EMPIRICAL ESTIMATION OF GROUNDWATER RECHARGE IN PARTS OF THE BASEMENT COMPLEX OF NORTHERN NIGERIA

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Abstract
Knowledge of recharge estimates is essential to the sustainable development and management of groundwater resources. In this study two empirical methods were employed in estimating of groundwater recharge in Gusau and Bauchi in semi-arid Northern Nigeria. The recharge estimates were based on the methods developed by Sinha and Sharma (1988) and Turc (1954).Variability of annual rainfall and recharge estimates were determined using the coefficient of variation, while the equality of variance of recharge estimates obtained from the empirical methods were determined using Levnne's Test. Simple Linear Regression was used to predict the mean groundwater recharge for the study period. Results of groundwater recharge for Bauchi based on the method developed by Sinha and Sharma gave a maximum and minimum estimate of 262.64mm and 158.50mm, while the highest and lowest estimate for Gusau was 252.49mm and 142.29mm. Highest and lowest annual average recharge estimate based on Turc's method was, 687.49mm and 170.13mm for Bauchi, while the maximum and minimum estimate for Gusau was 578.76mm and 69.52mm. The results of the coefficient of variation shows a high level of variability based on Turc's method, and a moderate degree of variability based on Sinha and Sharma's method. The results of Levene's Test indicated that variance of recharge estimates obtained from both methods differ significantly from each other. Regression model for the two locations revealed that rainfall generally accounts for more than 90 percent of groundwater recharge variation. The study recommended that scientific and periodic assessments of groundwater resources potential should be embarked upon.

Keywords: Recharge; Groundwater; Semi-Arid; Basement Complex; Rainfall.

INTRODUCTION
Groundwater recharge is a process by which water enters into the phreatic or saturated zone. It is the downward flow or percolation of water to the water table, adding to water in the groundwater reservoir (Sharp, 2007; de Vries and Simmers, 2002). The highly variable nature of groundwater recharge and its pivotal role in the sustainable development and management of groundwater resources therefore makes the quantification of natural recharge very important. In arid and semi-arid regions of the world where rates of natural groundwater recharge are generally low in comparison with average annual rainfall, quantification of the rate of natural groundwater recharge is necessary for the sustainable use and management of groundwater.

In the semi-arid areas of Northern Nigeria where groundwater is being increasingly utilized, the estimation of groundwater available for use is very important in order to prevent some of the negative environment consequences associated with over-abstraction and mining of groundwater. The increased reliance on groundwater in many parts of Northern Nigeria is attributed to a number of reasons. These include the highly seasonal nature of rainfall, low rainfall amounts and water balance deficit, increasing population, inadequate pipe-borne water supply for domestic and municipal uses, and over- abstraction of groundwater for agriculture and other uses. Furthermore, the downward trend of river discharge occasioned by the sahelian drought of the 1970s and 1990s also contributed to increased dependence on groundwater within the region as groundwater became the only reliable source of water during those periods.

The combined effects of climate variability, the generally low yields of crystalline basement rocks and heavy dependence on groundwater has often resulted in the drying up of shallow wells and boreholes, and decline in groundwater levels, which eventually culminates in higher pumping heads and greater costs of pumping. This situation therefore raises a lot of concerns about the sustainable development, use and management of groundwater in the region. As a starting point in the sustainable management of this vital resource, working estimates of the rates of groundwater recharge is required.

Numerous techniques and models have been developed over the years, to estimate natural groundwater recharge. These include the empirical method, groundwater resource estimation method, groundwater balance approach and soil moisture based methods (Kumar, 2000).Other methods as identified by Kumar & Seethapathi (2002), include groundwater balance method, soil water balance method, zero flux plane method, one-dimensional soil water flow model, inverse modeling technique and isotope and solute profile techniques.

A number groundwater recharge studies in which empirical methods were used exists in literature. For example, Oke et al., (2013) compared the estimated annual groundwater recharge for the Ogun-Oshun River Basin using three empirical methods, namely the Krishna Rao formula, the Kumar and Seethapathi formula and the modified Chaturvedi formula. The results of the study showed that the annual recharge estimate based the first two formulae were similar while the estimates based on the modified Chaturvedi formula differed significantly.

Utilising the Amristsar formula in combination with remote sensing techniques, Rawat et al., (2012) estimated groundwater recharge at Shankergarh block in Allahabad, India. The result of the study revealed a close correlation between the empirical method employed and the estimate obtained through remote sensing. Adeleke et al., (2015) used the modified Chaturvedi formula to estimate groundwater recharge for Odeda Local Government Area of Ogun State between 1983 and 2014. The result of the study showed that the rate of recharge was low with 11 percent of the rainfall received percolating into the underlying aquifers.

Furthermore, a number of studies exist on groundwater recharge in Northern Nigeria in which different estimation methods were used. These include the adoption of the water budget method in estimating groundwater recharge in the Hadejia-Nguru wetlands (Goes, 1999), the use of the chloride mass balance method in estimating groundwater recharge in Northeast Nigeria (Edmunds, et al, 2002), use of the unsaturated zone chloride profile technique in estimating groundwater recharge in Northeast Nigeria (Goni, 2001) and the utilization of a combination of empirical, chloride mass balance, climatic-hydrological balance, stream flow hydrographs and water table recharge methods, in estimating groundwater recharge in the parts of Sokoto Basin (Adelana, et al, 2006).

In recognition of the high variability of this natural flux and the important role that groundwater availability plays in the economic sustenance of Northern Nigeria, this study aims to estimate natural groundwater recharge at Gusau (Northwest Nigeria) and Bauchi

(Northeast Nigeria) located in the basement complex of Northern Nigeria using empirical methods. Secondly, the study aims to determine the level of variability of annual rainfall and the recharge estimates. Thirdly, the study aims to determine the existence or otherwise of equality or homogeneity in the variance of the recharge estimates derived from the empirical methods. Lastly the study aims to assess the extent to which rainfall accounts for variation in recharge over the study period as well as predict the mean groundwater recharge for the study period using the simple linear regression method.

MATERIALS AND METHODS

The study locations are Gusau and Bauchi. Gusau (Fig.1) is located between latitudes $12^0 13'$N and $12^0 18'$N and between longitudes $6^0 29'$E and $6^0 45'$E (Dalhatu & Garba, 2012). Gusau Local Government Area in which Gusau Town is located occupies an area of 3, 364 Km^2 (Ladan, et al., 2012). Gusau is located in the Sudan Savanna ecological zone of Nigeria. Climate-wise the dry season lasts from November to April, while the rainy season is from May to October. The rainfall pattern is characterized by a single peak, with an annual mean of about 875mm, while mean annual temperature is around 30^0C (Dalhatu & Garba, 2012).

The hydrographic features of Gusau area include River Sokoto and some of its tributaries, as well as some of the westward and southward flowing tributaries of Rivers Rima and Niger (Shear & Partners as cited in Dalhatu & Garba, 2012). Relief-wise Gusau is located at an altitude of 300m above sea level (Dalhatu & Garba, 2012). The topography of the area is undulating and slopes gently into the river valley (Swindel as cited in Dalhatu & Garba, 2012).

Bauchi town is located between latitudes $9^0 00'$N and $9^0 30'$N and between longitudes $10^0 25'$E and $11^0 20'$E. It occupies a total land area of 3, 604 hectares (36.04Km^2). Bauchi is located in the Sudan Savanna zone of Nigeria. The landscape is relatively flat, with a range of disjointed hills at the northern part of the town (Usman & Mohammed, 2012).

Rainfall in Bauchi is strongly seasonal, starting mostly in the first half of May and ending in September. Rain days vary between 100 and 160, while annual rainfall is about 1,000mm. Highest temperatures are recorded in April and May prior to the onset of the rainy season when mean monthly is about 29.7^0C while mean monthly temperature drops to 22.2^0C in the month of December (Hill & Wall, 1978; Hazell, 1985).

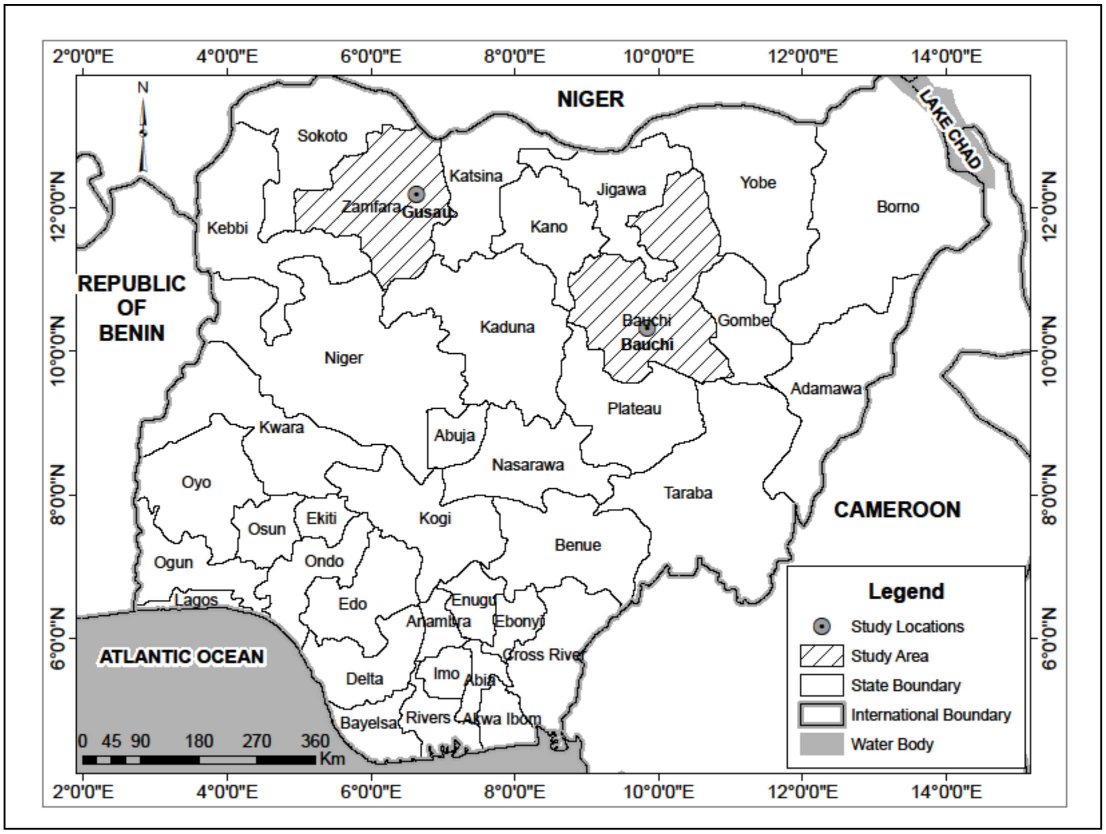

Fig. 1: Locations of Bauchi and Gusau

Bauchi and Gusau are underlain by the basement complex rocks of Northern Nigeria. The basement complex rocks are mostly made up of gneisses, migmatites and granites, with most of the area underlain by this rock characterized by a thin, discontinuous mantle of weathered rock (Du Preez & Barber, 1965).

Basement complex rocks are generally poor aquifers. The occurrence of groundwater depends on the thickness and extent of the decomposed mantle or the presence of joints and fractures in the fresh rock, with groundwater existing either in the weathered mantle or in the joints and fracture system in the unweathered rocks.

Study on the groundwater resources development of Bauchi State (Hazell, 1985) showed that the crystalline basement complex rocks have variable permeability, low water storage capacity, with the depth to water table in the weathered zone ranging from 3 to 18m, while the depth ranges between 25 and 40m where there are fractures and joints. According to Mustafa and Adamu as cited in Dike et al (2008), hydraulic conductivity of basement complex aquifers in Bauchi Town ranges between 0.09 and 0.46m/day, while transmissivity is less than $2m^2$/day. Average borehole depth is about 32m, with a yield of about 0.8m/s recorded in some parts of the metropolis. With regards to groundwater occurrence at Gusau, boreholes drilled into the pre-cretaceous crystalline rocks 23 miles from Gusau showed that the thin weathered veins made up of quartz fragments, sand and clay fillings were found to contain most of the exploitable water at depths ranging between 94 and 135 ft.

Data used for this study are rainfall and temperature data for the period 2000 to 2010. The data were obtained from the archives of the Nigerian Meteorological Agency (NIMET). Both datasets served inputs into the groundwater recharge equations. Two empirical methods were utilised in the estimation of groundwater recharge for this study. The first method was developed by Sinha and Sharma (1988). The method utilises rainfall as the only variable and it is applicable to semi-arid environments with rainfall greater than 380mm/year (Adelana et al., 2006). The formula as utilised in the works of Adelana et al (2006) is expressed as:

$$r = 50.8\ (p/25.4-15)^{0.4} \quad \ldots\ldots(1)$$

Where
r = Recharge
p = Precipitation
The second empirical method is based on Turc's (1954) empirical method for estimating recharge. The formula is expressed as:

$$r = P\ (1-[0.9+P^2/L^2]^{-0.5}) \quad \ldots\ldots(2)$$

Where
r = Annual average recharge (mm/yr)
p = Annual precipitation (mm/yr)
T = Mean annual temperature (^{0}C)

$$L= 300+25T+0.05T^2 \quad \ldots\ldots(3)$$

The two methods were adopted because empirical methods have been found to be useful in areas with inadequate hydrogeological data. Secondly, both methods were developed to estimate groundwater recharge in similar climatic and hydrogeological environments. Both methods were adopted as used in Adelana et al (2006), due to the similarities in environmental conditions, as Gusau and Bauchi are located in the same semi-arid region in which the Sokoto basin is located.

In order to determine the level of variability of annual rainfall and the estimated recharge over the 11-year study period, the coefficient of variability was used. This is expressed as:

$$CV\ (\%)\ \frac{\sigma}{\bar{X}} * 100 \quad \ldots\ldots (4)$$

where
σ = Standard deviation of the data series
$\bar{X}$ = Mean of the data series.
Levene's test was used to test the equality of variance between the recharge estimates derived from the two empirical methods. This is expressed as:

$$W = \frac{(N = (N - g)\ \sum_{k=1}^{g} n_k\ (Z_{k-}\ \bar{Z})^2}{(g - 1)\ \sum_{k=1}^{g} \sum_{k=1}^{n_k}\ (Z_{k_i} - \bar{Z}_K)^2} \quad \ldots\ldots (5)$$

Where

$$Z_{ki} = |Y_{ki} - Y_k| \quad \ldots\ldots (6)$$

$$\bar{Z}_k = \frac{1}{nk} \sum_{i=1}^{nk} Zki \quad \ldots\ldots (7)$$

$$\bar{Z} = \frac{1}{N} \sum_{k=1}^{g} \sum_{i=1}^{nk} Zki \quad \ldots\ldots (8)$$

$$\bar{Y}_k = \frac{1}{nk} \sum_{i=1}^{nk} Yki \quad \ldots\ldots (9)$$

Simple linear equation was used to predict the mean groundwater recharge for the study period. The equation of the simple linear regression is expressed as:

$$Y = (b_0 + b_1X_1) + \varepsilon_i \quad (10)$$

where

Y = Dependent variable predicted by regression model

b_0 = Intercept

b_1 = ith coefficient of X_i

X_i= ith independent variable from total set of q variables

ε_i = Random errors

RESULTS AND DISCUSSION

Recharge Estimates

The annual rainfall amount and the results of recharge estimates based on Sinha and Sharma (1988) and Turc (1954) for Bauchi and Gusau is as presented in Table 1.

Table 1: Annual Rainfall Amount and Recharge Estimates for Bauchi and Gusau

Year	Bauchi Annual Rainfall (mm)	Bauchi Recharge Estimates (mm)		Gusau Annual Rainfall (mm)	Gusau Recharge Estimates (mm)	
		Sinha and Sharma (Method 1)	Turc (Method 2)		Sinha and Sharma (Method 1)	Turc (Method 2)
2000	1058.9	188.98	320.95	862.1	208.28	194.58
2001	1300.8	213.36	501.46	732.8	145.29	125.24
2002	819.1	158.50	170.13	889.4	210.82	210.70
2003	989.5	180.85	263.40	1416.1	252.49	578.76
2004	865.5	165.1	188.07	755.4	197.10	129.78
2005	1034.5	186.44	292.97	920.3	172.21	220.23
2006	1017.9	184.40	281.96	961.8	217.42	236.12
2007	1136.9	197.61	376.54	615.8	181.86	69.52
2008	1133.1	197.10	361.23	954.0	216.41	271.70
2009	1531.3	261.62	674.23	1006.0	221.49	284.80
2010	1547.0	262.64	687.49	1035.9	224.03	283.11

For Bauchi the results of the natural groundwater recharge estimates based on method 1 (Sinha & Sharma, 1988) shows that the periods of highest and lowest recharge coincided with the period of highest and lowest annual rainfall amount. In 2010 when the highest annual rainfall amount of the series (1547mm) was recorded, the highest recharge estimate of 262.64mm was also computed. For the year 2002 when the lowest annual rainfall amount (819.1mm) of the series was recorded, the lowest recharge estimate of 158.50mm was also computed.

The results of the groundwater recharge estimation based on the second method (Turc, 1954) also shows that periods of highest and lowest annual average recharge estimates coincided with periods of highest and lowest annual rainfall. Year 2010 in which the highest annual rainfall of the series was recorded coincided with the year with the highest annual average groundwater recharge estimate of 687.49mm. Similarly, year 2002 when the lowest annual rainfall of the series was recorded coincided with the period of the lowest annual average recharge estimate of 170.13mm.

Furthermore, most of the estimated annual recharge based on Sinha and Sharma method (Fig.2) and Turc method (Fig.3) were below the 11-year mean of 199.7 mm and 374.4 mm respectively.

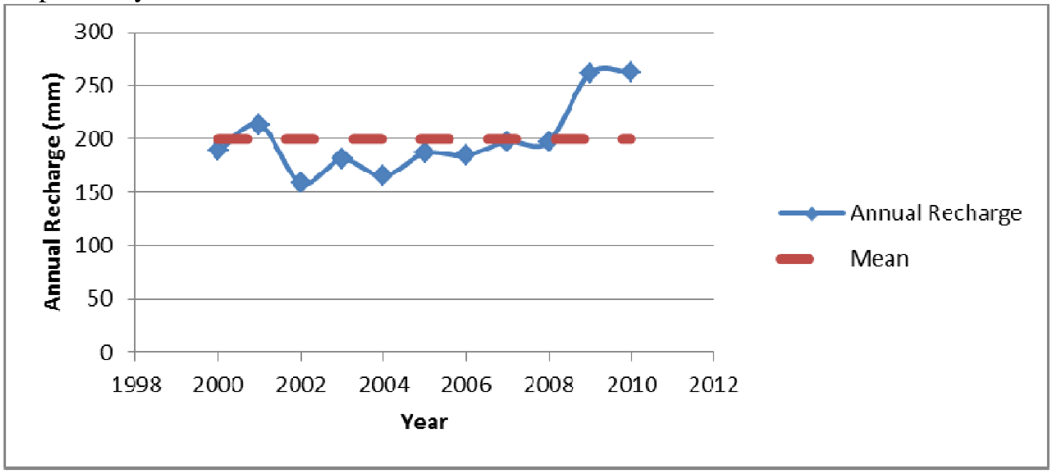

Fig.2: Annual and Long Term Mean of Recharge Estimate at Bauchi based on Sinha and Sharma Method

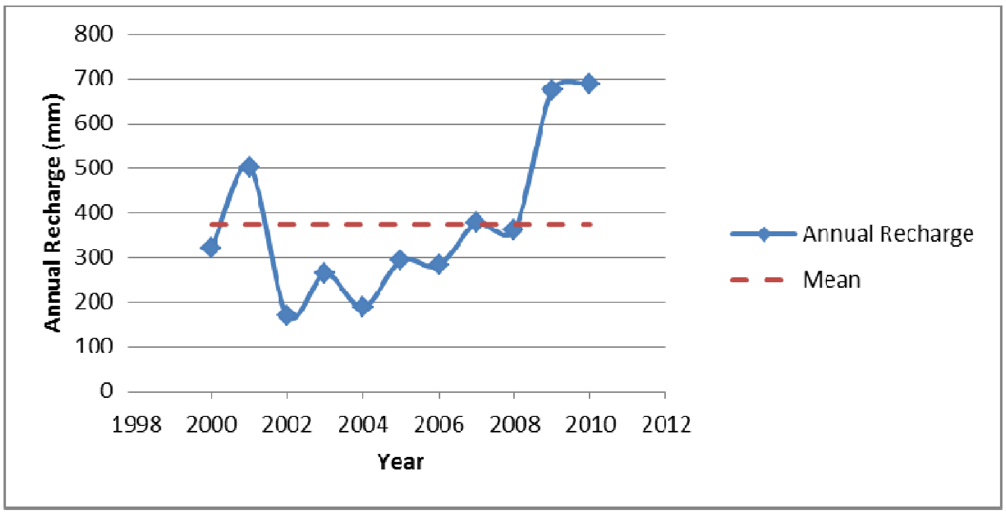

Fig.3: Annual and Long Term Mean of Recharge Estimate at Bauchi based on Turc Method

For Gusau, results of the recharge estimates based on method 1 show that the period with highest annual rainfall amount of the series (rainfall amount of 1416.1mm for 2003) coincided with the period of the highest annual recharge estimate of 252.49mm. On the other hand however, the period with the lowest annual rainfall of the series (615.8mm recorded in 2007) did not coincide with period of the lowest annual recharge estimate of 142.29mm which was computed for 2001. The year 2001 for which the lowest annual recharge estimate was computed coincided with the period with the second lowest annual rainfall of the series. High potential evapotranspiration may a contributive factor to the period of lowest annual rainfall not coinciding with the period for which lowest groundwater recharge was computed. For the second recharge method, periods of highest and lowest annual rainfall coincided with periods of highest and lowest annual average recharge estimates. Year 2003 in which the highest rainfall amount of the series was recorded coincided with the period of the highest annual average recharge estimate of 578.76mm. The same scenario was established for the period of lowest annual rainfall and lowest annual average recharge estimate. The period with

the lowest annual rainfall of the series (year 2007) coincided with the period with the lowest annual average recharge estimate of 69.52mm.
Comparison of the estimated annual recharge with the long term mean based on Sinhna and Sharma method shows that 7 out the 11 years had recharge estimates higher than the mean value of 204.3mm (Fig.4). For Turc method (Fig.5) an almost equal number of years had annual recharge estimates lower than and higher than the long term mean of 236.8mm.

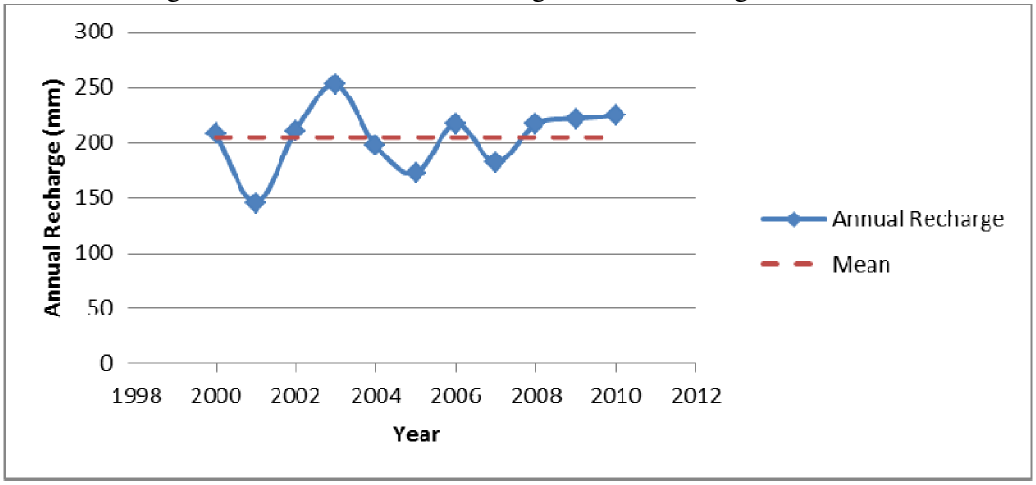

Fig.4: Annual and Long Term Mean of Recharge Estimate at Gusau based on Sinha and Sharma Method

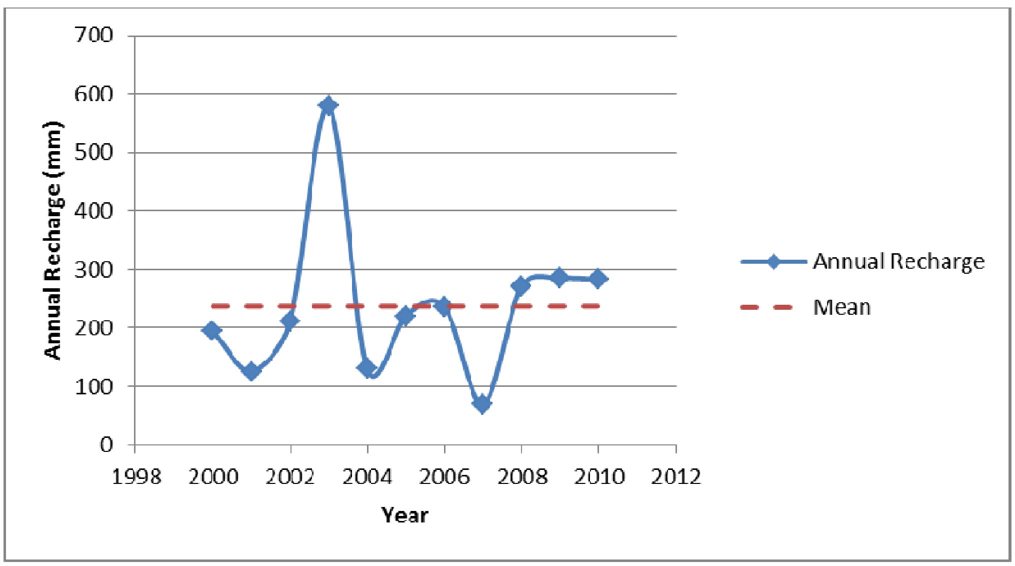

Fig.5: Annual and Long Term Mean of Recharge Estimate at Gusau based on Turc Method

Variability and Equality of Variance

The coefficient of variation for rainfall and recharge estimates for both locations is as presented in Table 2.

Table 2: Coefficient of Variation of Rainfall and Recharge Estimates

Location	Rainfall (mm)	Sinha and Sharma (Method 1)	Turc (Method 2)
Bauchi	21%	17 %	47%
Gusau	22%	14%	56%

As shown in the Table the CV for both locations based on the Turc method is much higher than coefficient of variation based on Sinha and Sharma method. This is an indication that CV derived based on Turc method is more variable. Due to the inherent variability of climatic and surface conditions, temporal variation of groundwater recharge occurs over different temporal scales. These variations are normal and they depict the dynamic balance between precipitation, infiltration, evaporation, transpiration, runoff, groundwater storage, withdrawal and base-flow discharge (Resse and Risser, 2010). Apart from these factors, drought, irrigation, agriculture and other forms of land use changes may also contribute to the temporal variation of recharge within the study locations.

The comparison of the CV of rainfall with CV of recharge estimates for both methods shows a closer relationship between rainfall and recharge estimate based on Sinha and Sharma method.Results of the Levene's test for equality of variance for Bauchi and Gusau are represented Tables 3 and 4 respectively.

Table 3: Levene's Test for Equality of Variance at Bauchi

		Levene Statistic	df1	df2	Sig.
Recharge	Based on Mean	11.462	1	20	.003
	Based on Median	7.032	1	20	.015
	Based on Median and with adjusted df	7.032	1	10.859	.023
	Based on trimmed mean	10.716	1	20	.004

Table 4: Levene's Test for Equality of Variance at Gusau

		Levene Statistic	df1	df2	Sig.
Recharge	Based on Mean	4.484	1	20	.047
	Based on Median	4.145	1	20	.055
	Based on Median and with adjusted df	4.145	1	10.824	.067
	Based on trimmed mean	4.240	1	20	.053

For Bauchi, $F(1, 20) = 11.46$, $P < 0.05$, where $P = 0.003$ and Gusau, $F(1, 20) = 4.48$, $P < 0.05$ where $P = 0.047$, the assumption of equality or homogeneity of variance has been violated , indicating that the variance of the recharge estimates obtained from Sinha and Sharma method, and those obtained from Turc method are significantly different from each other.

Regression Analysis

The results of the regression model for Bauchi based on annual rainfall and recharge estimates computed using the first empirical method is presented in Tables 5a to 5c, while the regression model obtained from annual rainfall and recharge estimates from the second empirical method is presented in Tables 6a to 6c.

As shown in Table 5a, R^2 equals 0.984 indicating that rainfall accounts for 98.4 percent of variation in natural groundwater recharge for the study period. Other factors that could be responsible for the variability include vegetation and soil properties. The F-ratio (552.799) in Table 5b is significant at $p < 0.01$ because the value in the column labeled sig (last column) is less than 0.01. This indicates that there is less than 1 percent chance that an F-ratio this large could be a chance occurrence, leading to the conclusion that the regression model results in significantly better prediction.

The value of b_0 (39.59) in Table 6c indicates that when there is no rainfall (when $X_i = 0$), the model predicts that recharge will be 39.59mm while the value of b_1 (Table 6c) which represents the gradient of the regression line indicates that if there is an increase in rainfall by 1mm, then the regression model predicts that recharge will increase by 0.142mm.

The mean rainfall value of 1,130.41mm and the regression equation $Y = (b_0 + b_1X_1) + \varepsilon_i$ was used to predict the mean recharge for the 11-year study period, When:
Y = Mean recharge for the 11-year period
b_0 = 39.59mm
b_i = 0.142mm
X_i = 1, 130.41mm
is expressed as:
Mean recharge = (39.59 + 0.142 x 1, 130.41) = 200.11mm

Table 5a: Summary of Regression Model

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.992[a]	.984	.982	4.57679

a. Predictors: (Constant), Rainfall

Table 5b: Analysis of Variance, Sums of Squares, F-Ratio and Associated Significance Value

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11579.488	1	11579.488	552.799	.000[a]
	Residual	188.523	9	20.947		
	Total	11768.011	10			

a. Predictors: (Constant), Rainfall
b. Dependent Variable: recharge

Table 5c: Beta Values of Regression Model

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	39.590	6.948		5.698	.000

Rainfall	.142	.006	.992	23.512	.000

a. Dependent Variable: recharge

With regards to the outcome of the regression model of annual rainfall and recharge estimates obtained from the second empirical method, Table 6a shows that rainfall accounts for 99 percent (R^2= 0.996) of the variation in groundwater recharge. Table 6b indicates that the F-ratio is significant at $P < 0.01$, while b_0 predicts that when there is no rainfall (when $X_i = 0$), the recharge value will be -453.70mm. Such negative value is however impossible in nature.

This is because during periods of rainfall cessation such as the dry season, natural groundwater recharge can occur from seepage from surface water bodies such as streams, lakes or ponds, irrigation return flow, inter-aquifer flows and urban recharge such as leaky water and sewage systems. b_i which is the slope of the regression line indicates that there will be an increase of 0.733mm in recharge for every 1mm increase in rainfall.

The prediction of the 11-year mean recharge based on a mean rainfall value of 1,130.41mm (ie X_i = 1, 130.41mm) and the regression equation $Y = (b_0 + b_1X_1) + \varepsilon_i$, when:
Y = Mean recharge for the 11-year period
b_0 = -453.70mm
b_i = 0.733mm
is expressed as:
Mean recharge = (-453.70 + 0.733 x 1, 130.41) = 374.89mm

Table 6a: Summary of Regression Model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.998[a]	.996	.996	11.80280

a. Predictors: (Constant), Rainfall

Table 6b: Analysis of Variance, Sums of Squares, F-Ratio and Associated Significance Value

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	309790.897	1	309790.897	2223.815	.000[a]
	Residual	1253.755	9	139.306		
	Total	311044.652	10			

a. Predictors: (Constant), Rainfall

b. Dependent Variable: Recharge

Table 6c: Beta Values of Regression Model

Coefficients[a]

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.

1	(Constant)	-453.700	17.917		-25.322	.000
	Rainfall	.733	.016	.998	47.157	.000

a. Dependent Variable: Recharge

The results of the regression model for Gusau based on annual rainfall and recharge estimates computed using the first empirical method is presented in Tables 7a to 7c, while the regression model obtained from annual rainfall and recharge estimates computed with the second empirical method is presented in Tables 8a to 8c.

As shown in Table 7a, the value of R^2 (0.616) indicates that rainfall accounts for 61.6 percent of the variation in natural groundwater recharge. The F-ratio (14.447) as shown in Table 7b is significant at $P < 0.01$ because the value 0.004 in the column labeled sig is less than 0.01. The value b_0 (102.612) in Table 8c indicates that when there is no rainfall (when $X_i = 0$), the model predicts a recharge of 102.62mm.The slope of the regression line (b_i) in Table 7c indicates that when there an increase of 1mm in rainfall, groundwater recharge will increase by 0.11mm.

The prediction of the 11-year mean recharge based on a mean rainfall value of 922.70mm (ie $X_i = 922.70$) and the regression equation $Y = (b_0 + b_1X_1) + \varepsilon_i$, when:
Y = Mean recharge for the 11-year period
$b_0 = 102.62$mm
$b_i = 0.11$mm
is expressed as:
Mean recharge = (102.62 + 0.11 x 922.70) = 204.12mm

Table 7a: Summary of Regression Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.785[a]	.616	.574	18.98552

a. Predictors: (Constant), Rainfall

Table 7b: Analysis of Variance, Sums of Squares, F-Ratio and Associated Significance Value

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5207.472	1	5207.472	14.447	.004[a]
	Residual	3244.051	9	360.450		
	Total	8451.523	10			

a. Predictors: (Constant), Rainfall

Table 7c: Beta Values of Regression Model

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	102.619	27.359		3.751	.005

Rainfall	.110	.029	.785	3.801	.004

a. Dependent Variable: Recharge

For the regression model of annual rainfall and recharge estimates obtained from the second empirical method, Table 8a indicates that rainfall accounts for 98 percent ($R^2 = 0.980$) of the variation in natural groundwater recharge for the study period. The F-ratio (448.948) in Table 8b is significant at $P < 0.01$ because the value 0.000 under the column labeled sig is lesser 0.01, while the value of b_0 predicts that when there is no rainfall (when $X_i = 0$), the recharge value will be -350.60mm. The negative value however, does not mean the cessation of recharge for reasons earlier explained. The value of b_i predicts that for every 1mm increase in rainfall, there will be a corresponding increase in recharge by 0.637mm.

The prediction of the 11-year mean recharge based on a mean rainfall value of 922.70mm (ie $X_i = 922.70$) and the regression equation $Y = (b_0 + b_1X_1) + \varepsilon_i$, when:
Y = Mean recharge for the 11-year period
$b_0 = -350.597$mm
$b_i = 0.637$mm
is expressed as:
Mean recharge = (-350.59 + 0.637 x 922.70) = 237.16mm

Table 8a: Summary of Regression Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.990[a]	.980	.978	19.67218

a. Predictors: (Constant), Rainfall

Table 8b: Analysis of Variance, Sums of Squares, F-Ratio and Associated Significance Value

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	173740.586	1	173740.586	448.948	.000[a]
	Residual	3482.953	9	386.995		
	Total	177223.540	10			

a. Predictors: (Constant), Rainfall

b. Dependent Variable: Recharge

Table 8c: Beta Values of Regression Model

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-350.597	28.349		-12.367	.000
	Rainfall	.637	.030	.990	21.188	.000

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-350.597	28.349		-12.367	.000
	Rainfall	.637	.030	.990	21.188	.000

a. Dependent Variable: Recharge

CONCLUSION AND RECOMMENDATION

The study has shown that empirical methods can be used as a plausible means of estimating groundwater recharge. The moderate (Sinha and Sharma Method) to high level (Turc Method) of variability as shown by the coefficient of variation is an indication that the variable nature of recharge should be given more consideration in the development of groundwater. This would help in preventing groundwater mining and ensure sustainable water use.

The study also showed through regression analysis that rainfall generally accounts for more than 90 percent of groundwater variation in the study locations. This therefore shows that statistical methods such as regression analysis can serve as a veritable means of predicting the rate of groundwater recharge.

Going by the results of this study, it is recommended that scientific and periodic assessments of groundwater resources potential should be embarked upon. Furthermore, more efforts should be aimed at water conservation through rain water harvesting in the wet season to reduce the level of reliance on groundwater.

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