y and X , are co-integrated, then the relationship between them can be expressed as an ECM [18]. The co-integration model is given as:

$$P_t = \beta_0 + \beta_1 R_t + \beta_2 SR_t + \beta_4 MT_t + \beta_5 XT_t + \beta_6 ET_t + U_t \quad (7)$$

3.6. Correlation and Regression Analyses

Pearson correlation coefficient was used to evaluate the strength of the relationship between meteorological factors. The impact of independent variables (*i.e.*, humidity, temperature, rainfall, wind speed, and duration of daily solar radiation) on estimated recharge was evaluated using linear regression.

4. Results

The methods discussed have used to estimate all parameters from January 1983 to December 2014. This covers a period of thirty-two (32) years. Table 1 below shows the amount of calculated groundwater recharge, evapotranspiration, the recharge coefficient, and the surface runoff. The ratio of recharge to total precipitation is 11% which, according to [16], is classified as a low rate of recharge. It is proven that aside from precipitation (with the high rate), other parameters (such as surface cover) also have a key role [4,5] in recharge. Table 1 below shows the hydrological data of the study area for 32 years, for 1983 to 2014.

Table 1. Hydrological data of the study area for 32 years (1983 to 2014).

Year	<i>P</i> (mm)	<i>R</i> (mm)	Min. Temp. (°C)	Max. Temp. (°C)	ET (mm/yr)	Run Off	<i>R_{coeff}</i> (%)
1983	901.6	159.0	22.3	32.1	1284.8	763.8	23
1984	1032.4	177.0	20.0	31.9	1252.0	874.9	20
1985	1185.7	196.0	21.5	31.9	1116.9	1005.2	21
1986	1210.7	199.0	24.8	31.9	1394.3	1026.5	20
1987	1224.5	199.4	26.4	37.7	1525.7	1038.2	21
1988	1576.1	237.8	20.9	36.3	1219.1	1337.0	19
1989	1222.6	200.3	19.4	37.1	2000.2	1036.6	20
1990	1336.1	213.0	20.4	37.6	2029.4	1133.1	20
1991	1185.0	195.9	20.1	36.5	1328.6	1004.7	20
1992	1445.6	191.2	18.5	37.4	1332.3	1226.2	20
1993	941.2	164.8	23.4	37.2	1357.8	797.4	22
1994	1009.6	174.2	31.4	37.3	1434.5	855.5	21
1995	1244.7	202.9	30.8	37.3	1401.6	1055.4	20
1996	1254.6	204.0	21.8	37.4	978.2	1063.8	20
1997	1233.5	201.7	29.9	37.4	1237.4	1045.9	20
1998	895.4	158.3	22.0	34.8	1076.8	758.5	22
1999	1037.5	177.9	13.8	31.9	981.9	879.2	23
2000	948.5	165.5	16.7	33.1	960.0	803.2	22
2001	950.0	165.5	15.3	33.3	1043.9	805.6	21
2002	1736.5	252.9	10.2	33.0	1284.9	1473.4	18
2003	1449.7	225.1	12.8	34.3	1325.0	1229.7	20
2004	1112.7	187.2	22.8	31.1	1262.9	943.2	20
2005	1112.7	187.2	13.4	33.0	1200.9	943.2	20
2006	1236.2	202.0	23.7	31.1	949.0	1048.2	21
2007	1943.9	273.1	26.0	32.2	1189.9	1651.4	18
2008	848.9	151.0	25.9	26.7	1215.5	719.0	22
2009	1189.9	197.8	26.0	30.5	1376.1	1008.7	20
2010	1233.9	201.7	25.8	36.4	1398.0	1046.2	21
2011	1497.7	223.5	25.4	36.6	1248.3	1245.0	15
2012	1241.5	204.2	25.0	36.8	1255.6	1052.7	15
2013	929.2	163.0	24.9	35.5	1379.7	787.2	22
2014	1058.0	180.3	22.9	32.2	1474.6	896.7	21

In the Table 1, *P* is the annual precipitation, *R* is the annual groundwater recharge (mm), *ET* is the evapotranspiration (mm/year), *Min. T* is the minimum temperature (°C), *Max. T* is the maximum temperature (°C), and *R_{coeff}* is the recharge coefficient (%).

Figure 2 shows the annual rainfall, recharge, evapotranspiration, and temperature from 1983–2014. Groundwater recharge increases with precipitation and show the same trends throughout the years. However, the evapotranspiration shows variation in trend throughout the study area. This is expected because evapotranspiration is a function of temperature, which showed a remarkable change throughout

the study area. Typically, low rainfall causes low groundwater recharge infiltrating into the aquifer, which is due to increase in temperature and evapotranspiration and *vice versa*.

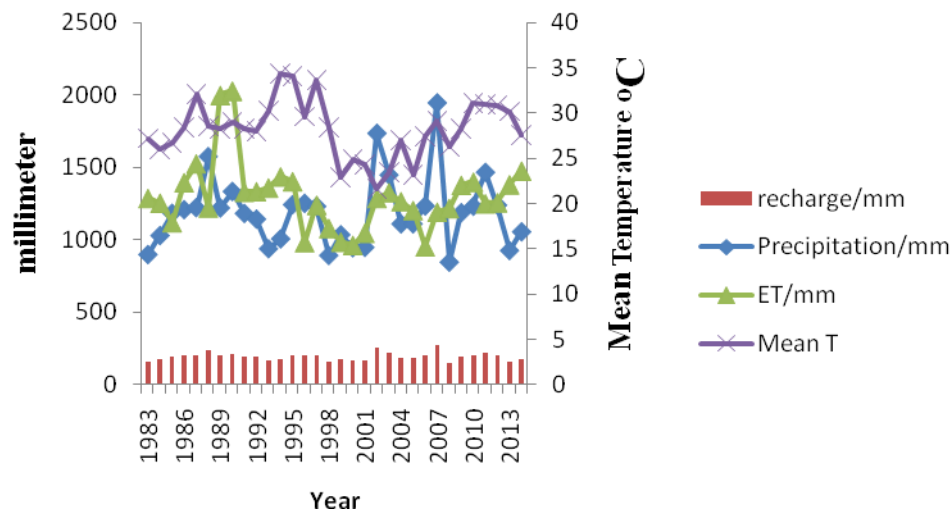


Figure 2. Total annual precipitation, groundwater recharge, evapotranspiration, and temperature.

There are objections to the use of either of these data since the data from the greater area is more useful for national decision-makers; the present method would be a great help to the local authority for future sustainable development of the region. The percentage of evapotranspiration, runoff, and recharge in the study area are 73%, 36%, and 11%, respectively. Typically low recharge causes high runoff over the surface.

4.1. Co-Integration

Table 2 presents the result of the ADF test. It is evident that recharge is non-stationary and likewise, the annual rainfall, but are stationary after the second differencing. Other climatic parameters are non-stationary. It has been ascertained that the variables exhibit unit root I (1) (non-stationary) at their levels, but stationarity after differencing, and there exists a long run relationship between the climate parameters.

Table 2. Result of stationary test from the Augmented Dickey-Fuller Test.

Climate Parameters	Level	1 st Difference	2 nd Difference	Decision
Precipitation	−4.364246	−5.394125	−3.565695	Stationary
Recharge	−4.224929	−5.074373	−3.699143	Stationary
Min Temperature	−2.302965	−5.385516	−9.299585	Non-stationary
Max Temperature	−2.174135	−4.069986	−4.069986	Non-stationary
Evapotranspiration	−2.761985	−5.987190	−8.289337	Non-stationary
Relative Humidity	−2.604266	−4.506285	−6.032715	Non-stationary
Solar Radiation	−3.820166	−6.558539	−8.069424	Non-stationary

Critical level (1%): −3.6752

Table 3. Johansen co-integration result.

Eigen Value	Likelihood	5% Critical	1% Critical	Hypothesized No. of CE(s)
0.751784	105.2439	94.15	103.18	None **
0.594706	64.83369	68.52	76.07	At most 1
0.481656	38.64253	47.21	54.46	At most 2
0.264670	19.58617	29.68	35.65	At most 3
0.223683	10.67054	15.41	20.04	At most 4
0.108415	3.327882	3.76	6.65	At most 5

** denotes rejection of the hypothesis at 5% (1%) significant level. Likelihood ratio test indicates 1 co-integration equation at 5% significant level.

Table 3 shows the Johansen co-integration results. The likelihood ratio shows that there is only one co-integrating (CI) equation in the analysis. The CI equation was based on the conformity of the coefficients with economic theory and its statistical significance. From the equation, the precipitation variable was considered to have a significant effect on estimated recharge in the study area during the period studied.

The adjusted R² shows that about 98% of the variation in recharge is explained by the effects of precipitation (Table 4). This shows that an increase in rainfall value will alter the recharge value to increase and *vice versa*.

Table 4. Results from the Error Correction Model.

Variable	Coefficient	Standard. Error	t-Statistics	Probability
Recharge	11.13899	0.356742	31.22419	0.0000
Solar Radiation	−6.177148	7.792169	−0.792738	0.4354
Min Temperature	0.890065	3.595027	0.247582	0.8065
Max Temperature	2.818525	7.302545	0.385965	0.7028
Evapotranspiration	−12.55190	37.99302	−0.330374	0.7439
Constant	−935.5960	229.9052	−4.069486	0.0004

Dependent variable: precipitation. $R^2 = 0.977$; Durbin Watson stat: 1.583017; F-stat: 212.6064

4.2. Correlation and Regression Analysis

This was to study the correlation between estimated recharge and climate parameters. Table 5 shows the Pearson correlation coefficient for meteorological parameters (1983–2014) on estimated recharge. The results showed that evapotranspiration was correlated with solar radiation at the 0.01 significance level, with $R^2 = 0.647$. Additionally, estimated recharge was correlated with precipitation at the 0.01 level ($R^2 = 0.943$). There is no significance at any level among the other parameters with regression analysis, which was conducted to evaluate the effect of climate parameters on estimated recharge. It was observed from Table 4 that all parameters showed minimal relationships to estimated recharge, except precipitation, which showed a dominant role of rainfall percolation of water into the ground in the study area. Tables 5 and 6 below show the Pearson correlation coefficient for meteorological parameters, and regression analysis of weather parameters on the estimated recharge in the study area.

Table 5. Pearson correlation coefficient for meteorological parameters.

	Precipitation (mm)	Recharge (mm)	Min Temp. (°C)	Max Temp (°C)	ET (mm)	Rel. Hum. (%)
Precipitation (mm)	1	0.943	0.279	0.258	0.059	−0.050
Recharge (mm)	0.943	1	0.433	0.231	0.064	0.051
Min. Temp. (°C)	0.104	0.085	1	0.261	0.327	−0.036
Max Temp. (°C)	0.244	0.263	0.205	1	0.019	0.303
ET (mm)	0.016	0.046	0.165	0.413	1	0.019
Rel. Hum. (%)	0.119	0.092	−0.118	0.389	−0.003	1
Solar Rad.	−0.013	0.023	−0.047	0.205	0.647	−0.017

Table 6. Regression analysis of weather parameters on estimated recharge.

Weathered Parameter / Recharge	Determination Coefficient (r^2)	Regression Equation
Precipitation (mm)	0.983	$Y = -962.462 + 11.2228X$
Min. Temperature (°C)	0.007	$Y = 20.2466 + 8.42E - 03X$
Max. Temperature (°C)	0.069	$Y = 31.5017 + 1.42E - 02X$
Relative Humidity (%)	0.008	$Y = 78.5326 + 1.22E - 02X$
Solar Radiation	0.001	$Y = 15.0630 + 1.39E - 03X$

5. Conclusions

The estimation of groundwater recharges have been carried out in Odeda Local Government Area, Abeokuta, Ogun State, Nigeria. The methods used have greatly helped in estimating the groundwater recharges in the area. The annual mean groundwater recharge for 32 years (1983–2014) has been estimated to be 194.7 mm *per annum*. The mean of the recharge coefficient is 20.2%, the rate of evapotranspiration is about 73%, and groundwater recharge is about 11%. Therefore, 16% of rainfall water makes some allowance for runoff (and/or interflow) in the study area. The study shows that there is variability in climate parameters. The study also shows that the climate has a significant effect on groundwater resources. This is clearly revealed in the rainfall variable; however, evapotranspiration and solar radiation have a relationship with each other. The study also shows that the change in climate has a significant effect on recharge. This is clearly revealed in the rainfall variable; however, temperature seems to be an unimportant variable of climate in determinants of recharge in the study area. The correlation between parameters showed the highest positive correlation between recharge and rainfall. In addition, correlation between temperature and humidity, solar radiation, and ET are at the 0.01 level. Results of linear regressions proved precipitation has a significant effect (with $R^2 = 0.983$) on the estimation of recharge.

Author Contributions

Victor Makinde conceived the research, Oluseyi Adeleke carried out the research which was thoroughly supervised by Victor Makinde and Ayobami Eruola. Oluwaseun Dada helped in acquiring the data. Oluseyi Adeleke, Akintayo Ojo and Taiwo Aluko analysed the data. Oluseyi Adeleke wrote the manuscript, Akintayo Ojo reviewed and adapted the manuscript to fit the style of the journal.

Conflicts of Interest

The authors declare no conflicts of interest.

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