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Research Article

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Estimation of Groundwater Recharge In Sokoto Basin, Using The Watertable Fluctuation Method

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Abstract Sokoto Basin is one of the major sub-basins of the Illummedan basin of West Africa. The Basin lies in the sub-Saharan Sudan belt of West Africa in zone of Savanna-type vegetation generally classified as semi-arid. It lies in northwestern Nigeria between latitudes 8°30[1] and 14°00[1] N and longitudes 3°30[1]and 7°00[1] E occupying a total of about 6.4 x 10^4 km^2 of land area with Niger Republic to the North, and covers Sokoto, Kebbi and Zamfara to the East; it also borders Niger State to the South-east, and Benin Republic to the west. The available water resources in the basin is marred with many challenges including high spatial and temporal variability in rainfall, global climate change, deforestation, land degradation, desertification and high population growth rate. These challenges put immense pressure on the water resources. The basin experiences a prolonged dry season when many rivers and streams dry up. As a result, surface water supplies are unreliable and insufficient to meet the water demands for socio-economic development in many places in the basin, thereby making groundwater sources the preferred and most cost-effective means of supplying water to the largely rural and dispersed population in the basin. A key prerequisite for efficient and sustainable management of the groundwater resource is the understanding and quantification of the groundwater recharge. This study estimates the total amount and spatial distribution of the groundwater recharge at different scales in the Sokoto Basin using water table fluctuation. The water table fluctuation method was used in the basin to evaluate the seasonal and annual variations in water level rise and to estimate the groundwater recharge. The results show that annual water level rise ranged from 2200 to 9750 mm in 2014. Based on standard values of specific yield and the measured water level rise, the estimated annual recharge ranged from 20.5 to 380.5 mm in 2014.

Keywords Groundwater, Recharge, Water table Fluctuation, Specific Yield, Sokoto Basin

Introduction

The evaluation of the groundwater resources involves several factors of which the groundwater recharge is a key. An understanding of the recharge processes and the quantification of natural recharge rate are basic prerequisites for efficient and sustainable management of the groundwater resources [1-2]. Quantification of the recharge is needed to estimate the sustainable yield of groundwater aquifers. Knowledge of aquifer sustainable yield is important for rational and sustainable exploitation of the groundwater resources [3-4].

The water resources in the basin is threatened by challenges including high spatial and temporal variability in rainfall, global climate change, deforestation, desertification, land degradation, construction of several boreholes for irrigation, over-abstraction, prolonged dry season leading to dry up of some rivers and high population growth rate. This makes it pertinent for efficient and sustainable management of the groundwater resources which requires the understanding and quantification of the groundwater recharge.

Location, Geomorphologic and Climatic Setting

The Sokoto Basin lies in northwestern Nigeria between latitudes 8°30^1 and 14°00^1 N and longitudes 3°30^{1}and 7°00^1 E occupying a total of about 6.4 x 10^4 km^2 of land area with Niger Republic to the North, and covers Sokoto, Kebbi, Kaduna and Zamfara to the East; it also borders Niger State to the South-east, and Benin Republic to the west This present research covers Kebbi, Sokoto and Zamfara states (Fig. 1). The whole basin can be described as Sudan and Sahel Savanna, and it extends beyond the border to Niger republic and the Northern part of Benin Republic. The basin topography consists of a vast floodplain (Fadama land) and rich alluvial soils that is suitable for the cultivation of different variety of crops. There are also isolated hills (inselberg) and hill ranges scattered all over the area [5].

Geomorphologically, the area is mainly undulating, only with depressions caused by Wadis and watercourses (Rivers Rima and Sokoto). The elevation of ground is between 250 and 350 meters above sea level. Resistant crusts of laterites and ironstone cap the hills in the area. Rivers Sokoto –River Rima system represents the principal drainage network in this region. Other rivers like Zamfara, Gulbin ka and Gagere are the main tributaries [6].

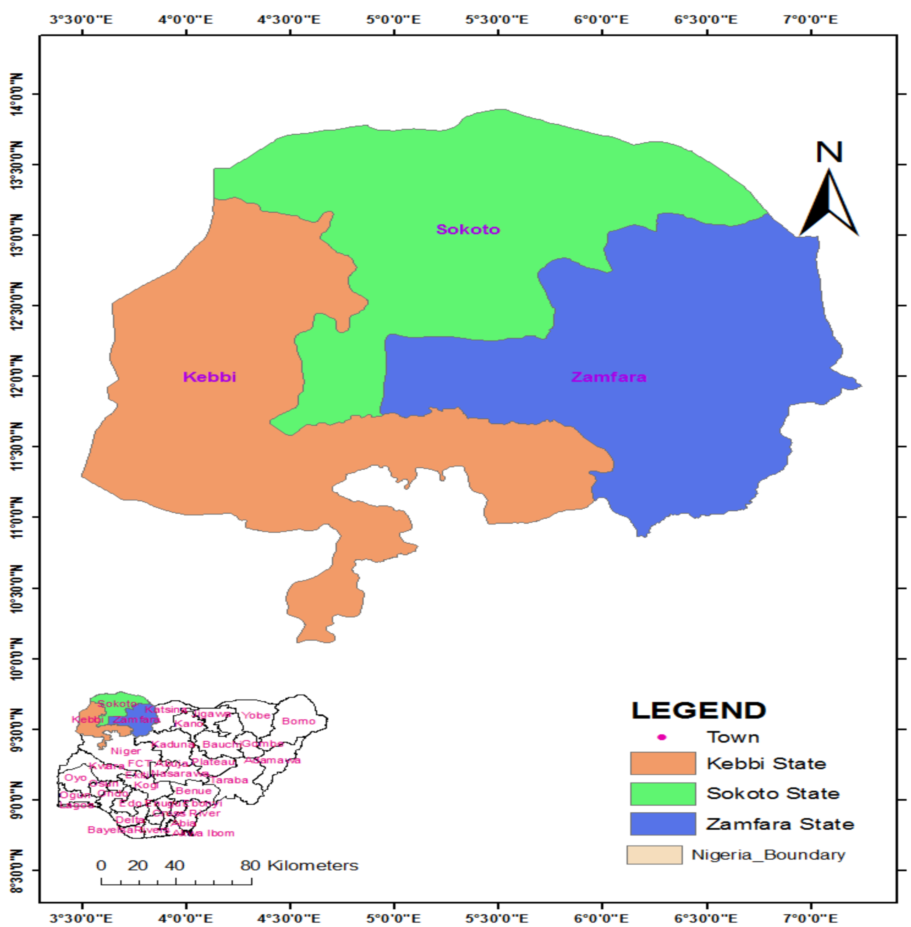

Figure 1: Location of Study Area

The sokoto basin falls within the hottest parts of Nigeria. The critical zone, located above latitude 10°N, belongs to the Sahel region of Africa, an area most affected by the droughts. Temperatures are generally extreme, with average daily minimum of 16^{o}C during cool months of January and December, and in the hottest month of April to June, an average maximum of 38^{o}C and minimum of 24^{o}C. Throughout the year the average maximum is 36^{o}C and average daily minimum is 21^{o}C. Rainfall is generally low. The average annual rainfall for 35 years is about 470mm. Much of the rain falls between the months of May to September, while the rainless months are October to April. Evaporation is high ranging from 80mm in July to about 210mm in April to May. A monthly average evaporation range of about 140mm represent 30% of monthly average precipitation into the catchment. The hottest months of April to May are periods of highest evaporation. Relative humidity is low most of the year and only increases during the wet seasons of June to September. The vegetation is typically Sudan savannah and is characterised by stunted and thorny shrubs, invariably of the acacia species [7].

Geological Setting

Basement rocks dominate about 50% of Nigeria's surface area while Cretacious and Cenozoic sediments cover the other 50%. In the southeastern sector of the Iullemenden basin i.e Sokoto basin, up to 200 meters of clastic sequence rests upon the Basement [8]. Moreover in Sokoto Basin sequences of semi-consolidated gravels, sands, clay, some limestone and ironstone are found. According to Kogbe [9], the sedimentary sequences are sub-divided from bottom to top into late Jurassic to early Cretacious Illo and Gundumi formations (Continental intercalaire), the Maestrichtian Rima Group (sub-divided into Taloka, Dukamaje and Wurno Formations), the late Paleocene Sokoto Group (sub-divided into Dange, Kalambaina and Gamba formations) and Eocene-Miocene Gwandu Formations (Figure.2)

Hydrogeological Setting

The analysis of pumping test data carried out in the shallow aquifer yielded transmissivities in the range of 200 to 5000m^2/d and storage coefficients of 10^{-2} to 10^{-5} indicating semi-unconfined to confined conditions[10]. Based on these, the hydraulic conductivity varies between 10^{-4} to $> 10^{-3}$ m/sec. The yield of tube wells up to 20 meters depth is generally > 2L/sec. The fluctuations of water table in the Fadama areas are about 2-3 meters throughout the year. The water table is lowest in June and highest in September at the end of the rainy season. As precipitation in the area is concentrated within 3-5 months a period, short-lived but strong surface runoff results.

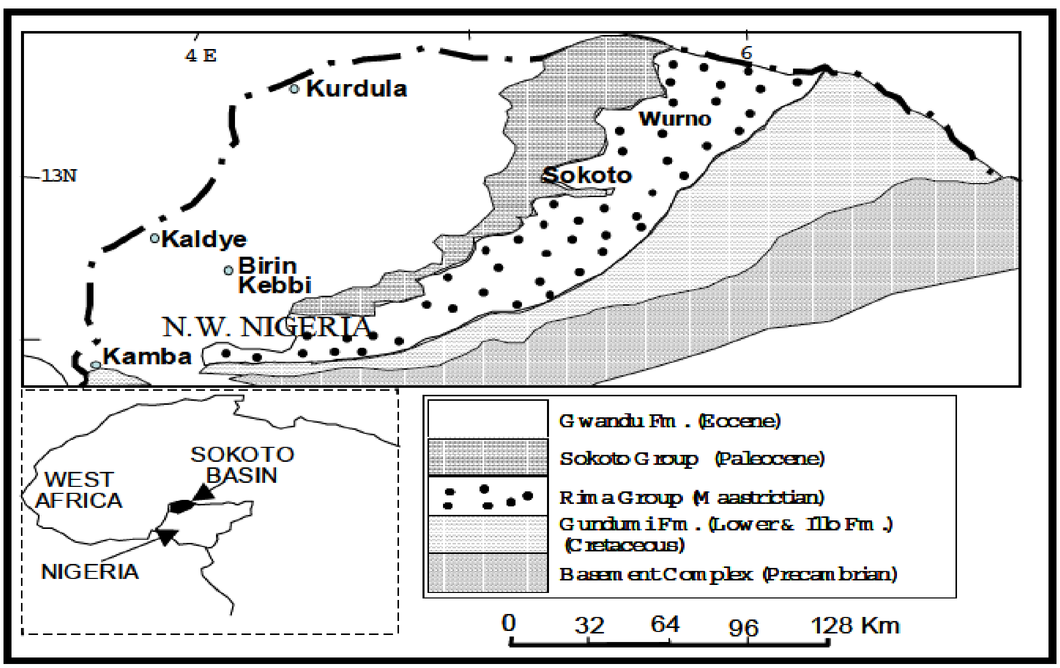

Figure 2 Geological map of Sokoto sedimentary Basin, Nw, Nigeria [9].

Materials and Methods

The water table fluctuation method (WTF) is one of the most widely used techniques for estimating groundwater recharge over a wide variety of climatic conditions [2,11-12].The use of the method requires knowledge of specific yield and changes in water levels over time.

The WTF method is based on the assertion that rises in water levels in unconfined aquifers are due to recharge water arriving at the water table, and that all other components of the groundwater budget, including lateral flow, are zero during the recharge period [2,11]. The groundwater recharge rate can be estimated as the product of the water level rise and the specific yield of the groundwater aquifer material. The recharge can be expressed as:

$R = S_y\, dh / dt = S_y \Delta h/\Delta t$ …………………3.1

Where: R is groundwater recharge (mm/time); Sy is specific yield (dimensionless); Δh is Peak rise in water level attributed to the recharge period (mm); and Δt is the time of the recharge period.

Water Level Measurement

Groundwater levels were monitored in 19 observation wells spread in locations within the three states that make up part of Sokoto basin. The locations and co-ordinates of the wells are shown in table 1 and Figure 3

The monitoring wells were completed in February 2014 by Nigerian Hydrological Services Agency (NIHSA) and installed with Orpheus mini data logger which provides precise measurements and recording of groundwater levels and temperature. The pressure probe equipped with a relative pressure measuring cell uses the hydrostatic pressure of the water to measure the water level. The stored values are made available through an infrared interface (Ir DA) for wireless readout by a PC with OTT Orpheus mini operating program. Data from the monitoring wells is been monitored and retrieved every 6 months and that commenced since February 2014. The project by NIHSA aims at providing decision support for integrated water resources management in the Sokoto Basin.

Estimation of water Level Rise

In this study the rise in water level dh was computed with the graphical approach as the difference between the peak water level during a recharge event and the extrapolated level to which water levels would have declined if the recharge event had not occurred. This was done by visually examining the entire water level records for each piezometer and manually extrapolating the antecedent recession curves. The rise in water level during the recharge period was obtained as the difference between the peak of the rise and the low point of the extrapolated antecedent recession curve at the time of the peak,

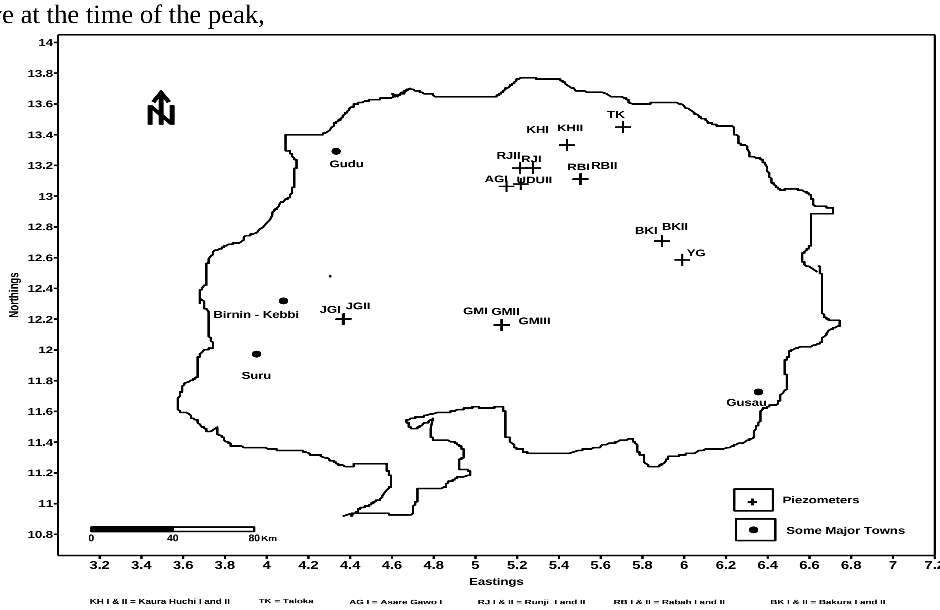

Figure 3: Location of selected monitoring wells.

Results and Discussions

Water Level Rise

The highest monthly rainfalls for the study area in 2014 were measured in August and water levels were highest in August and September (Figures 4-6).

Although the rainfall season in the study area starts in April/ May, water level in all observation piezometers started to rise in June/ July when about 39% of annual rainfall had occurred.

The rise in water level is almost entirely from the seasonal rainfall since water level rise occurred mostly in the rainfall period. Though there were some accumulations of recharge in the dry season possibly due to regional flow of groundwater, this was very small.

The 2 – to- 4 months lag between the start of the rainfall season and water level rise can be attributed to a period of refilling of the soil due to moisture deficit inherited from the previous dry season.

The annual and spatial variations in water level were quite high as depicted in the groundwater hydrographs.

The estimated annual water level rise ranged from 2200mm to 9750mm for a mean annual rainfall of 897mm in 2014 (table 2). The highest and lowest water level rise was recorded in Bakura II and Jega II respectively (Figures 6 and 7). The very high water level rise in Bakura II may have been influenced by the aquifer material (coarse - gravelly sands) and the shallow depth of the aquifer to the surface.

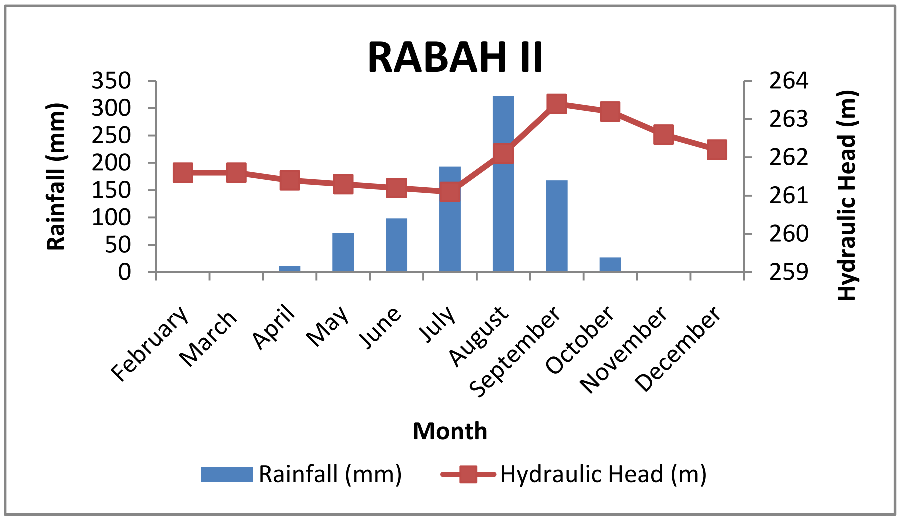

Figure 4: Groundwater hydrograph and bar graph of monthly rainfall at Rabah II at, Sokoto State.

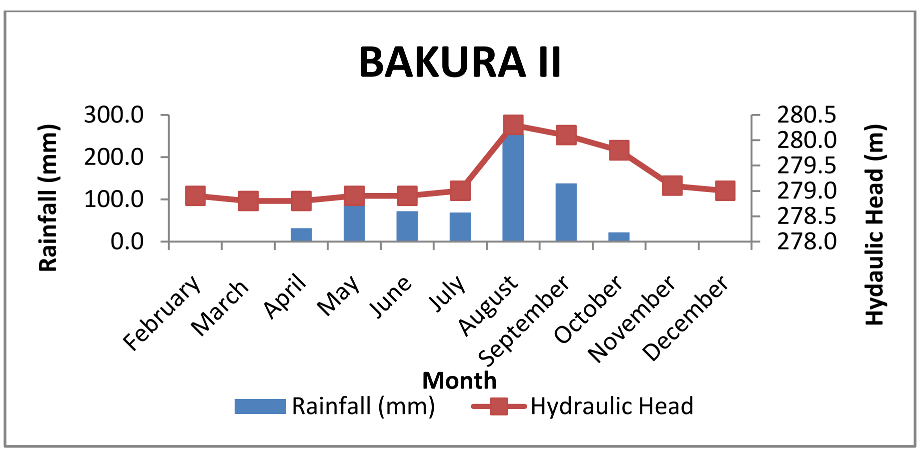

Figure 5: Groundwater hydrograph and bar graph of monthly rainfall at Bakura II , Zamfara State.

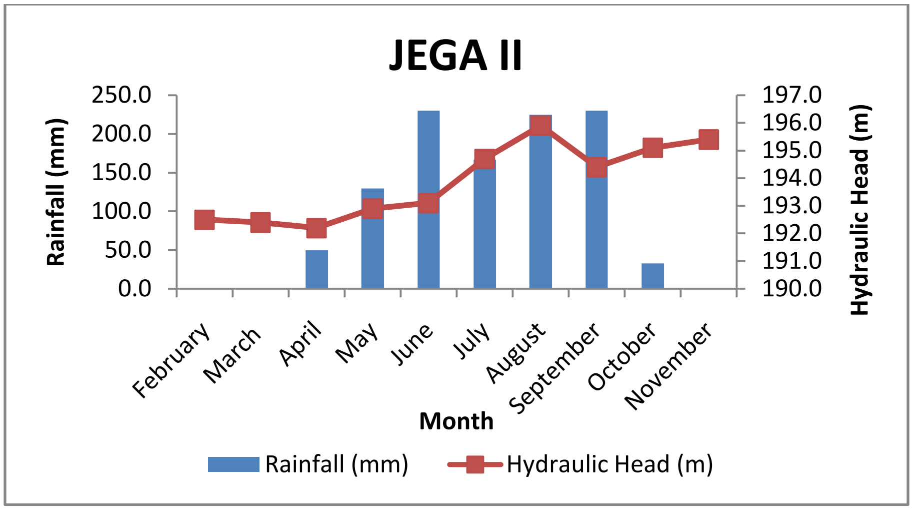

Figure 6: Groundwater hydrograph and bar graph of monthly rainfall at Jega II, Jega, Kebbi State

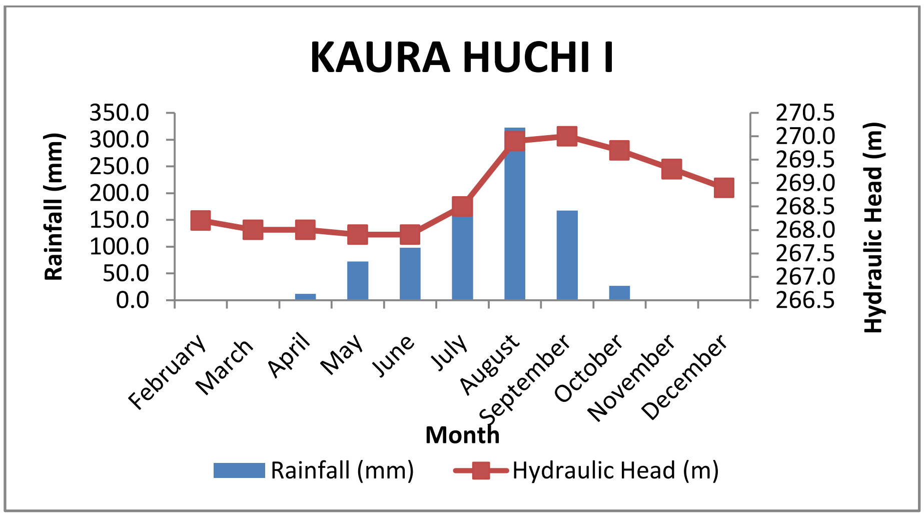

Figure 7: Groundwater hydrograph and bar graph of monthly rainfall at Kaura Huchi I, Gwadabawa, Sokoto State.

Recharge Estimates

The groundwater recharge for each of the observed wells was calculated by multiplying the water level rise with the specific yield values of the aquifer material in which the wells are situated. The calculated mean recharge for the study area ranged from 20.5 to 380.5mm in 2014, representing 3.0 to 35.0 % of the mean annual rainfall of 897mm (Table 1 and Figure 9).The results of this study is similar to recharge studies carried out elsewhere using water table method. Adelana et al [9] estimated recharge to aquifers in Wurno and Goronyo areas to be < 1% and 3.2% of the annual rainfall. Also Obuobie [13] applied the method to the Southern part of the White Volta Basin of Ghana and estimated recharge to range from 28.0-150.0 mm in 2006, representing 3.5-16.5 % of the mean annual rainfall and from 32.0-204.0 mm in 2007, representing 2.5-16.0 % of the mean annual rainfall with a specific yield range of 0.01-0.05. Similarly Sanwidi [14] used this method for the Kompienga Dam Basin in Burkina Faso near Ghana, and estimated the recharge to be from 5.3-29.4 % of the annual rainfall. Similarly, Martin [15] applied the method in the Atankwidi catchment, Ghana and estimated the recharge to vary from 1.8-12.5 % of the annual rainfall in 2003 and from 1.4-10.3 % of the annual rainfall in 2004. Atta-Dakwa et al [16] also applied the water table Fluctuation method for quantification of groundwater recharge in River Oda catchment in Ghana, and estimated recharge to be 133-467mm in 2009 representing 9-31% of annual rainfall and 47.6-427.9mm in 2010 representing 4-34% of annual rainfall.

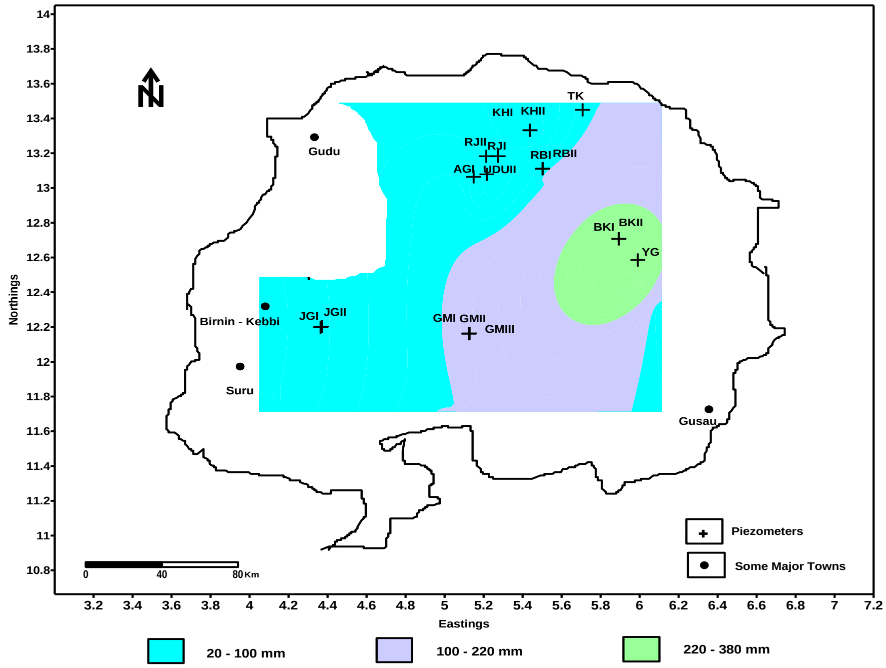

Figure 8: Spatially interpolated groundwater recharge in the Sokoto basin of Nigeria, in 2014

Table 1: Recharge values estimated in the Sokoto Basin in Nigeria, 2014

Piezometers	Aquifer material	Specific Yield	SWL (mm)	Recharge (mm)	% of Rainfall
Asaro Gawo	Medium-corse sands	0.03	3970	55.2 – 17 1.9 (113.6)	7 – 19 (13)
Kaura Huchi I	Limestone with joints cavities	0.03	2200	21 – 64.8 (43)	0.2 – 7 (4)
Kaura Huchi II	Limestone with joints & cavities	0.03	3290	23.1 – 42.3 (33)	3 – 5 (4)
Taloka	Medium Sands	0.21	5170	100 – 132.3 (116.2)	11 – 15 (13)
U.D.U II	Medium-coarse sands	0.03	4200	43.5 – 54 (49)	5 – 6 (6)
Runji I	Medium-coarse sands	0.03	2860	79.2 – 111.3 (95.3)	9 – 12 (11)
Runji II	Medium-coarse sands	0.03	2780	32.4 – 152 (77.2)	4 – 17 (11)
Rabah I	Medium Sands	0.21	4007	90 – 147 (118.5)	10 – 16 (13)
Rabah II	Medium sands	0.21	2880	105 – 180 (142.5)	12 – 20 (16)
Bakura I	Coarse-gravelly Sands	0.27	5070	356.4 – 405 (380.5)	32 – 37 (35)
Bakura II	Coarse-gravelly Sands	0.27	5490	137.7 – 485 (311.4)	13 – 37
Gummi I	Coarse -gravellySands	0.27	3860	91.8 – 178.2 (135)	8 – 16 (12)
Gummi II	Coarse sands	0.27	9750	64.8 – 199.8 (132.3)	6 – 18(12)
Gummi III	Coarse-gravelly Sands	0.27	9280	135 – 245 (190.4)	12 – 22 (17)
Yar Geda	Medium Sands	0.21	2060	63 – 73.5 (68.3)	6 – 7 (7)
Jega I	Medium-coarse sands	0.03	3240	30 – 46.2 (38.1)	4 – 7 (6)
Jega II	Medium-coarse sands	0.03	2260	39 – 57 (48)	6 – 8 (7)
Zauro I	Medium-Coarse sands	0.03	4650	15.3 – 40.8 (28.1)	2 – 6 (4)
Zauro II	Medium-coarse sands	0.03	1450	14 – 27 (20.5)	2 – 4 (3)

Spatial interpolation of the recharge for 2014 shows that with the exception of a few areas like Gummi and Bakura in Zamfara, groundwater recharge in the study area ranged from 20 to 100mm (Figure 8). The highest and lowest recharge values in 2014 were estimated at Bakura and Zauro, respectively.

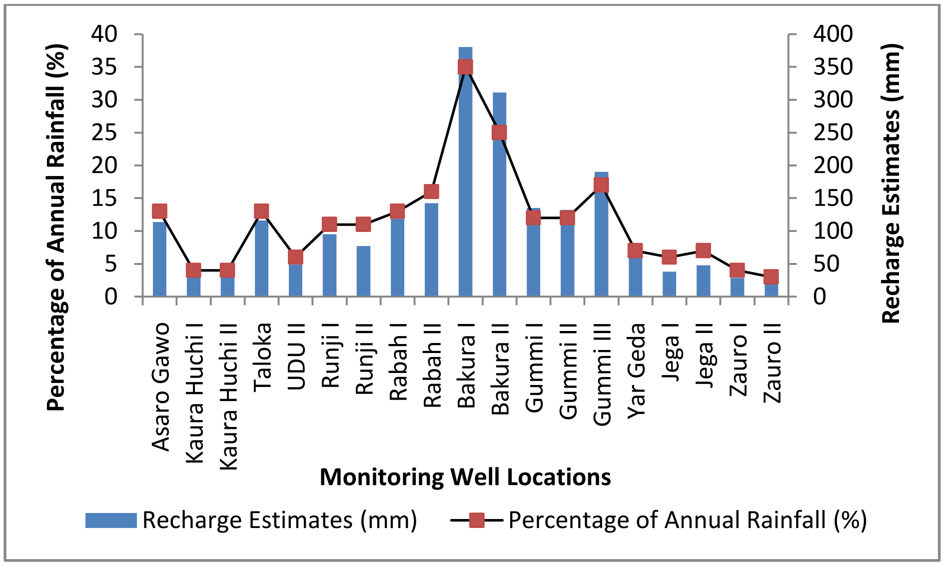

Figure 9: Recharge Estimates expressed as Percentages of Annual Rainfall

Conclusions and Recommendations

The water table fluctuation (WTF) method for estimating groundwater recharge requires data of specific yield and changes in the water table over time. It is best applied to systems with shallow water tables that display sharp rises and declines. The method requires no assumption on the mechanisms for water movement through the unsaturated zones hence the presence of preferential flow path does not restrict its use at the research site. The WTF method was applied to Sokoto basin to quantify groundwater recharge and to analyze the fluctuations in the watertable. Recharge estimation for the study area ranged from 20.5 to 380.5mm in 2014, representing 3.0 to 35.0 % of the mean annual rainfall of 897mm. It is recommended that irrigation water should be applied to obtain optimal moisture content and water table levels for effective crop production during the low to rainless months of October to April. Also, long term data could be collected to validate the study over a longer period.

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