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Assessment of Groundwater Recharge in Semi-Arid Region of Northern-Nigeria: Using Soil Moisture Deficit Method

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Abstract: Groundwater recharge into the water table aquifers in the semi arid region of Nigeria was estimated using soil moisture deficit method. Three sites representing the major geological basins of the area were used based on available data. The results show that the average annual value range from 169 mm for Maiduguri to 837 mm in Kano area. Recharge coefficient for the zone was found to range from 0.26-0.56. The month of August accounted for about 53% of the average annual estimate. Drought effect was evaluated by a comparison with the results obtained during the drought period of 1974-1983. It was found that about 69 mm (70%) of average annual potential natural groundwater recharge was lost as one of the adverse impacts of drought in the area. The study provides information that can be used for modeling and management of groundwater in the area.

Key words: Groundwater recharge, soil moisture deficit, semi arid, Nigeria

INTRODUCTION

Groundwater is a vital component of the water resources of many regions of the world, particularly in semi-arid climates, where it is often the only source of supply during the dry season. Management of this resource in a sustainable way depends on reliable estimate of groundwater recharge (Finch, 1999; Kumar, 1993).

The semi arid zone of Northern Nigeria lies within Latitudes 10°N and 14°N and Longitudes 3°E and 15°E. It is a region with great potentials for large-scale economic development due to warm temperatures and bountiful resources including farmlands, minerals and thermal energy (Schoneich and Askira, 1987; Adelana *et al*., 2003). The entire region (Fig. 1) is primarily oriented towards subsistence and extensive agriculture and animal husbandry. Naturally, this should be rainfall dependant, but failures in rainfall have some times triggered off famine in some areas resulting in emergency sales of livestock. The infrequent and short duration of rainfall, less than 60 days, in most places has made water availability as one of the primary restrictive factors of economic development of livestock and land resources in the area. Agriculture is also threatened by the encroachments of desert condition into the area as reported by Thambyahpillay (1987) and Mustafa and Babatola (1989).

According to Robins (1999), the provision of adequate supplies of safe drinking water is a priority throughout most Africa. In most of the rural and semi-urban areas, it is groundwater that provides the only affordable means of meeting their livestock and domestic demands. The ability of groundwater to supply reliable, good quality water makes it the preferred source in most part of Nigeria. According to Ndubuisi and Ujuanbi (2006), the evaporation rates of one exceptionally hot and dry season in Sokoto, Kano and Borno States of Nigeria may be sufficient to reduce the surface water bodies to very low levels. However, after the rivers, streams and ponds in the area have dried up, groundwater can still be accessed through wells, springs and boreholes.

The principal and most affordable mode of exploitation of groundwater is through large diameter dug wells, tapping the phreatic aquifers. Thus, every year, additional wells are dug or existing wells are deepened. This trend of increase in exploitation has not posed any serious problem for groundwater management as yet. However, if it is to continue in the same fashion, it is feared that it may lead to a serious depletion of groundwater reserves, especially during drought period (Alaku, 1991; Mbagiorgu, 1991). This will lower the water table and increase the energy cost for drawing or pumping out the water and may result in scarcity. This forces people, often women and children, to walk long distances in search of alternative sources for drinking water. This leads to out break of diarrheas, cholera, dysentery and loss of lives as reported during the 1971-1982 Sahelian drought in Nigeria by Thambyaphillay (1987) and

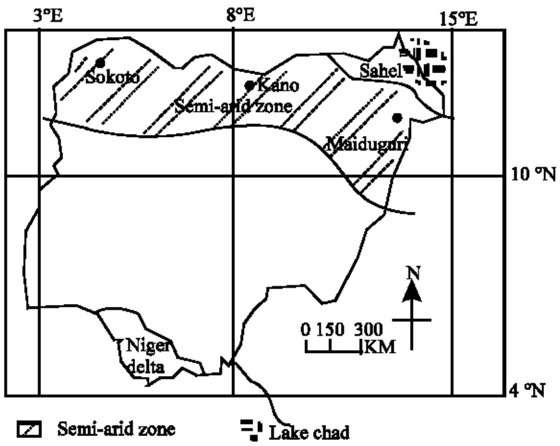

Fig. 1: Map of Nigeria indicating the study area

Mustafa and Babatola (1989) and the 1988-1992 drought that affected Malawi, Zimbabwe and parts of South Africa (Robins, 1999). Management of this resource in a sustainable way depends on reliable and current estimate of groundwater recharge. As reported by Olasehinde *et al.* (2001), there is insufficient information on groundwater recharge in the various seasons in the past and recent in the arid and semi arid regions of Nigeria.

Hence, the present investigation has been undertaken with the objective of estimating the amount of groundwater recharge and to compare the results with the past so that the effect of drought can be determined.

MATERIALS AND METHODS

Many methods are available in literature for estimation of recharge. These include: The hydraulic method, Iysimeter method, the isotope tracer method and the soil moisture balance method. In this study the Soil Moisture Deficit (SMD) model, as proposed by Ruston and Ward (1979) and modified by Odijie and Anyaeche (1991) and Ndubuisi (2005), was used to estimate the incidence of groundwater recharge. The choice was in view of its reliability and cost effectiveness.

The method uses daily time step to compute recharge (RECH) from rainfall after satisfying the Soil Moisture Deficit (SMD), Evapotranspiration (PE) and surface Runoff (RO) demands. Thus in the model recharge is calculated as the balance when direct surface runoff (RO), evapo-transpiration (PE) have be deducted from precipitation. It is usually expressed by the following basic equation:

$$\Delta S = P1 - PE - RO \qquad (1)$$

Where: P1 = Precipitation (mm), PE = Potential evapo-transpiration (mm), RO = Runoff (mm), ΔS = change in storage. Negative value of ΔS represents an increase in soil moisture deficit and positive values indicate potential recharge.

Basically the possibility of recharge depends on the SMD. This can assume four states, as follows:

A : SMD = 0
B : $0 \leq SMD \leq RC$
C : $RC \leq SMD \leq D$
Da : SMD = D

Where RC = Root constant and D = maximum soil moisture deficit.

Odijie and Anyaeche (1991) gave details on the model and method for estimating its parameters. The computer programme developed by Ndubuisi (2005) was adopted and applied. Drought effect was estimated by comparison between the values for the years 2001 to 2003 and that for 1974-1983.

The study area covers three major geological basins namely, the Iullemmeden (Olasehinde *et al.*, 2001; Oteze 1989, 1975); weathered basement rocks (Jones and Benson, 1991) or the Hadejia-Jamare (Ezigbo and Ogbukagu, 1991) and the Chad basin (Bumba *et al* .,1991; Ndubuisi, 2001). It is difficult to find a single area within the region that can represent the multifarious meteorological, vegetation and soil conditions. Therefore, the present investigation was carried out using data for selected stations representing each of the three major catchments basins. Thus available data for Sokoto, Kano and maiduguri (Fig. 1) were used for the Iullemmeden, Hadejia-Jamare and Chad Basins respectively. The daily rainfall (P1) and Evaporation (PE) data for the year 2001-2003 were obtained from the Nigerian meteorological Agency, Oshhodi and Lagos. The data for 1960- 1965 was obtained from Odijie and Olu (1985) and 1974-1983 from Odijie and Anyaeche (1991).

RESULTS AND DISCUSSION

The monthly and annual estimates from the study are presented in Table 1 (a-c). Table 2 shows summary of the monthly values of recharge. From Table1, the average annual recharges (TRECH) for the selected stations are 764.9mm for Sokoto, 837.0mm for Kano and 169.0 mm for maiduguri. The annual estimate is about 31.8% of the average annual rainfall for Sokoto area; 55.5% in Kano area and 26.3% for Maiduguri and environs. Therefore the ratio of recharge to rainfall, or recharge coefficient as suggested by Williams and Lawrence (1980), ranges from 26-56% for the study area. The higher coefficient for Kano may be attributed to relatively higher precipitation and lower Actual Evapotraspiration (APE) during the period of study.

Table 1a: Summary of Monthly Results for Kano (2001-2003)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Average
2001														
RECH=	0	0	0	0	0	14.08	494.74	468.29	141.33	0	0	0	1118.44	93.203333
AAE	0	0	0	14.85	9.68	142.11	129.25	85.25	101.86	4.34	0	0	487.34	40.611667
DR=	0	0	0	6.04	1.65	37.5	99.13	86.25	33.51	0	0	0	264.08	22.006667
APE=	369.27	336.16	462.66	406.78	299.09	162.8	129.25	85.25	101.86	279.62	329.34	316.47	3278.55	273.2125
RO	0	0	0	2.01	0.55	12.5	33.04	28.75	11.17	0	0	0	88.02	7.335
P1=	0	0	0	45.21	11	254.21	665.17	579.5	226.16	0	0	0	1781.25	148.4375
2002														
RECH=	0	0	0	0	0	0	78.21	294.74	90.37	42.79	0	0	506.11	42.175833
DR=	0	0	0	0	0	12.01	44.25	62.02	32.03	8.51	0	0	158.82	13.235
APE=	319.33	326.92	450.89	515.68	384.12	219.12	144.21	100.1	111.32	195.14	294.03	318.45	3379.31	281.60917
RO	0	0	0	0	0	4.8	17.7	24.81	12.81	3.41	0	0	63.53	5.2941667
P1=	0	0	0	3.08	1.1	91.96	302.39	414.26	219.89	59.51	0	0	1092.19	91.015833
2003														
RECH=	0	0	0	0	0	0	247.34	459.94	179.58	0	0	0	886.86	73.905
AAE	0	0	0	11	26.29	206.67	129.91	94.27	113.52	25.9	0	0	607.56	50.63
DR=	0	0	0	0	10.51	40.66	64.68	87.37	38.28	2.15	0	0	243.65	20.304167
APE=	343.97	340.89	474.65	455.51	380.16	215.38	129.91	94.27	113.52	224.73	354.97	337.92	3465.88	288.82333
RO	0	0	0	0	4.2	16.26	25.87	34.95	15.31	0.86	0	0	97.45	8.1208333
P1=	0	0	0	11	73.48	271.92	433.95	589.16	255.86	14.3	0	0	1649.67	137.4725

Table 1b: Summary of monthly results for Maiduguri (2001-2003)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Average
2001														
RECH=	0	0	0	0	0	6.03	0	125.42	89.63	0	0	0	221.08	18.42333
AAE	0	0	0	0	35.09	0	155.2	134.31	118.47	10.3	0	0	453.37	37.78083
DR=	0	0	0	0	4.42	19.67	16.01	40.16	35.21	0	0	0	115.47	9.6225
APE=	293.15	363.66	539.88	493.79	566.17	0	252.12	134.31	118.47	240.35	366.63	352.88	3721.41	310.1175
RO	0	0	0	0	1.47	6.56	5.3	13.39	11.74	0	0	0	38.46	3.205
P1=	0	0	0	0	40.81	131.12	121.11	268.84	238.48	0	0	0	800.36	66.69667
2002														
RECH=	0	0	0	0	0	0	0	50.27	0	0	0	0	50.27	4.189167
AAE	0	0	0	2.42	0	0	60.16	134.31	84.41	61.85	0	0	343.15	28.59583
DR=	0	0	0	0	0	8.2	17.79	28.43	0	4.14	0	0	58.56	4.88
APE=	293.15	363.66	539.88	493.79	566.17	0	252.12	134.31	118.47	240.35	366.63	352.88	3721.41	310.1175
RO	0	0	0	0	0	3.28	7.11	11.37	0	1.66	0	0	23.42	1.951667
P1=	0	0	0	2.42	0	54.67	122.54	197.56	0	29.04	0	0	406.23	33.8525
2003														
RECH=	0	0	0	0	0	0	51.67	163.63	20.89	0	0	0	236.19	19.6825
AAE	0	0	0	4.73	14.08	48.73	79.85	110.66	137.06	8.36	0	0	403.47	33.6225
DR=	0	0	0	0	0	13.27	30.51	41.93	12.13	2.06	0	0	99.9	8.325
APE=	350.9	445.06	614.9	553.74	516.34	240.57	178.75	110.66	137.06	257.62	356.51	309.98	4072.09	339.3408
RO	0	0	0	0	0	5.31	12.2	16.77	4.85	0.82	0	0	39.95	3.329167
P1=	0	0	0	4.73	14.08	98.01	222.53	281.71	86.9	16.17	0	0	724.13	60.34417

Table 1c: Summary of monthly results for Sokoto (2001-2003)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	Average
2001														
RECH=	0	0	0	0	0	0	146.56	80.97	23.49	0	0	0	251.02	20.91833
AAE	0	0	0	9.79	29.26	54.59	130.35	96.36	120.12	0	0	0	440.47	36.70583
DR=	0	0	0	3.98	9.08	3.12	56.48	23.07	17.74	0	0	0	113.47	9.455833
APE=	417.34	425.04	555.17	474.98	355.08	264.77	163.02	96.36	120.12	262.68	362.01	395.01	3891.58	324.2983
RO	0	0	0	1.33	3.03	1.04	18.83	7.69	5.91	0	0	0	37.83	3.1525
P1=	0	0	0	26.51	66.55	39.93	379.72	156.31	118.25	0	0	0	787.27	65.60583
2002														
RECH=	0	0	0	0	0	0	53.98	90.98	100.08	0	0	0	245.04	20.42
AAE	0	0	0	10.12	23.43	44.44	124.53	99.88	109.67	133.09	0	0	545.16	45.43
DR=	0	0	0	5.3	4.65	9.26	37.39	29.68	29.57	6.62	0	0	122.47	10.20583
APE=	409.53	391.71	521.29	401.28	400.4	293.92	161.26	99.88	109.67	167.64	327.58	358.49	3642.65	303.5542
RO	0	0	0	2.12	1.86	3.7	14.96	11.87	11.83	2.65	0	0	48.99	4.0825
P1=	0	0	0	36.63	33.88	74.14	254.76	201.41	197.12	47.63	0	0	845.57	70.46417
2003														
RECH=	0	0	0	0	0	0	103.09	162.64	32.83	0	0	0	298.56	24.88
AAE	0	0	0	10.12	19.25	41.81	127.27	114.62	133.32	19.1	0	0	465.49	38.79083
DR=	0	0	0	0	0	8.51	44.95	47.42	17.31	0	0	0	118.19	9.849167
APE=	443.3	434.72	589.49	477.29	457.82	293.26	160.93	114.62	133.32	217.47	372.57	374.11	4068.9	339.075
RO	0	0	0	0	0	3.41	17.98	18.97	6.92	0	0	0	47.28	3.94
P1=	0	0	0	10.12	19.25	78.43	316.58	317.57	119.02	8.14	0	0	869.11	72.42583

RECH=Recharge, AAE=Actual Evapotranspiration, Dr=Direct Recharge, APE=Actual potential evaporation

Table 2: Comparison of the Recharge Results

	Sokoto		Kano	Maiduguri	
Month	1960-1965	2001-2003	2001-2003	1974-1983	2001-2003
January	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	0.0	0.0
April	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	0.0
June	4.0	0.0	4.7	0.0	2.0
July	39.8	101.2	273.4	22.18	17.2
August	137.6	111.5	407.7	49.58	113.1
September	69.6	52.1	137.1	28.53	36.8
October	3.9	0.0	14.3	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0
T_A	254.9	264.8	837.2	100.29	169.1

Where T_A = Annual Average Recharge (mm)

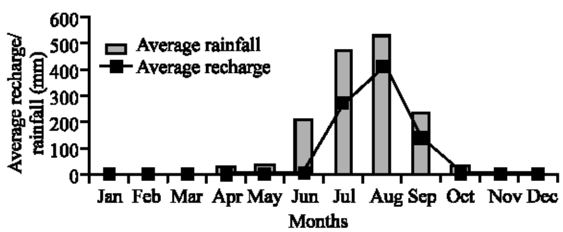

Fig. 2: Variation of average rainfall and recharge (2001-2003) for Sokoto

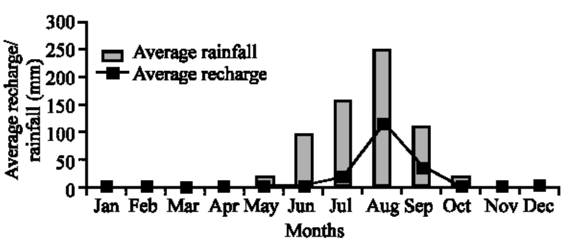

Fig. 3: Variation of average rainfall and recharge (2001-2003) for maiduguri

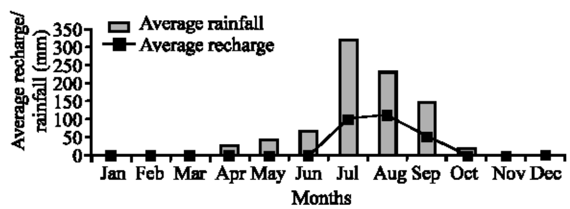

Fig. 4: Variation of average rainfall and recharge (2001-2003) for Sokoto

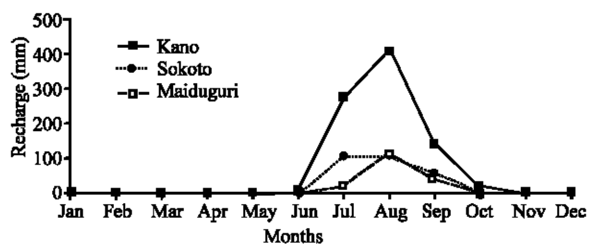

Fig. 5: Comparison of average recharge for 2001-2003

The average monthly estimate for August (Table 2) is about 52.6% of the average annual value for the region. Figure 2-4 are plots of out puts showing time series of rainfall and groundwater recharge at the selected stations as suggested by Finch (1999). A comparison of the result shown in Fig. 5 indicates that among the three stations and for the three consecutive years, 2001- 2003, the month of August consistently had the highest monthly groundwater recharge. The relatively lower daily SMD, APE and higher P1 during this month can explain this. Another observation from Fig. 2-5 is that the incidences of recharge occur within the wet months June to October only.

The comparison in Table 2 shows that the value of 264.9 mm obtained from 2001-2003 computations for Sokoto does not differ significantly from 255.0 mm obtained for 1960- 1965 for the same area. However, in columns 5and 6 of the same table, the annual average for 2001-2003 in Maiduguri is about 69 mm (or 69%) higher than 100. 29 mm for 1974-1983, which included the drought period. Therefore, there was about 69% loss of potential groundwater recharge during the drought period. This may be responsible for the low water levels and dry up of hand-dug wells reported by Mustafa and Babatola (1989).

Limitations of study:

- The estimate for 2001-2003 is from rainfall only and does not take into account of any seepage along stream channels, irrigated agricultural fields, lakes and ponds.
- In the method employed recharge is modeled as an instantaneous response to rainfall. The time lag between rainfall, infiltration and recharge is ignored. In some aquifers delays up to 6 months are possible

before percolation to the saturated zone. Therefore, a delay factor should be incorporated in future studies.

However, a comparison of the estimates found that the range of coefficients (0.26-0.36) obtained from this investigation falls within the range of 0.08-0.30 predicted by previous studies such as Athavale *et al.* (1980), Lloyd *et al.* (1966), Odijie and Anyaeche (1991) and Odijie and Olu (1985). This indicates that the result is consistent and reliable and can therefore be used as input in groundwater modeling.

CONCLUSION

A modified form of Soil Moisture Deficit was applied to representative sites within the arid zone of Northern-Nigeria. An assessment of groundwater recharge shows that annual recharge range from 169.2 mm in Maiduguri to 837.1 mm in Kano area and that recharge coefficients range of 26-56%. The results further indicated that the month of August accounts for about 53% of the average annual recharge and 19.4% of the average annual rainfall. The effect of drought on groundwater recharge from rainfall was also estimated. It was found to have contributed to an annual loss of 69 mm potential groundwater recharge in the area.

The range of coefficients (0.26-0.36) obtained from this investigation falls within the range of 0.08-0.30 predicted by previous studies such as Lloyd *et al.* (1966), Athavaile *et al.* (1980), Odijie and Anyaeche (1991) and Odijie and Olu (1985). This indicates that the estimated recharge is consistent and reliable and can therefore be used as input in groundwater modeling.

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