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Comparative Analysis of Empirical Formulae Used in Groundwater Recharge in Ogun – Oshun River Basins

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Authors' contributions

This work was carried out in collaboration between all authors. Author MOO designed the study, managed the literature searches, wrote the protocol, and wrote the first draft of the manuscript. Authors OM and OI managed the analyses of the study. Author OA performed the statistical analysis. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management. It is particularly important in regions with large demands for groundwater supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources. Estimation of recharge, by whatever method, is normally subject to large uncertainties and errors. In this paper, an attempt has been made to derive groundwater recharge from rainfall in ogun-oshun river basin using three empirical formulae and they include modified chaturvedi formula (1936) and Krishna Rao (1970) in Kumar, (2009); Kumar and Seethapathi (2002). Results from these three empirical formulae were compared using line graph, inter-item correlation and one way analysis of variance (ANOVA). A correlation coefficient of the range of 0.99-1.0 exist between each formula, and the rejection the null hypothesis that the means of the three formulae are not different from each other leading to the conclusion that any of the

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formula can be used for recharge estimations.

Keywords: Comparative analysis; empirical formulae; groundwater recharge; line graph; inter item correlation; ANOVA.

1. INTRODUCTION

Groundwater recharge is defined as water that infiltrates through the subsurface to the zone of saturation beneath the water table [1]. It results in the increase of groundwater storage and contributes to groundwater flow [2].

The amount of recharge in humid region (where these river basins situate) is usually high because the region receives large amount of rainfall, have favorable surface conditions for infiltration, and are less susceptible to the influences of high temperatures and evapotranspiration [1], and because of vegetative cover common in such areas. For example, [3] reported that a substantial rate of groundwater recharge occur in the regolith overburden in the Basement Complex of southwestern Nigeria where the mean annual rainfall ranges from 1145.5 mm to 1270.0 mm [4] but the surface runoff is quite low. Recharge in such regions is dependent on isolated areas where soils may be shallow and field capacities are exceeded locally, or on areas where there are fractured rock outcrops at the surface. The existence of large macropores (large pore spaces such as animal burrows, root channels, worm and termite casts) may also provide an important pathway for rainfall to bypass the soil mass and contribute to recharge.

The quantification of the rate of natural ground water recharge is a pre-requisite for efficient ground water resource management [5]; hence it is peculiarly important in regions with large demands for ground water supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of ground water resources [5]. While the estimation of recharge, by whatever method, is normally subject to large uncertainties and errors ; the use of empirical formulae shows great potential as an easy means of estimating recharge, which is often difficult if not impossible to obtain reliably by other methods [6]. This paper employed the use of empirical formulae for estimating groundwater recharges from rainfall obtained from raingauges stations in Abeokuta, Ijebu Ode, Ibadan, Oshogbo and Ikeja, situated within Ogun and Osun river basins.

1.1 Water Resources of Nigeria

The Federal Republic of Nigeria is located in West Africa between latitudes 40 north and longitude 20 and 150 east, with a total land area of 923.8 X 103 sq km bordered on the east by Chad and Cameroon, on the north by Niger, on the west by Benin and on the south by the Gulf of Guinea. The principal geographic feature is the Niger River which with its left bank tributary of the Benue River drains 60 percent of the country and forms an extensive delta at the south; Overall relief is very gentle; as there is a gradual loss of height from about 500m in the north to the coast [7].

The climate, which affects the quality and quantity of the country's water resources, results from the influence of two main wind systems: the moist, relatively cool, monsoon wind which blows from the south-west across the Atlantic Ocean towards the country and brings rainfall, and the hot, dry, dust-laden Harmattan wind which blows from the north-east across the Sahara desert with its accompanying dry weather and dust-laden air. The mean temperature is generally between 25 and 30ºC (77 and 86ºF), in the dry season the temperatures are more extreme, ranging between 20 and 30ºC (68 and 86ºF).

The highest annual precipitation of about 3,000 mm occurs in the Niger Delta and mangrove swamp areas of the south-east, where rain falls for more than eight months a year. There is a progressive reduction in precipitation northwards with the most arid north-eastern Sahelian region receiving as little as 500 mm a -1 precipitation from about 3-4 months of rainfall. Widespread flooding occurs in the southern parts of the country, while the northern parts experience chronic water shortages during the dry season when rain fed springs, streams and boreholes dry up.

There are four major drainage systems in the country: The Niger River Basin Drainage System with its major tributaries of Benue, Sokoto-Rima, Kaduna, Gongola, Katsina-Ala, Donga, Tarabe, Hawal and Anambara Rivers; The Lake Chad Inland Drainage System comprising the Kano, Hadejia, Jama'are Misau, Komadougou-Yobe, Yedoseram and Ebeji Rivers; The Atlantic Drainage System (east of the Niger) comprising the Cross, Imo, Qua Iboe and Kwa Rivers; while the forth drainage system is the Atlantic Drainage System (west of the Niger) made up of the Ogun, Oshun, Owena and Benin Rivers. Apart from the Lake Chad Inland Drainage System, the remaining three drainage systems terminate in the Atlantic Ocean with an extensive network of delta channels.

Consequently, groundwater resources are limited by the geological structure of the country, more than half of which is underlain by the Pre-Cambrian Basement Complex, composed mainly of metamorphic and igneous rocks. However, there are fairly extensive areas of fractured schists, quartzites and metamorphosed derivatives of ancient sediments from which water is often available at great depth. The sedimentary formations such as the Tertiary deposits of the Chad-Sokoto basins, the Cretaceous deposits of the Niger and Benue troughs, and the sedimentary formation of the Niger Delta, yield groundwater in varying quantities.

1.2 Study Area

The Ogun River basin is located in Southwestern Nigeria, bordered geographically by latitudes 6º 26' N and 9º 10'N and longitudes 2º 28'E and 4º 8 'E (Fig. 1). About 2% of the basin area falls outside Nigeria in the Benin Republic. The land area is about 23,000 km^2. The relief is generally low, with the gradient in the north-south direction. The Ogun River takes its source from the Igaran hills at an elevation of about 530 m above mean sea level and flows directly southwards over a distance of about 480 km before it discharges into the Lagos lagoon. The major tributaries of the Ogun River are the Ofiki and Opeki Rivers; two seasons are distinguishable in the Ogun river basin; a dry season from November to March and a wet season between April and October. Mean annual rainfall ranges from 900 mm in the north to 2000 mm towards the south. The total annual potential evapotranspiration is estimated at between 1600 and 1900 mm [8].

The two major vegetation zones that can be identified on the watershed are the high forest vegetation in the north and central parts, and the swamp/mangrove forests that cover the southern coastal and floodplains, next to the lagoon. The geology of the study area is described as a rock sequence that starts with the Precambrian Basement [9] and which consists of quartzites and biotite schist, hornblende-biotite, granite and gneisses. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the study area. The sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta formation, consists of grey sand intercalated with brown to dark grey clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base.

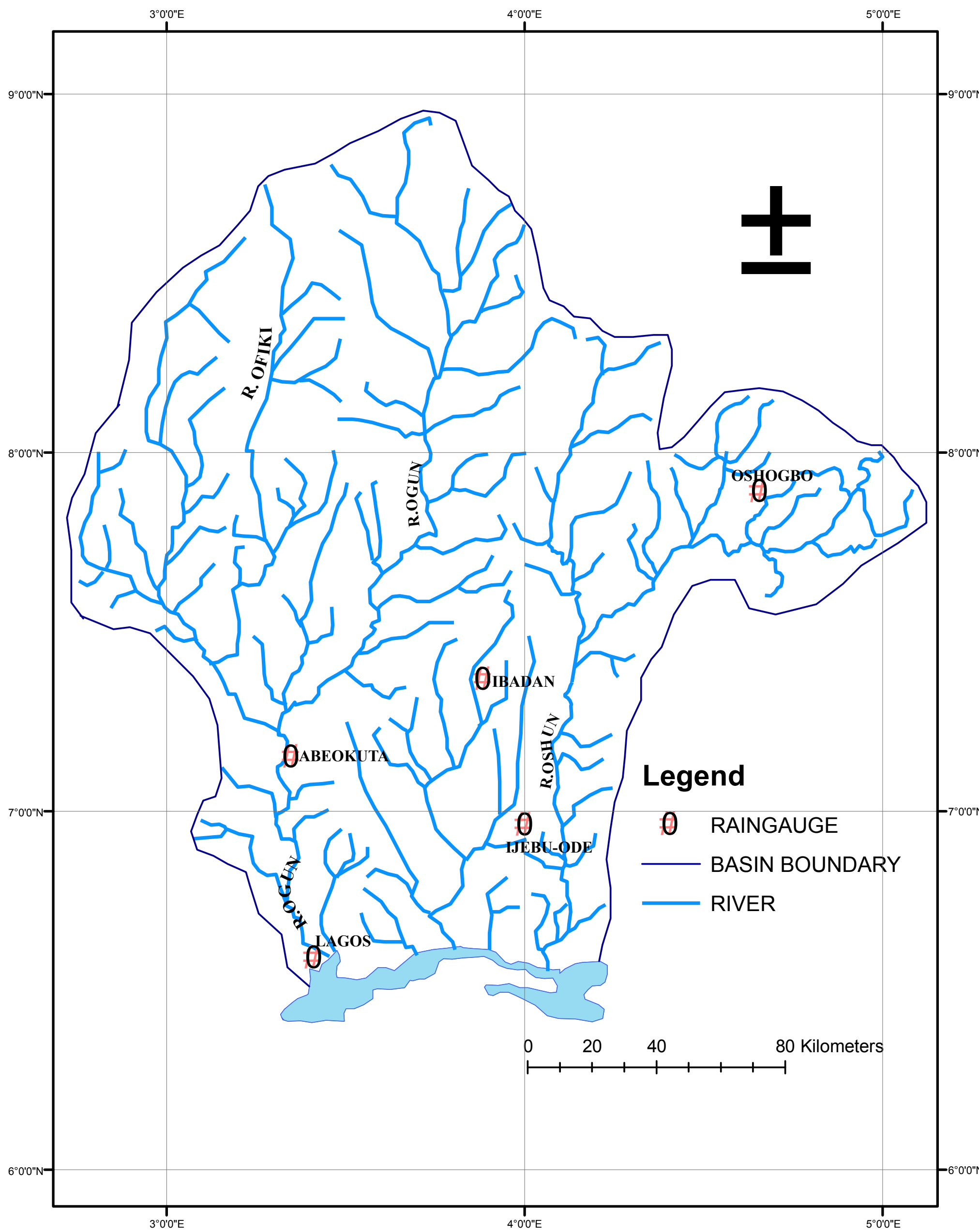

Fig. 1. MAP of Ogun and Osun River Basins

About 9 km upstream of Abeokuta town there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal plain sands in sequence towards the Lagos lagoon.

On the other hand, the drainage system of Osun River rises in Oke-Mesi ridge, about 5 km North of Effon Alaiye on the border between Oyo and Ondo States of Nigeria, and flows North through the Itawure gap to latitude 7 º53' before winding its way Westwards through Oshogbo and Ede and Southwards to enter Lagos lagoon about 8 km east of Epe (Fig. 1). The basin is underlain by metamorphic rocks of Precambrian basement complex, the great majority of which are very ancient in age. This basement complex showed great variations in grain size and in mineral composition. The rocks are quartz geniuses and schist consisting essential of quartz with small amounts of white micaceous minerals [10].

In addition, sedimentary rocks of cretaceous and latter deposits are found in the southern sections of the Osun basin. The remaining sections are composed of crystalline rocks of the basement complex, consisting mainly of folded gneiss, schist and quartzite complexes, which belong to the older intrusive series. Although in many places outcrops are plainly visible, large areas are overlain by layers of laterite soil formed by weathering and decomposition of the prevent rock material. Along the river basin the provenance of the minerals have been dealt with, based on heavy minerals studies.

1.3 Some Groundwater Studies Carried Out in Southwest Nigeria

Several methods of estimating groundwater recharge have been used in Nigeria in the last two decades [11,12,13,14,15,16,17,18,19,20,21,2,6]. Some of the methods are empirical, using simple mathematical relations. Others are hydrologic budgeting methods, the chloride mass balance method, and the groundwater level fluctuation method. [6]. Groundwater recharge studies in southwest Nigeria could be back dated to 1972 when [3] in his work 'Rural water supply in the Basement Complex of Western State, Nigeria' reported that in contrast to fact that the most important component of groundwater recharge is infiltration of rain, there was a substantial rate of groundwater recharge into the regolith overburden in the basement complex of south west Nigeria; Another groundwater study carried out in the southwest region of Nigeria is that presented by [22], in his study of the assessment of groundwater contribution to the environmental flow in Ogun river catchment where he explained that the flow nets analysis for upper and lower sections of the Ogun river showed that there is a considerable amount of groundwater flow. The study revealed that an intricate groundwater flow pattern that is controlled by lithological and structural factors creates a zone of surface and ground water interaction. He concluded that with the coming of a more holistic approach to environmental flows and environmental protection, surface water/groundwater (SW/GW) interactions should receive heightened attention at multidisciplinary scale and more so, by policy makers and watershed managers.

In 2007, [2] worked on the hydrograph analysis for groundwater recharge in the phreatic basement aquifer of the Opeki river basin which is one of sub-water shed of the Ogun River. By using hydrograph analysis, the estimation of groundwater recharge to the phreatic basement aquifer of the Opeki drainage basin, with an approximate land area of 980 km¬2, shows an annual value of between 29.23 x 106 m3 and 259.09 x 106 m3, with an average of 134.45 x106 m3 (i.e.137 mm). The study revealed that recharge is between 3 and 20 % of the total annual precipitation and that the base flow ranges from 6 – 47 % of the total annual stream flow with a mean annual runoff (MAR) of 708 mm. The dependence of base flow on the amount of groundwater recharge is evidenced by a high correlation coefficient of 0.98 and the positive influence of precipitation on baseflow and groundwater recharge, are provided by correlation coefficients of 0.6 and 0.7 respectively. In addition to this, the significant amount of recharge in the study area provides evidence of the considerable amount of groundwater in storage in the basement areas of southwestern Nigeria and on which effective water resources planning and development can be based.

In a project carried out by [23] on heavy minerals assemblage of sediments in Osun River basin in Southwest Nigeria to determine their concentrations and provenance, twenty-five sediment samples were analyzed for heavy mineral assemblage determination. The separation of these minerals was carried out using bromoform (Specific gravity 2.85) and slide examination under the petrographic microscope. The heavy minerals assemblages of Zircon Tourmaline Rutile (ZTR), Silimatate, Garnet, Epidote and Staurolite indicated its derivation from mixed sources of acid igneous rock to medium and high grade metamorphic rocks. The calculated ZTR % values varied between 21.1% in Ekiti to 56.7% in Lagos state and the mean ZTR percentage indices was 36.4%. The two most abundant are Staurolite and Rutile with 43.92% and 11.95% respectively. They found out that their concentrations and sizes increase from Ekiti state in the upper section of Osun basin to Lagos in the southern part of the basin according to coastal drift whereas the mineralogical component remains constant.

2. MATERIALS AND METHODS

2.1 Introduction

Numerous methods are used to estimate recharge rates and all have their limitations. Both [24] and [25] noted that no single estimation technique has been identified, which does not give suspects results. [25] therefore advocated 'finding an average of several techniques' when accurate values are required. For instance, [26] argued that water balances are prone to error especially in semi aid regions where recharge components is small in relation to the measurement of evapotranspiration, runoff and precipitation. [27] also asserted that 'methods which rely on the direct measurement of soil water fluxes are problematic because fluxes are low and difficult to detect'. A problem with water table fluctuation measurements is that they require accurate estimates of aquifer parameters in order to equate changes in saturated volume to recharge [28].

While there are numerous problems with physical recharge measurement techniques, equal concern needs to be expressed as to whether the values obtained from point measurements are representative for the specified area of interest. [29] expresses this concern when he concluded that the most important problem to overcome in the estimation of groundwater recharge is probably the assessment and prediction of this spatial variability.

Certain chemical recharge estimation techniques tend to overcome some of the spatial variability problems. For example, a tracer's concentration, like the chloride concentration in rainfall, should represent a spatially uniform concentration in the soil surface [27]. Their reliability in certain environments, however, may also be questionable. For example, the accumulation of chloride in the soil by evapotranspiration in dry areas, or its elevated concentrations in coastal areas could undermine the assumptions on which the method is based [29]. The chloride concentrations in rainwater may be very low and therefore difficult to accurately quantify. Where aquifers store sufficient water, the chemical methods have the advantage in that data collected may represent many years of recharge from which a historical record can be derived [30]. In contrast, direct physical methods only provide data over the duration of the monitoring period.

Other recharge estimation methods include steady state flow approximation based on Darcy's Law and rainfall-recharge relationships.

2.2 Rainfall-Recharge Relationships

The simplest empirical formula takes recharge R as a proportion (a) of precipitation (P):

$$R = a.\ p \qquad \text{eq. 1}$$

Equation.1 assumes that recharge is a constant fraction of rainfall. In some environments, particularly in arid and semi-arid areas, recharge may not be experienced after short, low intensity rainfall events [31]. Rather than considering recharge from rainfall events, it is commonly averaged over a year, and mean annual precipitation (MAP) is used as the P-value. [32,31,33,34].

$$R = a\,(P - P\ min) \qquad P > P\ min \qquad \text{eq. 2}$$

Or

$$R = (P - P\ av) \qquad \text{eq. 3}$$

Where:

P min = minimum precipitation
P av = average precipitation

[35] obtained a figure of 4.6% of MAP in excess of 263 mm, in a study of De Aar and Dewetsdorp (South Africa), which focused on saturated volume fluctuations. Taking soil thickness into account, Kirchner et al. (1991) produced the following formulae:

$$\text{Thin soil cover: } R = 0.06\,(MAP - 120)\ [mm] \qquad \text{eq. 4}$$

$$\text{Thick soil cover: } R = 0.023\,(MAP - 51)\ [mm] \qquad \text{eq. 5}$$

$$\text{Alluvial cover: } R = 0.12\,(MAP - 20)\ [mm] \qquad \text{eq. 6}$$

Many rainfall-recharge relationships have been developed for dolomitic aquifers, and not all are linear. [36], [37] plotted recharge estimates from dolomitic aquifers in different areas, and showed that a linear relationship is obtained above an annual rainfall of 313 mm. This was adjusted to give the following general formula [25]:

$$R = 0.32\,(MAP - 360)\ [mm] \qquad \text{eq. 7}$$

In the case of mountainous catchments, [25] adopted the view that the base flow component of stream flow can be used to estimate groundwater recharge. This relies on assumptions, which may not necessarily hold true since it assumes that base flow can reliably be separated from total flow, and that all the recharge is derived from the delineated catchment. When relating base flow to MAP in mountainous catchments, representative rainfall data can be problematic. Because of steep slopes, orographic rainfall variations can be significant, and rain gauges are unlikely to reflect the true average precipitation over the catchments.

Base flow studies in several mountainous catchments have been collated to produce the general formula [25]:

$$R = 0.73\ (P\ av - 480)\ [mm] \qquad \text{eq. 8}$$

Numerous other rainfall-recharge relationships have been developed from point studies of South African aquifers. Some of the more complex formulae do not necessarily preserve linearity, for example:

$$R = a\ (P / P\ av)\ P \qquad \text{eq. 9}$$

And

$$R = a\ .P\ av\ (1 - b \times Pav / P) \qquad \text{eq. 10}$$

Where a and b are empirical parameter.

While equation 10 shows that recharge varies proportionally to the deviation of rainfall from the average value, equation 11 assumes that the ineffective portion of rainfall varies, depending on the extent of the rainfall deviation from the long-term average. [38] has used the following relationship to obtain a first estimate of groundwater recharge:

$$R = (MAP)\ 2/10000\ [mm] \qquad \text{eq.11}$$

This formula translates to using 1% of MAP where MAP = 100 mm; 2% of MAP where MAP = 200 mm; etc.

The three main criticisms of simple rainfall-recharge formulae are:

Relationships may not be transferable to areas other than those in which they were derived;

They ignore temporal distribution of rainfall;

Their accuracy is dependent on the accuracy of the recharge estimates from which the relationship was derived.

2.3 Materials

Rainfall data were obtained from the Nigerian Meteorological Agency (NIMET), Oshodi Lagos state data base. Twenty years continuous monthly data were available for Abeokuta, Oshogbo, Ikeja, Ibadan, and Ijebu-ode; between 1987 and 2006.

2.4 Procedure

Arithmetic mean method was first of all used to calculate the Areal rainfall in the basin.

Ra=∑_(i=1)^n▒Pa÷N eqn. 12

Where

Ra = Areal rainfall
Pa = point rainfall
N = number of point rainfall

Three empirical formulae showing rainfall-recharge relationship were selected for the estimation of recharge based on the work of Modified Chaturvedi formula and Krishna Rao in [39,40].

The formulae were selected because of the similarities between the Indian monsoons climate where they were created and the humid sub-tropical climate of southwest Nigeria.

Brief descriptions of how these methods are established are discussed next.

Chaturvedi formular in [39]: Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi, derived an empirical relationship to arrive at the recharge as a function of annual precipitation.

$$Rr = 2.0\ (P - 15)0.4$$

Where,

Rr = net recharge due to precipitation during the year, in inches; and
P = annual precipitation, in inches.

This formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified form of the formula is:

$$Rr = 1.35\ (P - 14)0.5$$

A detailed seasonal groundwater balance study in Upper Ganga Canal command area for the period 1972-73 to 1983-84 by [40] to determine groundwater recharge from rainfall. It was observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. The recharge coefficient (based upon the rainfall in monsoon season) was found to vary between 0.05 and 0.19 for the study area. The following empirical relationship (similar to Chaturvedi formula) was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$$Rr = 0.63\ (P - 15.28)0.76$$

Where, Rr = Groundwater recharge from rainfall in monsoon season (inch);
P = Mean rainfall in monsoon season (inch).
Krishna Rao (1970)

Krishna Rao gave the following empirical relationship in 1970 to determine the groundwater recharge in limited climatological homogeneous areas:

$$Rr = K\ (P - X)$$

Where, Rr = Groundwater recharge from rainfall in monsoon season (mm);
P = Mean rainfall in monsoon season (mm).

The following relation is stated to hold good for different parts of Karnataka:

$Rr = 0.20\ (P - 400)$ for areas with annual normal rainfall (P) between 400 and 600 mm
$Rr = 0.25\ (P - 400)$ for areas with P between 600 and 1000 mm
$Rr = 0.35\ (P - 600)$ for areas with P above 2000 mm

Where,

Rr and P are expressed in millimetres, K = 0.25 & 0.35, and X = 400 & 600

Data analysis was undertaken using descriptive statistics with graphical representation and inferential statistics, which include inter-item correlation and ANOVA.

Statistical analysis was generally carried out on rainfall and recharge of the Ogun-Osun river basin using the computer software, statistical package for social sciences (SPSS 16.0).

3. RESULTS AND DISCUSSION

This paper examines the results obtain from the data analysis and discusses salient issues emanating from recharge calculations using the three empirical formulae under the following sub headings;

3.1 Descriptive Statistics of Rainfall

Table 3.1 below shows the annual rainfall data obtained from Nigeria Meteorological Agency (NIMET). The study was limited to twenty years from 1987-2006 for consistency purpose as only two stations – Abeokuta and Oshogbo were up to 2010.

Table 3.1 Table of annual rainfall from Nimet

		Annual Rainfall (mm)				
	Year	**Abeokuta**	**Oshogbo**	**Ibadan**	**Ijebu-ode**	**Lagos**
1	1987	1277.10	1368.60	1285.10	1501.90	2057.00
2	1988	1604.40	1464.50	1397.80	1653.20	2432.10
3	1989	1401.00	1191.10	1223.70	1445.50	1702.60
4	1990	1111.00	1411.10	1283.90	1713.80	2030.20
5	1991	1173.10	1684.40	1369.30	1646.90	1722.90
6	1992	1076.70	1404.80	1088.60	1611.80	1357.60
7	1993	1193.60	1263.80	1478.10	1456.90	1828.20
8	1994	712.20	1207.80	905.90	1556.90	1602.30
9	1995	1177.50	1452.50	1534.70	1643.80	2025.30
10	1996	1471.60	1349.40	1653.70	2032.40	2535.90
11	1997	1354.90	1231.10	1097.10	1705.70	1936.80
12	1998	1118.40	1203.30	1018.00	1172.80	1232.90
13	1999	1530.40	1529.30	1814.90	1819.40	2056.90
14	2000	1201.90	1367.80	1244.50	1655.00	1458.90
15	2001	849.20	1014.70	1289.70	1462.30	1110.00
16	2002	1235.10	1361.00	1515.30	1426.50	1523.20
17	2003	1214.70	1633.00	1143.00	1572.00	1549.00
18	2004	1153.30	1393.70	1314.20	1766.60	2117.40
19	2005	917.50	1130.20	1204.20	1473.30	1745.60
20	2006	1157.20	1469.70	1260.10	2043.60	996.20
21	2007	1615.70	1421.70			
22	2008	1408.70	1610.10			
23	2009	1351.10	1310.20			
24	2010	1450.70	1691.80			

Table 3.2 below show that Abeokuta contributed the lowest mean annual rainfall of 1196.54 mm (see Fig. 2 for the variation of the mean annual rainfall) to the drainage basin, with a maximum and minimum of 1604.40 mm and 712.20 mm respectively, also rainfall along the

years of study deviates largely from the mean with a standard deviation of 216.91 mm; while Oshogbo contributed a mean annual rainfall of 1356.59 mm with maximum and minimum of 1684.40 mm and 1014.70 mm respectively, a standard deviation 165.41 mm also indicate a largely distributed rainfall along the years.

Table 3.2 Tables of descriptive statistics of annual rainfall

	Annual rainfall				
	Abeokuta	**Oshogbo**	**Ibadan**	**Ijebu-Ode**	**Lagos**
N Valid	20	20	20	20	20
Missing	0	0	0	0	0
Mean	1196.5400	1356.5900	1306.0900	1618.0000	1751.0500
Median	1185.5500	1368.2000	1284.5000	1627.8000	1734.2500
Std. Deviation	216.90448	165.41236	217.98307	204.11800	410.53156
Variance	47047.553	27361.247	47516.620	41660.000	168536.159
Minimum	712.20	1014.70	905.90	1172.80	996.20
Maximum	1604.40	1684.40	1814.90	2043.60	2535.90

Ibadan contributed a mean annual of 1306.09 mm, with a maximum and minimum of 1814.90 mm and 905.90 mm respectively, rainfall also largely disperse from the mean with a standard deviation of 217.98 mm. Ijebu-ode has a mean of 1618.0 mm annual rainfall and varies largely from the mean with a standard deviation of 204.11 mm.

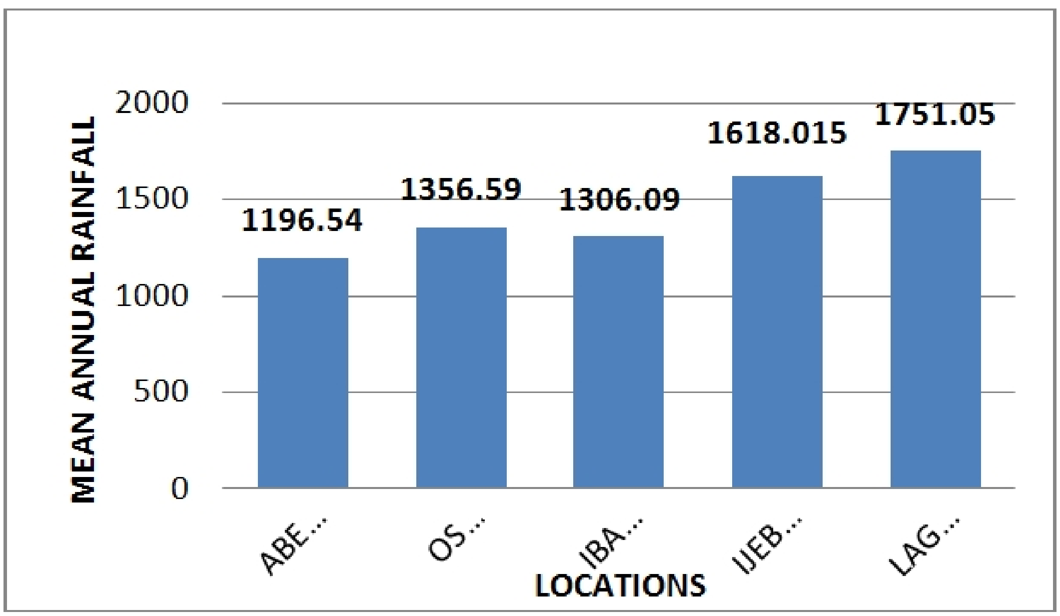

Fig. 2. Showing variation of the mean annual rainfall in relation to locations

Lagos contributed the highest annual rainfall to the drainage area within the years of study; a mean annual rainfall of 1751.05 mm is the largest of all the locations, the maximum and minimum annual rainfall are 2525.90 mm and 996.20 mm respectively. The rainfall variation in Lagos deviates largely from the mean with a standard deviation of 410.53 mm.

The graph in (Fig. 3) indicates that large amount of rainfall were generally contributed to the river basin from Lagos state along the years, except in 2006 when 996.20 mm of rainfall was contributed, this is generally because Lagos state is a coastal area having an advantage of tropical Mari-time Air mass blowing from the Atlantic Ocean.

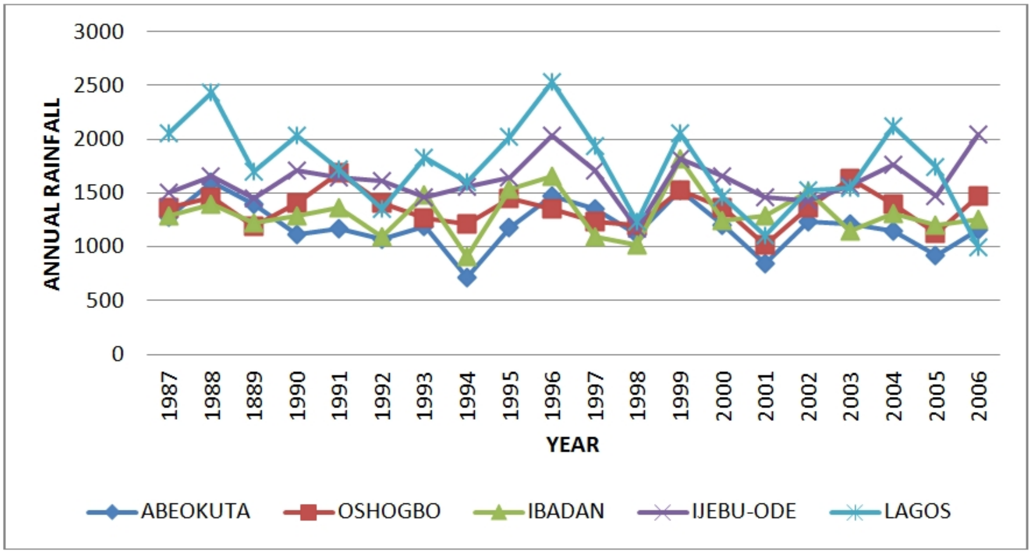

Fig. 3. Showing trend of variation of annual rainfall

The line graph also shows that Abeokuta contributed the lowest amount of rainfall along the years with a range of 892.20 mm.

3.2 Annual Areal Rainfall in Ogun-Osun River Basin

Annual areal rainfall was calculated using the Arithmetic Mean method. The technique calculates areal precipitation using the arithmetic mean of all the point considered in the study which includes Abeokuta, Oshogbo, Ibadan, Ijebu-ode and Lagos.

The Table (3.3) statistically described in table 3.4 shows that for the twenty years of study, the mean annual Areal rainfall of the river basin is 1445.8 mm.

Table 3.3 Table of annual areal rainfall

	Year	Annual Areal Rainfall
1	1987	1497.94
2	1988	1710.40
3	1989	1392.78
4	1990	1510.00
5	1991	1519.32
6	1992	1307.90
7	1993	1444.12
8	1994	1197.02
9	1995	1566.76
10	1996	1808.60
11	1997	1465.12
12	1998	1149.08
13	1999	1750.18
14	2000	1385.62
15	2001	1145.18
16	2002	1415.82
17	2003	1422.34
18	2004	1549.04
19	2005	1294.16
20	2006	1385.36

Table 3.4 Descriptive statistics of annual areal rainfall

N	Mean	Std. Deviation	Minimum	Maximum	Valid	Missing
	20	0	1445.8	181.52108	1145.18	1808.60

The standard deviation of 181.5 mm shows that the areal rainfall deviate largely within the twenty years; with highest Areal rainfall of 1808.60 mm in 1996, and lowest mean annual rainfall of 1145.18 mm in 2001.

3.3 Results of Groundwater Recharge Estimation

The annual areal recharge of the river basin within 1987 and 2006 was calculated using the three formulae: Modified Chaturvedi formula, Krishna Rao in [39] and [40]. Although the Chaturvedi and the Kumar and Seethapathi's were developed in inches, the final recharge estimated was converted to millimeters (mm) to ensure consistency in unit of measurement.

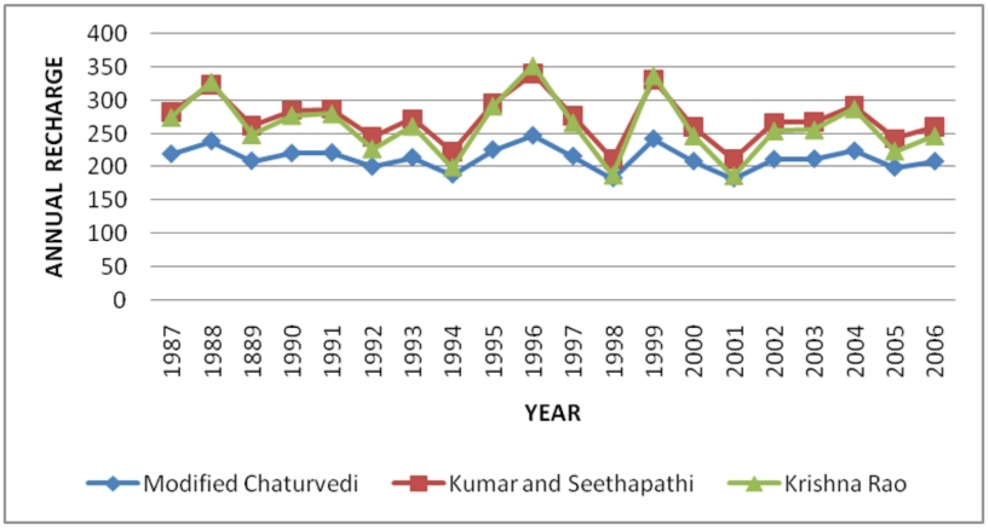

Fig. 4. Showing trend of recharge estimation variation within the formulae

3.4 Descriptive Statistics of Annual Areal Groundwater Recharge

The Table 3.5 below shows that maximum and minimum recharge from the Modified Chaturvedi formula are 247.48 mm and 182.73 mm respectively, the standard deviation of 17.79 mm signifies that the recharge slightly deviate from the mean of 213.81 mm. However, when the mean of the annual areal recharge is divided by the mean of the annual areal rainfall and multiplied by 100; it was discovered that 16 % of the rainfall became groundwater recharge. In addition, the line graph indicates that recharge varies below 211.66 mm within the twenty years of study.

Table 3.5 Statistics of areal recharge from the formulae

	N Valid	Missing	Mean	Std. Deviation	Minimum	Maximum
Modified Chaturvedi formula	20	0	213.81	17.79416	182.73	247.48
Kumar and Seethapathi formula	20	0	271.73	35.27197	211.66	340.00
Krishna Rao Formula	20	0	261.46	45.38243	186.30	352.15

The recharge estimated from the Kumar and Seethapathi's formula within the twenty years of study has a maximum and minimum 340 mm and 211.66 mm respectively with a mean of 271.72 mm and 35.29 mm standard variations showing that the recharge values deviates largely from their mean. When the mean of the annual areal recharge is divided by the mean of the annual areal rainfall and multiplied by 100, it was deduced that about 18% of the rain that fell in the twenty years of study went into the ground. Recharge from Kumar and

Seethapathi's formulae has the highest mean although it's maximum and minimum values are lower when compared with the other two formulae; The line graph show that recharge ranges from 340 mm to 211.66 mm. Recharge values from the Krishna Rao's formula is quite similar to Kumar and Seethapathi's, because it also deviate largely from its mean of 261.46 with a standard deviation of 45.38, the maximum and minimum values are 352.15 mm and 186.30 mm. When considering the amount annual areal rainfall within the years of study with the estimated recharge; like the Kumar and Seethapathi's formula about 18 % of the rainfall became groundwater recharge.

From descriptive statistics it can be concluded that 'Kumar and Seethapathi' and the Krishna Rao's formulae are similar to each other, while the modified Chaturvedi formula is slightly different from the latter.

3.5 Comparative Analysis of Recharge Formulae Using Inter-Item Correlation Matrix and ANOVA

In other to find out if any differences actually exist between these formulae, inter item correlation Matrix was used to confirm any correlation.

Table 3.6 Inter-Item correlation matrix of annual areal recharge

	Modified Chaturvedi formula	Kumar and Seethapathi formula	Krishna Rao formula
Modified Chaturvedi formula	1.000	1.000	0.999
Kumar and Seethapathi formula	1.000	1.000	1.000
Krishna Rao formula	0.999	1.000	1.000

Thus, from the Table 3.6, the correlation between Modified Chaturvedi Formula and Kumar and Seethapathi Formula is positive one (+1), which means they are perfectly positively correlated; while its correlation with Krishna Rao Formula is (+0.999), which means they are highly positively correlated. The Kumar and Seethapathi formula and Krishna Rao have a correlation of (+1) which makes them perfectly positively correlated to each other.

Being perfectly and positively correlated needed to be examined further to confirm if there exist any variations. Thus the item statistics showing the mean, minimum and maximum, range and variation of the three formulae was analyzed.

Table 3.7 Summary Item Statistics of The Recharge Formulae

	Mean	Minimum	Maximum	Range	Minimum/ Maximum	Variance	N of Items
Inter-Item Correlations	.999	.999	1.000	.001	1.001	.000	3

It was revealed in the Table 3.7 above that the three formulae do not vary in correlations which make them highly similar to each other.

3.6 Tests for Hypothesis Using One Way- ANOVA

The hypothesis of the paper was tested using One-way ANOVA in other to determine if there are significant differences between the means of the three recharge formulae. The hypothesis is stated thus;

H0= there is no significant difference between the means of the three recharge formulae
H1= there is significant difference between the means of the three recharge formulae

The Table 3.8 below show that with a degree of freedom of d1=2, and d2=57; ft=15.83 at 0.05 significant level. The significant value of 0.00 is less than 0.05; we reject the null hypothesis that there is no significant difference between the means of formulas, and accept the alternate hypothesis that there is significant difference in the means of the three formulae.

Table 3.8 showing the result of One way ANOVA

	ANOVA				
	Sum of square	**df**	**Mean Square**	**F**	**Sig**
Between Group	38201.59	2	19100.79	15.83	0.00
Within Group	68785.28	57	1206.759		
Total	106986.9	59			

It is argued that, taking a clue from the table 3.6 that although Modified Chaturvedi formula, Kumar and Seethapathi's formula and Krishna Rao formula are perfectly correlated; table 3.8 shows that there exists a significant difference in the means. Thus, the correlation between Krishna Rao formula and Modified Chaturvedi formula at 0.999 is suspected. It is therefore concluded that although any of the recharge formula can be used for estimations, it is safer to use Kumar and Seethapathi's formula than any of the other two.

4. CONCLUSION

This paper presents a comparation of three empirical methods used to estimate recharge in the Ogun-Oshun River Basin southwest Nigeria. The high amount of rainfall both in temporal and spatial strongly affects recharge in this area, and as a result high recharge coincided with periods of high rainfall and low recharge with low rainfall. Result show that there was high amount of rainfall in Lagos state within the twenty years of study. This could be due to the moist, relatively cool, monsoon wind which blows from the south-west across the Atlantic Ocean towards the country and brings rainfall to the area; while Abeokuta has the lowest rainfall.

It was observed that about 16% to 18% of the areal rainfall of the study area became groundwater recharge which also confirms the result of a study carried out by Idowu and Martins in 2007 on the hydrograph analysis for groundwater recharge in the phreatic basement aquifer of the Opeki river basin which is one of sub-water shed of the Ogun River, where they arrived at a conclusion that recharge is about 2 %-20 % of rainfall.

The three empirical formulae correlate positively with each other when subjected to inter-item correlation analysis; and with results from the analysis of variance (ANOVA). It can be concluded that although Modified Chaturvedi formula, Kumar and Seethapathi formula and Krishna Rao formula are perfectly correlated, there exists a significant difference in the means. Thus, the correlation between Krishna Rao formula and Modified Chaturvedi formula at 0.999 is suspected. It is therefore concluded that although any of the recharge formula can be used for estimations, it is safer to use Kumar and Seethapathi formula than any of the other two.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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