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ASSESSMENT OF NATURAL GROUNDWATER RECHARGE IN TUDUN WADA LOCAL GOVERNMENT KANO STATE, NIGERIA

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ABSTRACT

Water is important natural resources on earth which cater for all human endeavors. Estimation of groundwater recharge is an essential for efficient groundwater resources management. This research entails the assessment of natural groundwater recharge in Tudun Wada Kano, Nigeria. This study carried out on 2015 attempted to derive an empirical relationship to determine the groundwater recharge from rainfall in Tudun Wada based on seasonal groundwater balance using data from 2002 to 2013. This 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 techniques. The variance was found to be 29.50 %, and the recharge of groundwater commences at P = 15.28 inches and the relative errors was found to range from 0.95 to 28.43%.

Keywords: groundwater; rainfall; recharge; wet season; water balance; empirical relation.

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1. INTRODUCTION

Groundwater is among the most important natural resources to human activities which are extracted from the ground. The amount of water extracted without causing depletion in groundwater, depend upon the nature of the aquifer and the groundwater recharge of the area. Rainfall is the fundamental source of groundwater recharge, the amount of recharge depends upon the nature of rainfall, the duration it takes, regional site, nature of soil, the antecedent soil moisture and usually the depth to the water table. When rain falls, during the wet period the amount of water moves as moisture in the unsaturated zone which were controlled by suction pressure, hydraulic conductivity, moisture content and gravity will fill the saturated zone after passing the water table is termed as "groundwater recharge". Recharge has been defined as the process of addition of water to the saturated zone.

It is very important to estimate the rate of aquifer replenishment but is the most difficult task to measure without a number of errors. Recharge estimation has no reliable techniques that will lead to the accurate results; however it can be based on a wide variety of models which are formulated to represent the actual physical processes. The most commonly methods use for estimation of natural groundwater recharge include groundwater balance method, soil water balance method, zero flux plane method, one dimensional soil water flow model and inverse modeling techniques and isotopes and solute profile techniques [1].

1.1. Natural Groundwater Recharges Estimation in Nigeria

In Nigeria, rainfall is the most reliable source for groundwater recharge. The most commonly used methods for estimation of natural groundwater recharge in Nigeria are groundwater level fluctuation method, Empirical Method and Chloride Mass Balance (CMB). According to the studies carried out by different scientist and organizations in some part of the world including the countries with same tropical equatorial nature with Nigeria such as Malaysia, used to derived a correlation for groundwater level fluctuation and rainfall, some empirical relationship have been derived for computation of natural recharge to groundwater from rainfall.

Chlorine Mass Balance used to estimate the natural groundwater recharge in the North Kelantan River catchment, the result illustrated that estimate of deep percolation using CMB method range from 17 to 30% of precipitation (between 475 and 769 mm/yr.) in the study area [2]. In [1] assessed the natural groundwater in Upper Ganga Canal Command Area in which an Empirical relationship was used to determine groundwater recharge from rainfall in the study area based upon the seasonal groundwater balance study carried out for a number of years [1]. Sayeed estimate groundwater recharge using Empirical method in the tropical zone (Selangor Malaysia) in which the groundwater recharge coefficient and effective rainfall were determined. The results showed that groundwater recharge was 326.39 mm per year; and recharge coefficient was found to be 18% for the study area. However, to the best of the author's knowledge, there had been no similar work or even any related work carried out in survey area. Earlier works done in the study area are not related such as excavation of numerous boreholes and Dam [3]. In this paper, an attempt has been made to assess and derived an empirical relationship to determine groundwater recharge from rainfall in Tudun Wada Kano, Nigeria based upon seasonal groundwater balance study carried out for a year 2002 to 2013. This present research will help the government and individual people to manage their water resources due to rapid increases in population and agricultural entities within the study area [4-6].

2. METHODOLOGY

2.1. Study Area

Tudun Wada local government Kano State, Nigeria is located at 110151N latitude and 80241E longitude; covering a total area of 1,204km^2 (465 sq. mi) with a population of 281,742 as for 2006 census. The area experiences a tropical climate having rainy and dry seasons. Rainy season begins in April/May and ends mostly in October while dry season prevails for the rest of the year. The mean annual rainfall is 785mm with a relative humidity ranges from 20-70% and the mean annual temperature varies from 21^{0}C to 27^{0}C [7]. The geology of the area comprises three groups of rocks namely migmatites and gneisses, derived from Birr main and sedimentary rocks through high grade metamorphism and granitization [8]. As Tudun Wada is one of the 44 local government of Kano State, Nigeria indicates that the aquifers of the basement complex area of Kano State are the weathered and fractured rocks in which groundwater exist under water table condition, which lies at a depth generally less than 20m and the maximum depth of boreholes rarely exceeds 60m [9]. The hydraulic conductivity of the aquifer ranges from 0.039 to 0.778m/d with an average of 0.0330m/d.

With respect to the hydro-geologic, the aquifers in Tudun Wada are generally overlaid by igneous rock, metamorphic rock and some consolidated alluvium layer which is built of clay mixed with sand in some areas especially near the river area. The main limestone is found in the southeast of the town and at the northeast. The center of the town is consisting of granite and some metamorphic rocks. In the southwest was limestone as the major overlaid in all the basements [10-12].

2.2. Model Design and Sensitivity

Estimation of parameters is subject to a degree of uncertainty which is associated with the conceptual model, data and parameters for to be observed [13]. Uncertainty estimation is dealt with calibration and estimation procedures and may be affected by uncertainty due to weakness in determining the exact parameter, either by inadequate or inappropriate spatial and temporal distribution of the observed data and boundary conditions.

2.3. Chaturvedi Formula

Based on the water level fluctuations and rainfall amounts in India (Ganga Yamuna), Chaturvedi derived an empirical relation in 1936 to arrive at the recharge as a function of annual precipitation.

$$R = 2.0(P - 15)0.4 \quad (1)$$

where R = net recharge due to precipitation during the year in inch and P = annual precipitation in inch. This formula was later modified by further work at U.P Irrigation Research Institute as:

$$R = 1.35\,(P - 14)05 \quad (2)$$

And it is now used for estimation of groundwater recharge due to rainfall worldwide. According to this relation, it may be noted that there is lower limit of the rainfall below which the recharge due to rainfall is zero. Therefore the percentage of rainfall recharge will be from zero at P = 14 inches to 18% at P = 28 inches and can also decreases. In this formula, the lower limit account for the runoff, soil moisture deficit, interception and evaporation losses. This is also applicable to a certain limit of the study area depending on the nature of the soil.

2.4. Groundwater Balance Method

The impact of man activities in hydrologic cycle and the quantitative estimates of water resources are very essential and can be done by water balance techniques. This water balance approach can be used to make a quantitative evaluation of water resources and its dynamic behavior under the influence of human activities [14-16]. Water balance refers to the ways in which an organism maintains water in dry or hot conditions. The study of water balance is defined as the systematics presentation of data on the supply and use of water within a geographical region for a specified period [1]. The basic component of water balance is:

$$\text{Input to the system} - \text{Output from the system}$$
$$= \text{Change in storage of the system over a period of time.}$$

The inflow and outflow component for groundwater balance equation at a time Δt is given by:

$$\mathrm{Ri} + \mathrm{Rc} + \mathrm{Rr} + \mathrm{Rt} + \mathrm{Si} + \mathrm{Ig} = \mathrm{Et} + \mathrm{Tp} + \mathrm{Se} + \mathrm{Og} + \Delta\mathrm{s} \quad (3)$$

where Ri =Recharge from field irrigation; Rc = Recharge from canal seepage; Rr = Recharge from rainfall; Rt = Recharge from tanks; Si = Influent seepage from river; Ig = Inflow from other basin; Et =Evapotranspiration; Tp =Draft from groundwater; Se = Effluent seepage to rivers; Og = Outflow to other basin and Δs = Change in groundwater storage.

Equation (3) is a suitable method for groundwater balance estimation, especially in an unconfined aquifer where the boundaries of an area of the studies do not represent stream line. However, the lateral inflow and outflow (Ig andOg) of the groundwater crossing the area boundaries will be accounted in the balance equation [2]. Also, specific yield Sy is one of the factors influencing the changes in water table of the area in which fluctuation is occurring. It has been observed that Sy changes with the change in depth of the water table especially in the shallow areas in which the water tables is less than 3 meters deep. In this area when the water table drops some part of it will retained by the soil particles and when the water rises, air can be trapped in the vicinity that are filling with water. However, Sy for rising water is generally less than that of falling water table. Wherever possible, all the elements of the water balance equation are computed using independent methods, even though some errors most occur in due processes because of the shortcomings in the techniques used. The water balance equations mostly do not balance even if all the elements are computed using independent methods. The discrepancy of water balance is taking as a residual terms of the water balance equation and will be included in the estimation of the values of components which are not taken into account. However, obtained impossible to compute the value of a balance component, the component may be evaluated as a residual term in the water balance equation.

In the study area, water balance can be computed for any time interval because most of the rainfall occurs in a part of year. It is desirable to conduct water balance study for wet period and dry period. In such situation, the study will be from time of maximum water table elevation to the time of minimum water table elevation as the dry period. And at the time for maximum water table to the time of minimum water table elevation in a wet period as well. In Tudun Wada Kano, Nigeria, the rainiest period can be taken from April to October and all the rest of months will be a moderate or dry period. Therefore, it is more preferable to use a complete data for a cycle covering from wet and dry year. Equation (3) is very essential in covering both the area of study and the period for which the balance is assessed. In area like the study area in which the wet season come with heavy and moderate rainfall, the water balance approach is the most suitable method to be applied in assessing the water balance study and is more preferable to computed the season separately (wet and dry season) by the following steps:

i- Years must to be divided into wet and dry period.

ii- The components of the water balance equation other than rainfall recharge for wet period must to be estimated using the available hydrological and meteorological data and employing the subsequent methods for estimation.

iii- The rainfall recharge and recharge coefficient will be estimated and the estimates in (ii) above must to be substituted in water balance equation and hence, this estimate with those given by other empirical relations will be compared.

iv- For dry period, all the components of water balance equation including the rainfall recharge which calculated using recharge coefficient value obtained through the water balance of monsoon season will be estimated. The rainfall recharge will be very small in this case. The balance between the left and the right sides of the equation will indicate that the overall recharge from all the sources of recharge and discharge has been quantified with a good degree of accuracy.

3. RESULTS AND DISCUSSION

3.1. Determination of Natural Groundwater Recharge

When the rain falls on the ground and percolated into the soil, part of it will be used to fill the soil moisture deficiency while the remaining moves to the water table. The part of the rain infiltrate and reaches the water table is called recharge from rainfall to the aquifer, it is depend upon hydro-meteorological and topographic factors such as soil texture; depth to the water table; vegetation and urbanization [17-19]. The groundwater balance for the study area was carried out seasonally, for wet seasons which occur in April and usually ends in October and for dry season occur between Novembers to March. The data used covered from 2002 to 2013 and followed the essential steps of [1]. The components of groundwater balance equation with the exception of rainfall recharge were estimated using various hydrological and meteorological information and techniques. The rainfall recharge for monsoon seasons of these years of study was computed by substituting these estimates in the groundwater balance equation [20-21]. Table 1 shows the rainfall recharge in wet seasons of all the study years as well as the recharge coefficients.

Table 1. Groundwater recharge from rainfall

S/N	Year	Mean Rainfall in Wet Season (inch)	Groundwater Recharge from Rainfall in Wet Season (inch)	Recharge Coefficient
1	2002	29.45	5.80	0.20
2	2003	35.24	6.50	0.18
3	2004	33.98	5.90	0.17
4	2005	24.50	4.60	0.19
5	2006	21.80	3.11	0.14
6	2007	28.37	4.30	0.15
7	2008	33.22	5.19	0.16
8	2009	22.80	4.08	0.18
9	2010	27.33	4.22	0.15
10	2011	25.91	4.03	0.16
11	2012	31.83	4.83	0.15
12	2013	28.03	4.24	0.15

From Table 1, it was observed that the recharge coefficient varies from 0.14 to 0.20 and was calculated as the ratio of recharge by rainfall against rainfall in monsoon season (recharge/rainfall ratio) [22-24]. It is also indicated that rainfall gives almost equal recharge to the groundwater with a slight different from the year 2002 to 2013 in Tudun Wada Kano, Nigeria. The recharge is not linearly proportional but most of the years with high rainfall have high recharge [25]. The years that have low recharge (2006) also have lower rainfall. For dry seasons, unaccounted water was calculated using the relation as (inflow-outflow-change in groundwater storage), the discrepancy was found to be less than 60 Million Cubic Meters in all the cases of the study area of area of 1,204km^2 (465 sq. mi) and the total population of 281,742 (as for census, 2006) and the total quantity of water involved, this is a reasonable unaccounted water. Therefore, overall water balance has to be considered to avoid all errors [26-28]. The empirical relationship similar to Chaturvedi formula was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the wet season through the non-linear regression techniques.

$$R = 0.63\,(P - 15.28)0.76 \quad (4)$$

where $R =$ Groundwater recharge from rainfall in wet season (inch) and $P =$ Mean rainfall in wet season (inch).

The proposed relationship above explained the percentage of variance as 29.50%, and the recharge to groundwater at P = 15.28 inch shows that the lowest recharge was found to be 2.62 in the year 2006. The table 2 above explained the relative errors (%) in the estimation of rainfall recharge from the proposed empirical relationship in comparison with water balance study. Using this relation it was found that the relative error values range from 0.95 to 28.43, but for the Chaturvedi formula (Equation (1) and Equation (2)) the relative errors were almost has the same values with the result above with a slight differences as indicated in (Table 3).

Table 2. Relative errors with proposed relationship

S/N	Year	Mean Wet Rainfall P (inch)	Rainfall Recharge During the Wet Season, R (inch)		Relative Error (%)
			Groundwater Balance Study	Proposed Relationship $R = 0.63(P-15.28)^{0.76}$	
1	2002	29.45	5.80	4.72	18.62
2	2003	35.24	6.50	6.13	5.69
3	2004	33.98	5.90	5.83	1.19
4	2005	24.50	4.60	3.41	25.87
5	2006	21.80	3.11	2.62	15.76
6	2007	28.37	4.30	4.45	3.49
7	2008	33.22	5.19	5.65	8.86
8	2009	22.80	4.08	2.92	28.43
9	2010	27.33	4.22	4.18	0.95
10	2011	25.91	4.03	3.80	5.71
11	2012	31.83	4.83	5.32	10.14
12	2013	28.03	4.24	4.36	2.83

Table 3. Relative errors with Chaturvedi formula

S/N	Year	Mean Wet Rainfall, P (inch)	Rainfall Recharge from Groundwater Balance Study (inch)	Chaturvedi Formula $R = 2.0(P-15)^{0.4}$		Modified Chaturvedi Formula $R = 1.35(P-14)^{0.5}$	
				Rainfall Recharge (inch)	Relative Error (%)	Rainfall Recharge (inch)	Relative Error (%)
1	2002	29.45	5.80	5.82	0.34	5.31	8.45
2	2003	35.24	6.50	6.66	2.46	6.22	4.31
3	2004	33.98	5.90	6.49	10.00	6.03	2.20
4	2005	24.50	4.60	4.92	6.96	4.37	5.00
5	2006	21.80	3.11	4.31	38.59	3.77	21.22
6	2007	28.37	4.30	5.64	31.16	5.12	19.07
7	2008	33.22	5.19	6.39	23.12	5.92	14.07
8	2009	22.80	4.08	4.55	11.52	4.00	2.00
9	2010	27.33	4.22	5.46	29.38	4.93	16.82
10	2011	25.91	4.03	5.20	29.03	4.66	15.63
11	2012	31.83	4.83	6.19	28.16	5.70	18.01
12	2013	28.03	4.24	5.58	31.60	5.06	19.34

4. CONCLUSION

Water balance approach is a good method for assessing the natural groundwater recharge from rainfall. In the present study Empirical relationship has been suggested for estimation of the groundwater recharge from rainfall with a reasonable accuracy. The result for the analysis was found to be reasonable and important as seen in the above paragraph. Therefore for a quick assessment of natural groundwater recharge, the Equation (4) above is more appropriate especially in a tropical region such as the study area.

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6. REFERENCES

[1] Kumar C P, Seethapathi P V. Assessment of natural groundwater recharge in Upper Ganga Canal command area. Journal of Applied Hydrology, 2002, 15(4):13-20

[2] Saghravani S F, Azhari A. Simulation of clear water local scour around a group of bridge piers using an Eulerian 3D, two-phase model. Progress in Computational Fluid Dynamics, 2012, 12(5):333-341

[3] Saghravani S R, Yusoff I, Mustapha S, Saghravani S F. Estimation of groundwater using Empirical method: A case study in the tropical zone. Sains Malaysiana, 2013, 42(5):553-560

[4] Glover C R. Irrigation water classification systems. Las Cruces: New Mexico State University, 1993

[5] Kamaruddin A F, Toriman M E, Juahir H, Zain S M, Rahman M N, Kamarudin M K, Azid A. Spatial characterization and identification sources of pollution using multivariate analysis at Terengganu river basin, Malaysia. Jurnal Teknologi, 2015, 77(1):269-273

[6] Iranmanesh A, Ii R A, Wimmer B T. Multivariate statistical evaluation of groundwater compliance data from the Illinois Basin-Decatur Project. Energy Procedia, 2014, 63:3182-3194

[7] Sha'Ato R, Aboho S Y, Oketunde F O, Eneji I S, Unazi G, Agwa S. Survey of solid waste generation and composition in a rapidly growing urban area in Central Nigeria. Waste Management, 2007, 27(3):352-358

[8] McCurry P. A general review of the geology of the Precambrian to Lower Palaeozoic rocks of northern Nigeria. In C. A. Kogbe (Ed.), Geology of Nigeria. Lagos: Elizabethan Publishing Company, 1989, pp. 13-37

[9] Mohammed S. E. A. Stochastic functional differential equations. Boston: Pitman Advanced Publishing Program, 1984

[10] Bosch J. H. A. The quaternary deposits in the coastal plains of Peninsular Malaysia. Kuala Lumpur: Geological Survey of Malaysia, 1984

[11] Gopinath S, Srinivasamoorthy K. Application of Geophysical and hydrogeochemical tracers to investigate salinisation sources in Nagapatinam and Karaikal Coastal Aquifers, South India. Aquatic Procedia, 2015, 4:65-71

[12] Hairoma N, Gasim M B, Azid A, Muhamad H, Sulaiman N H, Khairuddin Z, Mustafa A D, Azaman F, Amran M A. saltwater intrusion analysis in east coast of Terengganu using multivariate analysis. Malaysian Journal of Analytical Sciences, 2016, 20(5):1225-1232

[13] Zhu C. Estimate of recharge from radiocarbon dating of groundwater and numerical flow and transport modeling. Water Resources Research, 2000, 36(9):2607-2620

[14] Gasim M B, Toriman M E, Idris M, Lun P I, Kamarudin M K, Azlina A N, Mokhtar M, Mastura S S. River flow conditions and dynamic state analysis of Pahang River. American Journal of Applied Sciences, 2013, 10(1):42-57

[15] Ismail A, Toriman M E, Juahir H, Zain S M, Habir N L, Retnam A, Kamaruddin M K, Umar R, Azid A. Spatial assessment and source identification of heavy metals pollution in surface water using several chemometric techniques. Marine Pollution Bulletin, 2016, 106(1):292-300

[16] Elbeih S F. An overview of integrated remote sensing and GIS for groundwater mapping in Egypt. Ain Shams Engineering Journal, 2015, 6(1):1-5

[17] Ahmad N N, Hossain D M. Climate change and global warming discourses and disclosures in the corporate annual reports: A study on the Malaysian companies. Procedia-Social and Behavioral Sciences, 2015, 172:246-253

[18] Gasim M B, Azid A, Hairoma N, Yaakub N, Muhamad H, Azaman F, Wahab N A. Study on selected parameters of groundwater quality based on different tides, east coast of Terengganu, Malaysia. Asian Journal of Applied Sciences, 2017, 10(1):18-24

[19] Toriman M E, Gasim M B, Ariffin N H, Muhamad H, Hairoma N. The influence of tidal activities on hydrologic variables of Marang River, Terengganu, Malaysia. Malaysian Journal of Analytical Sciences, 2015, 19(5):1099-1108

[20] Abdullahi M G, Toriman M E, Gasim M B, Juahir H. Rainfall dyanamics of Terengganu Malaysia and its recent trends analysis using Mann-Kendal Test. Journal of Advances in Biotechnology, 2014, 4(2):372-381

[21] Gasim M B, Surif S, Mokhtar M, Toriman M E, Rahim S, Bee C H. Analisis banjir disember 2006: Tumpuan di kawasan bandar Segamat, Johor. Sains Malaysiana, 2010, 39(3):353-361

[22] Chaturvedi R S. A note on the investigation of ground water resources in western districts of Uttar Pradesh. Annual Report, Uttar Pradesh: UP Irrigation Research Institute, 1973, pp. 86-122

[23] Hashemi H, Berndtsson R, Kompani-Zare M, Persson M. Natural vs. artificial groundwater recharge, quantification through inverse modeling. Hydrology and Earth System Sciences, 2013, 17(2):637-650

[24] Jyrkama M I, Sykes J F, Normani S D. Recharge estimation for transient ground water modeling. Groundwater, 2002, 40(6):638-648

[25] Rushton K R, Ward C. The estimation of groundwater recharge. Journal of Hydrology, 1979, 41(3):345-361

[26] Sanford W. Recharge and groundwater models: An overview. Hydrogeology Journal, 2002, 10(1):110-120

[27] Saghravani S R, Yusoff I, Othman Z, Wan M T W Z. Estimation of natural groundwater recharge using chlorine mass balance in the north Kelantan River catchment. In 8th Mathematics and Physical Sciences Graduate Congress, 2012, pp. 45-51

[28] Todd D. K., Mays L. W. Groundwater hydrology. New Jersey: Wiley, 2005

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