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MODIFIED NUMERICAL FORMULA AND COST BENEFIT OF GROUNDWATER RECHARGE IN KANO NIGERIA

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ABSTRACT

In this study, the relationship between rainfall and groundwater recharge (GR) was established and evaluated with cost benefit. Rainfall data in Kano, Nigeria between 1905 and 2018 was analysed statistically and was used to fix the unknown constants of the modified numerical formula (NF) using Microsoft Excel Solver. The NF was used to estimate GR from the rainfall. Accuracy of the NF was evaluated statistically (relative error; the degree of accuracy, numerical reliability, Model of Selection Criterion (MSC) and Akaike Information Criterion (AIC)) and compared with standard formulae in use using field GR Uttar Pradesh (UP) as the reference GR. A basic cost benefit of GR was conducted using standard method.

The study showed that non parameter test of the rainfall data revealed that Mann- Whitney (U), Wilcoxon (W) and standardized index were 1532, 3878 and – 0.185 respectively. Sen's slope estimator of the rainfall data was 54.59 mm Yr^{-1}. GR estimated using the modified numerical formula was similar to GR using UP, Chaturvedi, Kumar and Seethapathi , Rao Islam, Amritsar and BhaHacharjee, but different in magnitude of GR. NF provided the lowest relative error of 0.006 %, the highest MSC of 15.94; the degree of accuracy of 99. 99 % and the lowest AIC of -486.64 with BhaHacharjee formula having highest relative error of 244.16%, the lowest MSC of -4.88; the degree of accuracy of -144.16 % and the highest AIC of 1881.0. The current average cost benefit of groundwater recharge in Kano was found to be 1034.28US \$ (₦377,512.4) $m^{-2}Yr^{-1}$. It is concluded that the modified numerical formula GR with minimum error and it is good tool in water resources management.

***Keywords**: Groundwater recharge, soil-moisture, numerical solution, Microsoft Excel Solver, Kano.*

INTRODUCTION

Groundwater is an essential natural resource for human life. It is one of the most treasured natural resources, which maintains human health, economic development and ecological diversity (Natarajan *et al.*, 2018). Groundwater has several inherent qualities (consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost, drought reliability, etc.). It has been reported that groundwater is an immensely significant and reliable source of water supplies in all climatic regions (Jumadi, 2015; Natarajan *et al.*, 2018). It has been documented that groundwater is emerging as an intimidating poverty alleviation tool, which can be delivered direct to poor communities more cheaper, quicker and easier than canal water (Jumadi, 2015, Umaru *et al.*, 2018; Natarajan *et al.*, 2018). It has been documented that there are 37 x 10^{9} m^{3} of freshwater out of which, 22% exists as groundwater. Groundwater constitutes about 97% of freshwater potentially available for human use (Natarajan *et al.*, 2018). It has been highlighted that excessive use and continued mismanagement of water resources due to increasing water supply and water demands by extravagant users have led to water shortages (Natarajan *et al.*, 2018, Umaru *et al.*, 2018). The only solution to maintain constant level groundwater is to recharge groundwater regularly. The groundwater recharge rate varies both spatially and temporally. It has been reported that the key factors influencing groundwater recharge include characteristics of the recharge beds, such as topography, land use and vegetation cover, existing soil moisture and the ability of the recharge beds and aquifer materials to capture and transmit water (Natarajan *et al.*, 2018). Interest in quantifying groundwater recharge rate has increased because of concerns that land use changes may reduce recharge and that ground water resources in some areas may not be sustainable during drought periods (Natarajan *et al.*, 2018). It is well established that there is a wide range of direct and indirect methods of estimating GR. The degree of approximation of these methods depends on different spatio-temporal scales (Scalon *et al.*, 2002, 2006, Qinghua *et al.*, 2016; Brian *et al.*, 2016). The methods of estimating GR include lysimeter measurements, soil moisture budgets and effective infiltration coefficients, as well as water table rise, tracer, Wells Water-table fluctuations, numerical method and remote sensing methods (Chandra, 1979, Andreo *et al.*, 2008, Dripps and Bradbury, 2010, Hartmann *et al.*, 2012, 2013; Seyed *et al.*, 2013, Umaru *et al.*, 2018). Kumar (2000) grouped the methods and the techniques of estimation of groundwater recharge into four groups as empirical methods; groundwater resource estimation; groundwater balance approach and soil moisture data based methods (Seyed *et al.*, 2013, Islam *et al.*, 2014, 2015).

The empirical methods are the following formulae such as modified Chaturvedi, Kumar and Seethapathi, UP and Rao formulae. Chaturvedi (1973) derived an empirical equation which expresses recharge as a function of annual precipitation as follows (Kumar and Seethapathi, 2002; Oke *et al.*, 2017):

$$R_r = 2.0(P-15)^{0.4} \quad (1)$$

where, R_r is the net recharge due to precipitation during the year (inches), and P is the annual precipitation (inches).

The Chaturvedi formula was restructured and modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified Chaturvedi (UP) form of the formula is as follows (Oke *et al.*, 2017):

$$R_r = 1.35(P-14)^{0.5} \quad (2)$$

Kumar and Seethapathi (2002) established an empirical relationship between groundwater recharge and the corresponding values of rainfall in the monsoon season using the non-linear regression formula as:

$$R_{rm} = 0.63(P_m - 15.28)^{0.76} \quad (3)$$

where, R_{rm} is the groundwater recharge from rainfall in monsoon season (inch), and P_m is the mean rainfall in monsoon season (inch).

Rao derived an empirical relationship to determine the groundwater recharge in limited climatological homogeneous areas as follows (Natarajan *et al.*, 2018, Oke *et al.*, 2017, Kung *et al.*, 2013):

$$R_r = K(R-X) \quad (4)$$

where, R_r is the recharge (mm); K is constant; R is the precipitation (mm), and X is the number of point rainfall. The following boundary empirical equations were applied to different parts of Karnataka as follows (Natarajan *et al.*, 2018):

R_r = 0.20 (P - 400); for regions with annual normal rainfall (P) between 400 and 600 mm;
R_r = 0.25 (P - 400); for zones with P between 600 and 1000 mm
R_r = 0.35 (P - 600); for regions with P above 2000 mm.

Seyed *et al.* (2013) developed empirical relationship between recharge and the corresponding values of rainfall and wind speed (W_s) at 1-meter as follows:

$$R_r = 5.377 + 0.071P \quad (5)$$

$$R_r = 5.170 + 0.072P + 0.014W_s \quad (6)$$

In Islam *et al.* (2013), empirical relationship between recharge and the corresponding values of rainfall was expressed. The relationship is as follows:

$$R_r = 0.85(P-27.51)^{0.56} \quad (7)$$

Other groundwater recharge formulae found in literature are as follows (Natarajan *et al.*, 2018):

Amritsar formula (in inches)

$$R_r = 2.5(P-16)^{0.500} \quad (8)$$

BhaHacharjee formula (in cm)

$$R_r = 3.47(P-38)^{0.400} \quad (9)$$

More information on groundwater recharge methods can be found Kung *et al.* (2013) , Rana and Ray (2014), Adeleke *et al.* (2015), Islam *et al.* (2015), Sabri *et al.* (2015), Oke *et al.* (2015, 2016, 2017), Natarajan *et al* (2018), Ala-aho *et al.* (2015) Asani *et al.* (2019) and Umar *et al.* (2018). In summary, a general and non-linear regression formula that relates rainfall to groundwater recharge can be expressed as follows:

$$R_{gr} = A((P - B))^c \quad (10)$$

where, R_{gr} is the groundwater recharge (mm); A, B and c are the constants for the formula and P is the depth of rainfall (mm). The general and non-linear regression formula was proposed based on Natarajan *et al.*(2018), Ala-aho *et al.*(2015); Asani *et al.* (2019); Oke *et al.* (2015, 2016, 2017).

Estimating groundwater recharge in Nigeria has been a difficult issue. The key factors responsible for this difficult issue comprise of the paucity of data, non-availability of mathematical and numerical formulae applicable in the country. Literature stressed the prominence of groundwater recharge in the national development and economics (Natarajan *et al.*, 2018, Ala-aho *et al.*, 2015; Asani *et al.*, 2019). These discoveries show that there is the necessity to develop a numerical formula for groundwater recharge in Nigeria and evaluate the formula. The key objective of this study, therefore, is to advance numerical formula for groundwater recharge that will be applicable in Kano, and evaluate its accuracy using relative error; total error; degree of accuracy, numerical reliability, Model of Selection Criterion (MSC) and Akaike Information Criterion (AIC).

MATERIALS AND METHODS

Rainfall data between 1905 and 2018 for Kano, Nigeria was obtained from Akintola (1986) and Nigerian Meteorological Agency (NiMet) meteorological station. The rainfall data were analysed using statistical methods (Non- Parameter tests, sequence analysis, standardised index, Sen's slope estimator and consistency test). The data were used to calculate the groundwater recharge from rainfall using UP empirical formulae. The constants in the adopted general formula (A, B and c) were determined using Microsoft Excel Solver. Microsoft Excel Solver was selected based on availability (at no additional cost) and accuracy in numerical solutions. This numerical formula was used to compute groundwater recharge from the rainfall in Kano. Accuracy of the numerical formula was evaluated using analysis of variance (ANOVA), relative error; Model of Selection Criterion (MSC) and Akaike Information Criterion (AIC) and compared with selected numerical formula such as as Rao, Chaturvedi , Kumar and Seethapathi , Islam, Amritsar and BhaHacharjee formulae. Relationship between rainfall and groundwater recharge estimated was established and annual groundwater recharge cost benefit was computed using formula from TetraTech (2016). Procedures employed in the computations of formulae's constants using Microsoft Excel Solver are as follows (Umaru *et al.*, 2018, Idi-Mohammed *et al.*, 2019):

- Microsoft Excel Solver was added in on the toolbar of **M**icrosoft Excel;
- Target (limit) value of the iteration was set for the software based on square of difference as:

$$\left[\sum_{t=1}^{n} R_t - \sum_{t=1}^{n} A\left(P_t - B\right)^{c}\right]^{2} = 0 \qquad (11)$$

- Changing cells of the iterations were selected, number of iterations, degree of accuracy and maximum time for the iteration were set for the software to meet the target; and the iteration started through Microsoft Excel Solver (figure 1).

The model of selection criterion (MSC) is interpreted as the proportion of expected groundwater recharge variation that can be explained by the obtained groundwater recharge. Higher the value of MSC indicates higher the accuracy, validity and the good fitness of the method. MSC can be computed using equation (12) as follows (Oke *et al.*, 2017, Umaru *et al.*, 2018):

$$MSC = \ln \frac{\sum_{i=1}^{n}\left(Y_{obsi} - \overline{Y}_{obs}\right)^{2}}{\sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^{2}} - \frac{2p}{n} \qquad (12)$$

where, Y_{obsi} is the groundwater recharge estimated using UP formula; $\overline{Y}_{obs}$ is the average groundwater recharge estimated using UP formula; p is the total number of fixed constants to be estimated in the equation; n is the total number of groundwater recharge estimated, and Y_{cali} is the groundwater recharge estimated using modified model equation. The AIC was derived from the Information Criterion of Akaike (1976). It allows a direct comparison among models with a different number of constants. The AIC presents the information on a given set of constant estimates by relating the coefficient of determination to the number of constants. The AIC and relative errors (RErr) were determined using equations (13 and 14 respectively) as follows:

$$AIC = n\left(\ln \sum_{i=1}^{n}\left(Y_{obsi} - Y_{cali}\right)^{2}\right) + 2p \qquad (13)$$

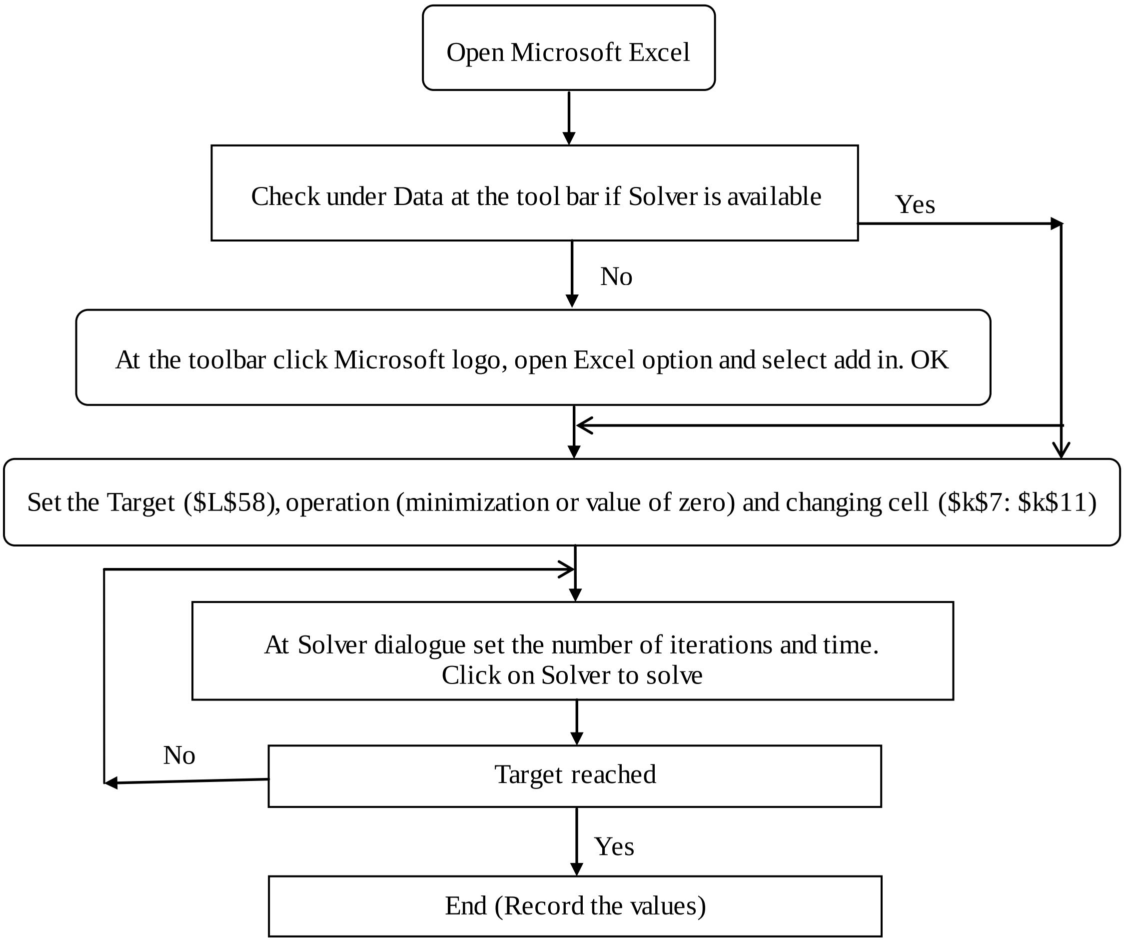

Figure 1: Procedure for using Microsoft Excel Solver in the computation of the constants (Oke *et al.*, 2017, Umaru *et al.*, 2018)

$$REerr(\%) = \frac{\sum_{i=1}^{n} 100\left(\frac{Y_{obsi}-Y_{cali}}{Y_{obsi}}\right)}{n} \qquad (14)$$

The average per unit present value of groundwater recharge benefit is calculated as follows:

Annual cost benefit of groundwater recharge was computed as follows (assuming that 365 Nigerian Naira (₦) is equivalent to 1 US$, TetraTech, (2016):

$$AV_{gr} = P_{gr}\left(\frac{i(1+r)^t}{(1+i)^t-1}\right)\sum_{i=1}^{n} R_i \qquad (15)$$

where, AV_{gr} is the annual cost benefit of groundwater recharge ($ m $^{-2}$), P_{gr} is the average per unit present value of groundwater recharge benefit ($/m^2), t is the number of year (2018 as the base year, t = X – 2018), R_i is the monthly groundwater recharge, n is the number of month, r is the likely inflation rate per year (13.5 %) and i is the interest rate per year (25 %). The average per unit present value of groundwater recharge benefit is calculated as follows:

$$P_{gr} = B_d\left(\frac{(1+r)^t}{(1+i)^t}\right) \qquad (16)$$

where, P_{gr} is the average per unit present cost of groundwater recharge benefit ($/m^2), and B_d is the cost benefit = cost of treated bottled water per m^2

$$= \frac{cost\ \ of\ \ treated\ \ bottled}{surface\ area\ of\ the\ container}$$

RESULTS AND DISCUSSION

Rainfall and Statistical Evaluation: Figure 2 presents results of sequence plot, spectral density and spectral analysis of the rainfall respectively. Figure 2a reveals that magnitude of annual rainfall in Kano varies with the year. The magnitude of the annual rainfall was higher in recent years (2014 to 2018). Figure 2b presents periodogram of the annual rainfall. Periodogram of greater than 2 x 10^5 contribute to frequency more than 0.9 out of 1.0, which indicates that more portion of the rainfall were above annual average. Figure 2c presents spectral density of the annual rainfall. Figure 3 presents monthly and annual rainfall in Kano. From the figure (Figure 3a) the monthly rainfall varied with the month as well as the year (Figure 3b). Figure 3a indicated that heavy rainfall season in Kano starts from May and ends in the month of September every year. Tables 1 and 2 show the summary of Analysis of Variance (ANOVA) computed for the monthly and annual rainfalls respectively. The table (Table 1) revealed that there was significant difference between the monthly rainfalls within the year at 95% confidence level ($F_{113,1243}$ = 1.75, p = 5.14 x 10 $^{-06}$). The table (Table 1) also revealed that there was significant difference between the patterns of the monthly rainfall in Kano ($F_{113,\ 1243}$ = 485.61, $p < 0.05$). Table 3 revealed that there was no significant difference between total amounts of annual rainfall at 95 % confidence level ($F_{113,\ 1243}$ = 0.064, $p > 0.05$).

Table 4 revealed that there was significant difference between total amount of rainfall within the months of September and October at 95 % confidence level ($F_{1,\ 226}$ = 1665.46, $p < 0.05$). These two tables revealed that there were months without heavy rainfall and there were months with heavy rainfall, but the total amount of rainfall in these years were not significantly different.

Standard Anomaly Index (SAI): It provides an area average index of relative rainfall yield based on the standardization of rainfall totals. It was calculated as follows:

$$Z = \frac{X_i - \overline{X}}{SD} \qquad (17)$$

where X_i; X and *SD* are the rainfall at time i, mean rainfall and standard deviation of the entire series respectively.

Sen's Estimator: It is well known that if a linear trend is present in a time series (Equation 8), then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968b). The slope estimates of N pairs of data are first computed as follows:

$$f(t) = Q(t) + \beta \qquad (18)$$

$$Q_I = \frac{X_j - X_k}{j-k} \qquad (19)$$

Non parameter test revealed that Mann - Whitney (U), Wilcoxon (W) and standardized index were 1532, 3878 and – 0.185 respectively. Sen's slope estimator was 54.59 mm Yr^{-1}.

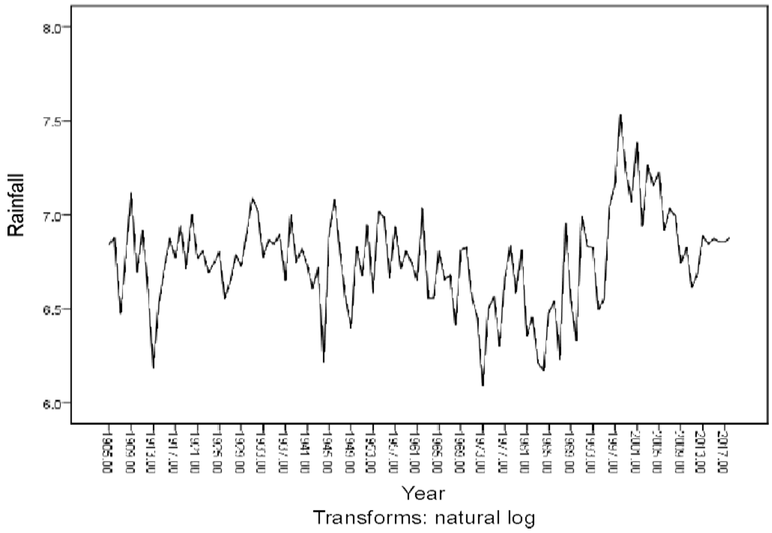

Figure 2a: Sequence plot of rainfall

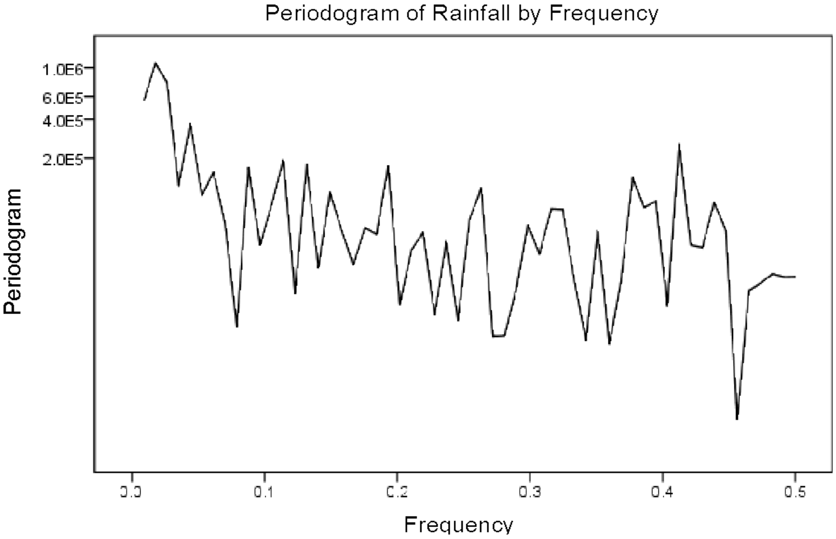

Figure 2b: Spectral analysis periodogram of rainfall by frequency

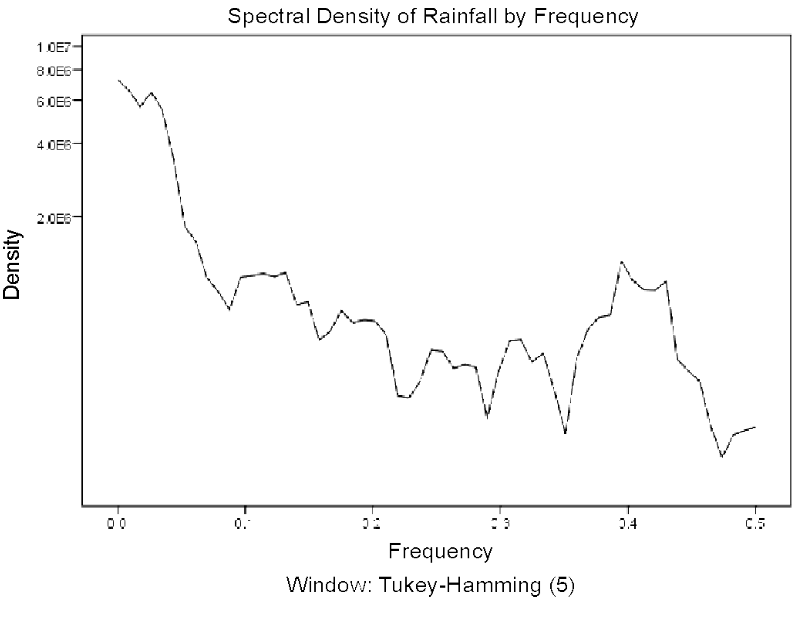

Figure 2c: Spectral density of rainfall by frequency

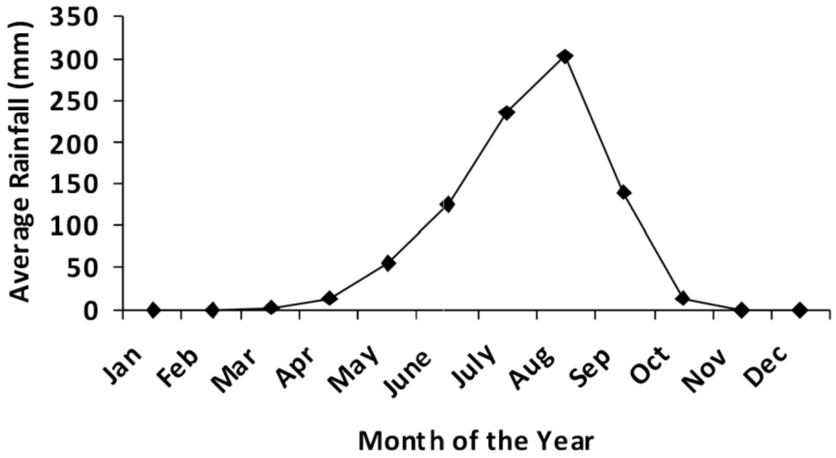

Figure 3a: Distribution analysis of average rainfall

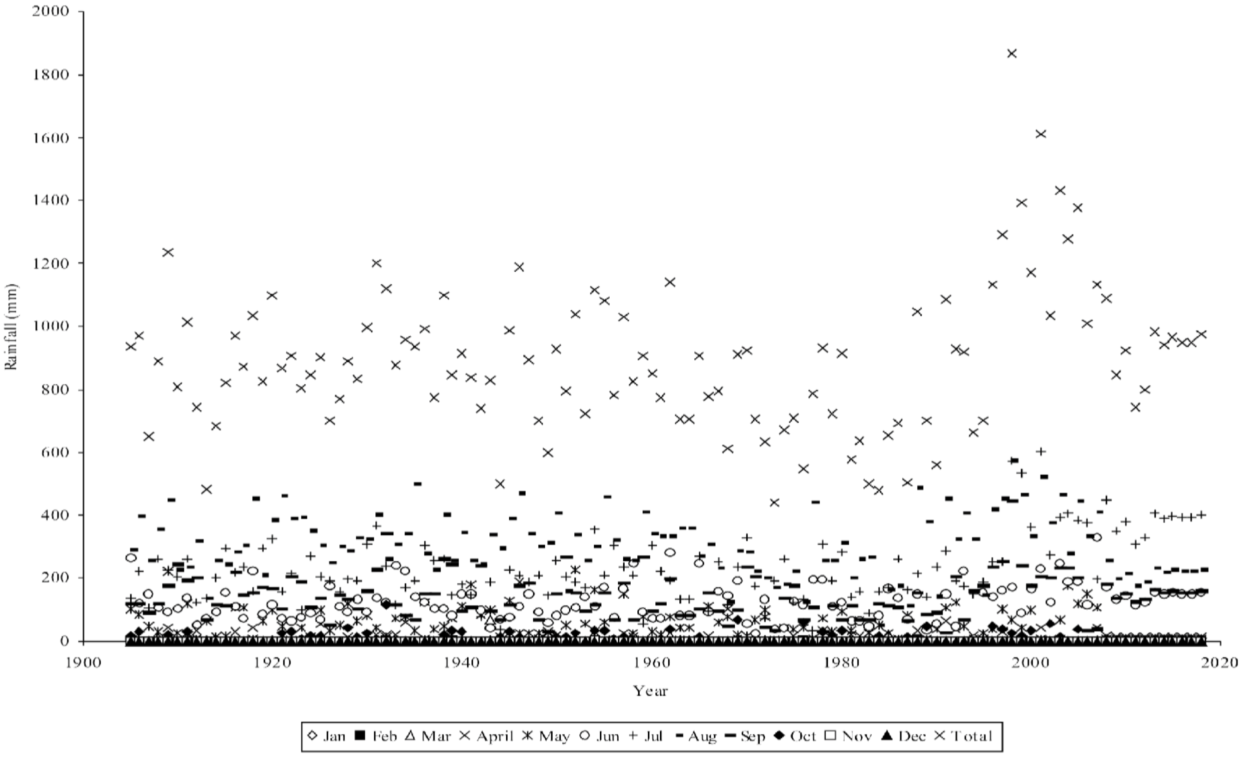

Figure 3b: Rainfall in Kano, Nigeria over a period of 114 years

Table 1: ANOVA of the monthly rainfall in Kano over a period of 114 years

Source of variation	Sum of squares	Degree of freedom	Mean sum of square	F- value	P-value
Years	510147.6	113	4514.581	1.754221	5.14 x 10 $^{-06}$
Months	13747160	11	1249742	485.6096	0.0000
Error	3198926	1243	2573.553		
Total	17456234	1367			

Table 2: ANOVA of the frequency of rainfall in Kano over a period of 114 years

Source of variation	Sum of squares	Degree of freedom	Mean sum of Square	F- value	P-value
Within the months	285846.9	11	25986.08	16.97653	1.21×10^{-05}
Between the months	18368.48	12	1530.706		
Error	304215.4	23			

Table 3: ANOVA of the frequency of rainfall in Kano over a period of 114 years

Source of variation	Sum of squares	Degree of freedom	Mean sum of square	F- value	P-value
Within the years	3060886	113	27087.48	0.064101	1.000
Between the years	48173858	114	422577.7		
Error	51234744	227			

Table 4: ANOVA of the total of rainfall in Kano over a period of 114 years

Source of variation	Sum of squares	Degree of freedom	Mean sum of square	F- value	P-value
Within the two months	45112973	1	45112973	1665.455	3.1×10^{-106}
Between the months	6121771	226	27087.48		
Error	51234744	227			

The Numerical Formula: The numerical formula for groundwater recharge in Kano is as presented in equation (20). The constants were A = 6.824; B = 355.920 and c = 0. 500. This indicates that the numerical formula for groundwater recharge can be expressed as follows:

$$R_{gr} = 6.824(P - 355.920)^{0.500} \tag{20}$$

In Lukman *et al.* (2018), the numerical formula for groundwater recharge in Katsina is as presented in equation (21). The constants were A = 6.809; B = 355.646 and c = 0. 500. This indicates that the numerical formula for groundwater recharge can be expressed as follows:

$$R_{gr} = 6.809(P - 355.646)^{0.500} \tag{21}$$

This result shows that the numerical formula is similar to formulae in literature such as Seyed *et al. (*2013); Islam *et al.* (2014); Ala-aho *et al.* (2015); Oke *et al.* (2016, 2017) and Natarajan *et al.* (2018), but different in the magnitude of the constants. Idi-Mohammed *et al.* (2019) expressed relationship between rainfall and ground water recharge in Maiduguri as follows:

$$R_{gr} = 6.758(P - 354.891)^{0.501} \tag{22}$$

Umar *et al.* (2019) expressed relationship between rainfall and ground water recharge in Ibadan as follows:

$$R_{gr} = 6.821((P - 356.152))^{0.500} \tag{23}$$

Seyed *et al.* (2013) describes relationship between rainfall and groundwater recharge in tropical zone (Selangor, Malaysia) as follows:

$$R_{gr} = 5.377 + 0.071P \tag{24}$$

$$R_{gr} = 5.3170 + 0.072P + 0.014w_s \tag{25}$$

where, w_s is the wind speed and P is the rainfall.
Israil *et al.* (2016) presents relationship between groundwater recharge and electrical resistivity of the soil was provided as:

$$R_{gr} = 24.655x + 129.47 \tag{26}$$

where, x is the electrical resistivity of the soil

Oke *et al.* (2016) documented that relationship between rainfall and field groundwater recharge in Abeokuta and Ikeja, Nigeria as follows (using water balance method):

$$R_{gr} = 0.15P - 102.8 \text{ , and} \tag{27}$$

$$R_{gr} = 0.320P - 258 \text{ .} \tag{28}$$

From Oke *et al.* (2016) correlation coefficients (R) for Abeokuta (equation (27)) and Ikeja (equation (28)) were 0.180 and 0.393 respectively.

In Oke *et al.* (2017), the numerical formula for field groundwater recharge using water balance method for

Abeokuta is presented in equation (29). The constants were $A = 1.673$; $B = 7.219$ and $c = 0.672$ with square correlation coefficient of 0.9981between rainfall and groundwater recharge. This result indicated that the numerical formula for groundwater recharge has a good relationship with rainfall and can be written as follows:

$$R_{gr} = 1.673\left(\left(P - 7.219\right)\right)^{0.672}. \tag{29}$$

In Umar *et al.*, (2018), the constants are $A = 0.621$; $B = 1.019$ and $c = 0.814$. This formula indicates that groundwater recharge in Yola, Nigeria using rainfall only can be expressed as follows:

$$R_{gr} = 0.621\left(\left(P - 1.019\right)\right)^{0.814}. \tag{30}$$

Lukman *et al.* (2018) developed numerical formula that relates rainfall to groundwater recharge in Sokoto, Nigera as follows: $R_{gr} = 6.814(P - 355.722)^{0.500}$ (31)

In Asani *et al.* (2019), the numerical formula for groundwater recharge in Ilorin, Nigeria is as presented in equation (32). The constants were A = 6.821; B = 356.153 and c = 0. 500. The results indicated that the numerical formula for estimating groundwater recharge in Ilorin from rainfall can be written as follows:

$$R_{gr} = 6.821\left(\left(P - 356.153\right)\right)^{0.500} \tag{32}$$

These results revealed that no numerical formula has the same constant, which indicates that the formulae have different constants and the formulae are not expected to provide the same magnitude of the groundwater recharge.

Groundwater Recharges: Figure 4 presents the statistical summary of groundwater recharges using the modified formula and other (as Rao, UP, Chaturvedi , Kumar and Seethapathi , Islam, Amritsar and BhaHacharjee) formulae that are in use. The Figure 4 revealed that groundwater recharge using the Rao formula had the lowest minimum and the mean in all the cases, while groundwater using the BhaHacharjee 's formula had the highest maximum and the mean in all the cases. The Figure 4 also revealed that the lowest standard deviation came from Chaturvedi formula in all the case, while the highest standard deviation came from BhaHacharjee's formula. The result indicates that variation in the groundwater recharge was higher in BhaHacharjee formula than any other formula. The highest median came from BhaHacharjee formula, and the lowest median came from BhaHacharjee formula. The result observed in term of median indicates that BhaHacharjee formula gave a higher value of groundwater recharge than other formulae. The study also revealed that the modified numerical formula provides the least variation in all cases. Two empirical formulae exhibit some similarities and closeness. The two empirical formulae are the numerical formula, and Chaturvedi formulae. The Figure 4 shows that the groundwater recharges vary with the empirical formulae used. Table 5 presents results and summary of statistical analysis conducted using ANOVA. This result indicates that accuracy of these formulae is not the same. Analysis of variance of this groundwater recharges revealed that there were significant differences between the groundwater recharges within the formulae ($F_{7,791} = 7192.387$, $p < 0.05$) and within the year ($F_{113,791} = 54.694$, $p = 1.29 \times 10^{-305}$) at 99% confidence level.

Performance Evaluation of the Numerical Formula: Table 6 presents the performance evaluation of the formulae. The Table revealed that the BhaHacharjee formula had the lowest MSC and accuracy, the highest AIC and errors (relative error, total and root square errors) . From Table 6, it is revealed that the highest MSC and accuracy; lowest errors (total, relative and root square) and AIC are from the modified numerical formula. Chaturvedi was the next to the numerical formula with lower MSC, higher AIC and errors compared to modified formula, which indicates that the numerical formula is accurate followed by Chaturvedi. A slight reduction in the accuracy of these two formulae may be attributed to the development of the formula (Chaturvedi) as an imperial unit formulae and conversion from imperial unit to system international unit. There are two empirical formulae that exhibit some similarities and closeness. The two empirical formulae are the modified formula and Chaturvedi formula. Table 6 shows that the computed MSC were lower for two formulae (Amritsar and BhaHacharjee formulae), which indicates that utilization of these two formulae in the groundwater recharge should be at the lowest level.

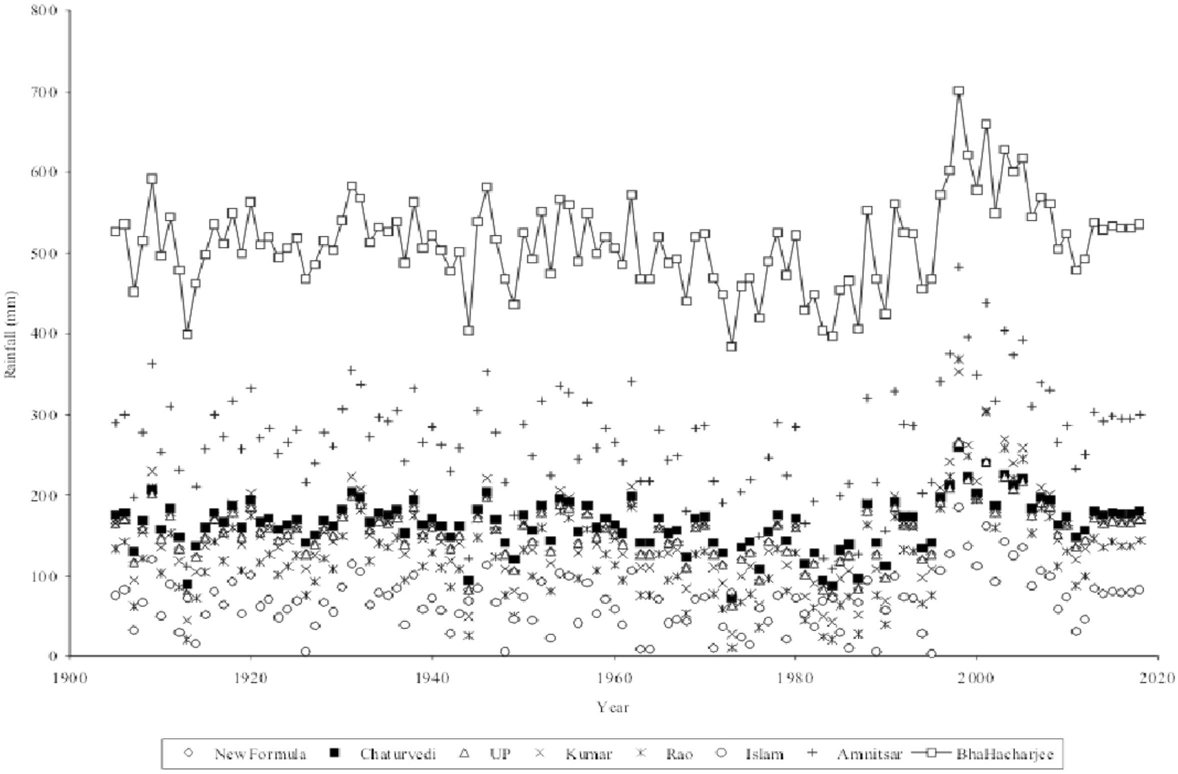

Figure 4: Estimated groundwater recharge using various numerical formulae

Table 5: ANOVA of the groundwater recharges (Maiduguri)

Source of Variation	Sum of squares	Degree of freedom	Mean sum of square	F- value	*P*-value
Years	1864023.87	113	16495.79	54.69366	1.2932E-305
Methods	15184730.4	7	2169247	7192.387	0
Error	238568.17	791	301.6032		
Total	17287322.4	911			

Table 6: Results of statistical evaluations of the formulae

	Modified formula	Chaturvedi	Kumar and seethapathi	Rao	Islam	Amnitsar	BhaHacharjee
Relative error (%)	0.006	7.72	10.87	26.98	57.18	73.36	244.16
Total error	0.013	13937.81	45814.17	180898.14	905349.28	1638879.79	14650995.19
Root square error	1.17E-04	122.26	401.88	1586.83	7941.66	14376.14	128517.50
AIC	-486.637	1093.83	1229.49	1386.05	1569.63	1637.29	1887.00
MSC	15.942	2.08	0.89	-0.49	-2.10	-2.69	-4.88

Relationship between Rainfall and Groundwater recharge: Figures 5 and 6 show numerical relationships between rainfall and groundwater recharge from Kano and cost benefit of groundwater recharge respectively (linear with interaction was selected based on previous studies Umar *et al.*, 2018). From the figure correlation factor between rainfall and groundwater recharge were 0.145, 0.1328, 0.1456, 0.2315, 0. 250, 0.1237, 0.2874 and 0.2348 for modified formula, Chaturvedi, UP, Kumar and Seethapathi, Rao, Islam, Amritsar and BhaHacharjee formulae respectively. Coefficient of determination (R^2) of for the two relationships were 0.9668, 0.9449, 0.9670 , 0.9913, 1.000, 0.7003, 0.9556 and 0.9829 for the modified formula, Chaturvedi, UP, Kumar and Seethapathi, Rao, Islam, Amritsar and BhaHacharjee formulae respectively. These results indicate that the correlation between these to parameters were good and fair for these two relationships (Loveday, 1980). These Coefficients of determinations revealed that the relationship is of linear with intercept. Figure 6 presents annual cost benefit of groundwater recharge. From the figure, it can be seen that annual cost benefit of the process varies with the years. These results indicate that larger rainfall, higher surface area and regular rainfall provides higher cost benefit of groundwater recharge. The average annual cost benefit was 1034.28US $ (₦377,512.4) $m^{-2}Yr^{-1}$.

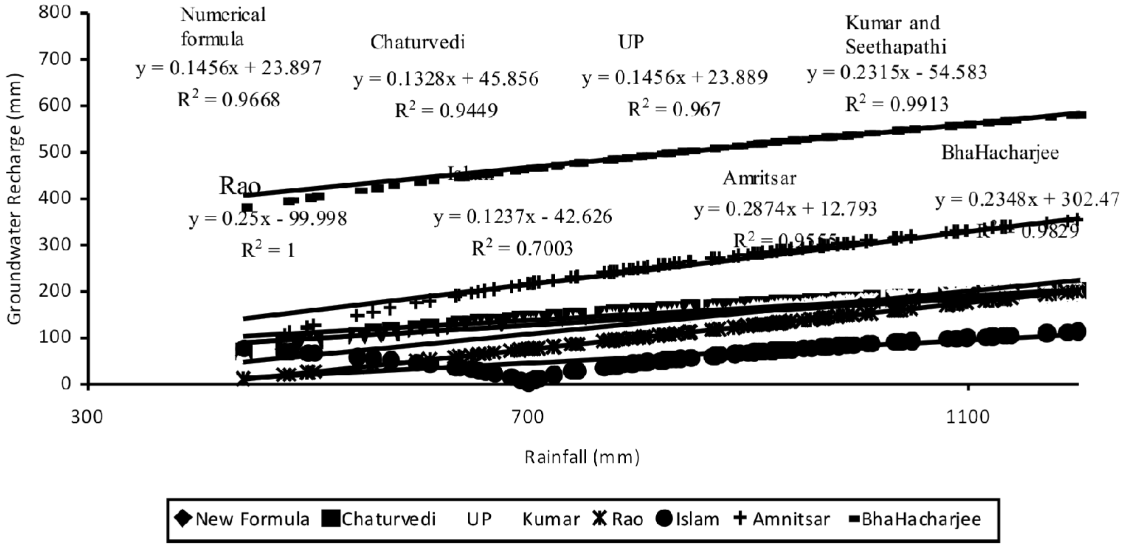

Figure 5: Relationship between rainfall and groundwater recharge using various formulae

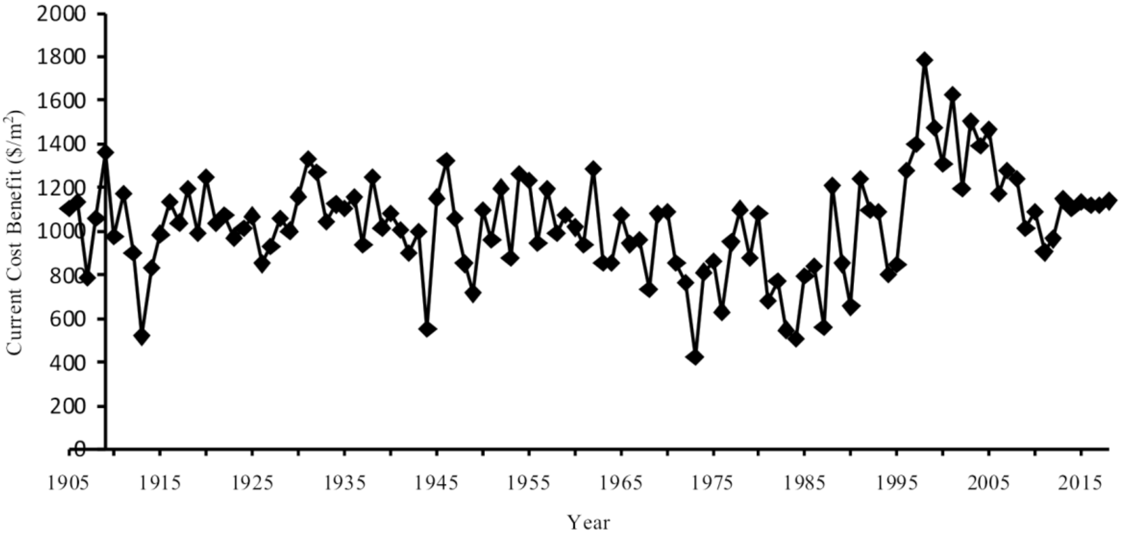

Figure 6: Cost benefit of the groundwater recharge

CONCLUSIONS

It can be concluded that:

a. The numerical formula and other empirical formulae correlate positively with rainfall,
b. Modified numerical formula, Chaturvedi, UP, Kumar and Seethapathi, Rao, Islam, Amritsar and BhaHacharjee formulae gave different groundwater recharges,
c. Performance evaluation of the formulae revealed that care should be taken in the use of Amritsar and BhaHacharjee formulae based on the value of MSC, AIC and their accuracies, and
d. Modified numerical formula is among the best tools for groundwater recharge estimate based on MSC, AIC and relative error.

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