Ethiopian Journal of Environmental Studies & Management 7(2): 142 – 152, 2014.
ISSN:1998-0507 doi: http://dx.doi.org/10.4314/ejesm.v7i2.5
Submitted: November 1, 2013 Accepted: March 6, 2014

RAINFALL INCIDENCES AND GROUNDWATER CHARACTERISTICS IN THE SEDIMENTARY BASIN OF SOKOTO METROPOLIS, NIGERIA

***IFABIYI, I.P.[1] AND ALIYU, A.[2]**
[1]Department of Geography and Environmental Management, P.M.B. 1515, University of Ilorin.
[2]Department of Geography, Usmanu Danfodiyo University Sokoto, Nigeria.

Abstract
Groundwater fluctuation is an important phenomenon in water supply within semi-arid regions. Sokoto state has a dry season of 8 months and rainy season of 4 months; this has a profound impact on groundwater level. This study examines groundwater fluctuation within Sokoto metropolis. Groundwater levels in selected shallow wells were monitored after 3 incidences of rainfall in 20 shallow water wells between May and June, 2011. Measuring tape and Global Positioning System (GPS) were used as instruments of data collection. The water levels and the GPS values served as input into Surfer 10 Digital Elevation Mapper, using 3D (Dimension) digitizing and one grid vector mapping techniques. Also, digitized map of Sokoto metropolis was imported into Surfer 10 digital elevation Mapper environment to enable the positioning of the sampled sites of water levels for both dry and rainy events. One grid vector was used to classify Sokoto metropolis into areas of high, moderate and low water levels. One way ANOVA statistical technique was used to test differences in rainfall and water level fluctuations in shallow wells of Sokoto metropolis. The results showed that there were no significant variations between levels of groundwater with rainfall events. It also showed that groundwater flow in Sokoto metropolis is in 4 different directions. In addition, Sokoto metropolis was classified into 6 regional groundwater regions. The paper suggests a need for further study.

Introduction

Groundwater is the portion of water beneath the surface of the earth that is connected with well tunnels or drainage galleries, or that flows naturally to the earth's surface via seeps or springs (Todd, 1980). Groundwater fluctuates both seasonally and intermittently. Fluctuations can be caused by transfer of water between the capillary fringe and the water table, resulting from changes in atmospheric pressure. This mechanism can produce daily fluctuation of 1.5 to 6cm in summer and 0.5 to 1cm in winter for shallow water table (Turk 1975). Water tables or piezometric surfaces may also fluctuate under the influence of earth tides, produced due to bulging of the earth to the gravitational attraction of the sun and moon. Earth tides produce an expansion (commonly called dilation) of aquifers and other subsurface formations resulting in groundwater declines (Hsieh *et al*., 1988). Water levels in wells reaching into confined aquifer have been observed to decline by as much as 17cm due to this (Bredehoeft, 1967). Conversely, the opposite action of bulging causes comprehension of aquifer and it will lead to an increase in groundwater levels. High evaporation rates may be sufficient to reduce the surface water bodies to very low levels (Ndubuisi and Ujuanbi 2006). Groundwater levels and base flow can further be influenced by several activities. These activities include: stream regulation, direct pumping, artificial diversion of water into or out a basin, or part of basin transfer, direct discharges into stream for mine dewatering activities, seasonal return flow from drainage or irrigation areas. It may also include, artificial drainage of floodplain, (for agriculture or urban development) other such as changes in land use (clearing, reforestation lead to changed crop type), can significantly alter evapotranspiration rates. Groundwater extraction may also lower water table and decrease or reverse the hydraulic gradient towards the stream (Griffiths and Clausen,1997; Smakhtin, 2001; Singh, 2001; Quian, 2003; Neal *et al*., 2004; Brodie and Hostetler, 2005). Tianqi, (2003) examined the importance of basin scale on groundwater and discovered that small or average sub basin size produces higher peak discharge, larger base flow and total runoff for floods, while similar effects on annual runoff was not discernible. Flugel (1995) also reported that interflow is also a dominant flow process to groundwater recharge and river runoff.

***Corresponding Author:** Ifabiyi, I.P.
Email: tokunifabiyi@unilorin.edu.ng

A recent study by Ifabiyi (2011) in a study of the effects of basin variable on groundwater response used factor analysis to reduce 30 basin variables to 8 orthogonal variables (namely: length of mainstream, total rainfall, %younger granite, leminiscate ratio, savanna scrubland, % forest, basin scale, and % *fadama* (wetland)) which altogether explained 84.3% of the variance., he further reported that that these 8 factors explained 86.0% of the groundwater pattern in the Upper Kaduna Catchment, Nigeria; Of which total rainfall, percentage of forest and percentage area underlain by younger granite were the most significant, explaining 76.4% of the variance in groundwater.

The amount of water flowing into wells depends on four factors: the level of water table compared to the bottom of the well, the characteristics of the overburden into which the well is sunk; the size of the hole/well and lastly well completion and development strategies (Chleq and Dupriieze, 1990). The most convenient mode of exploitation of groundwater is through large diameter dug wells, tapping the phreatic aquifers. In view of the increasing population and pressure on the available water resources, shallower wells are increasingly being developed. The increase in exploitation may lead to depletion of groundwater reserves especially during drought periods (Alaku, 1991).

Population growth and urbanization constitutes a major problem in developing countries, where inadequate provision of social and infrastructural facilities is common. Most of the urban and rural centres in Nigeria have centralized water supply system, which relied heavily on surface water resources, the rate of population and urbanization growth are faster than the rate at which water supply facilities are been developed, this eventually results to insufficient water supply. Groundwater level is directly related to groundwater movement, groundwater flows toward stream, rivers, lakes, creeks and boreholes. Knowledge of groundwater flow direction is required, it will assist in mapping out the recharge point and in sustaining land use activities and it could also be used to predict how contamination moves through groundwater system. Groundwater flow from high hydraulic head to low hydraulic head (Oseji, 2009; Oseji, 2012; Oseji, *et al*., 2012)

Groundwater possesses numerous advantages over its surface water counterparts. For example, it has higher quality. Groundwater has a better quaility compared to surface waater. However, groundwater varies from place to place; it is faced with over abstraction, decreasing rainfall and the problem of increasing population especially in the semi arid northern Nigeria. This has resulted in the progressive lowering and fluctuation of groundwater levels over the recent past. Studies of groundwater fluctuation is important in many respects, these include: its relevance to tracing groundwater recharge, its relevance to groundwater quality, it is of assistance in aquifer management and it's central to the development of water table maps (Mazor, 2004) Sokoto is in a semiarid environment, it experiences high solar radiation and evapotranspiration, it has longer sunshine hours, it has 3 months of effective rainy season, during which groundwater is recharged. For about 9 months the city experiences water deficit. Sokoto is underlain by sedimentary formation where depth to water is relatively deep. All these suggest a need for an examination of groundwater characteristics in Sokoto. This present study will attempt to study groundwater fluctuation and rainfall incidences in Sokoto metropolis.

Study Area

Sokoto state is located in North-Western Nigeria between latitudes 10° 20′ and 14° 00′N and longitudes 3° 30′ and 6° 58′E, occupying about $6.4x10^4 km^2$ of land area.

It falls within a region where rainfall distribution is irregular in time and space and characterised by a prolonged dry season and a short rainy season lasting from June to September. The climate is semi-arid. Rainfall in Sokoto shows a marked variation with annual mean precipitation varying from 350mm (at Kalamalo in the extreme North) to 670mm (at Sokoto Airport). Rainfall is concentrated in a short wet season which extends from mid-may to mid September whilst the dry season (with no single rain) lasts more than seven (7) months. Rainfall is highly variable from year, in the harmattan season, daily temperature may be about 17^oC, with large diurnal range march and April are very hot sometimes > 40^o C.

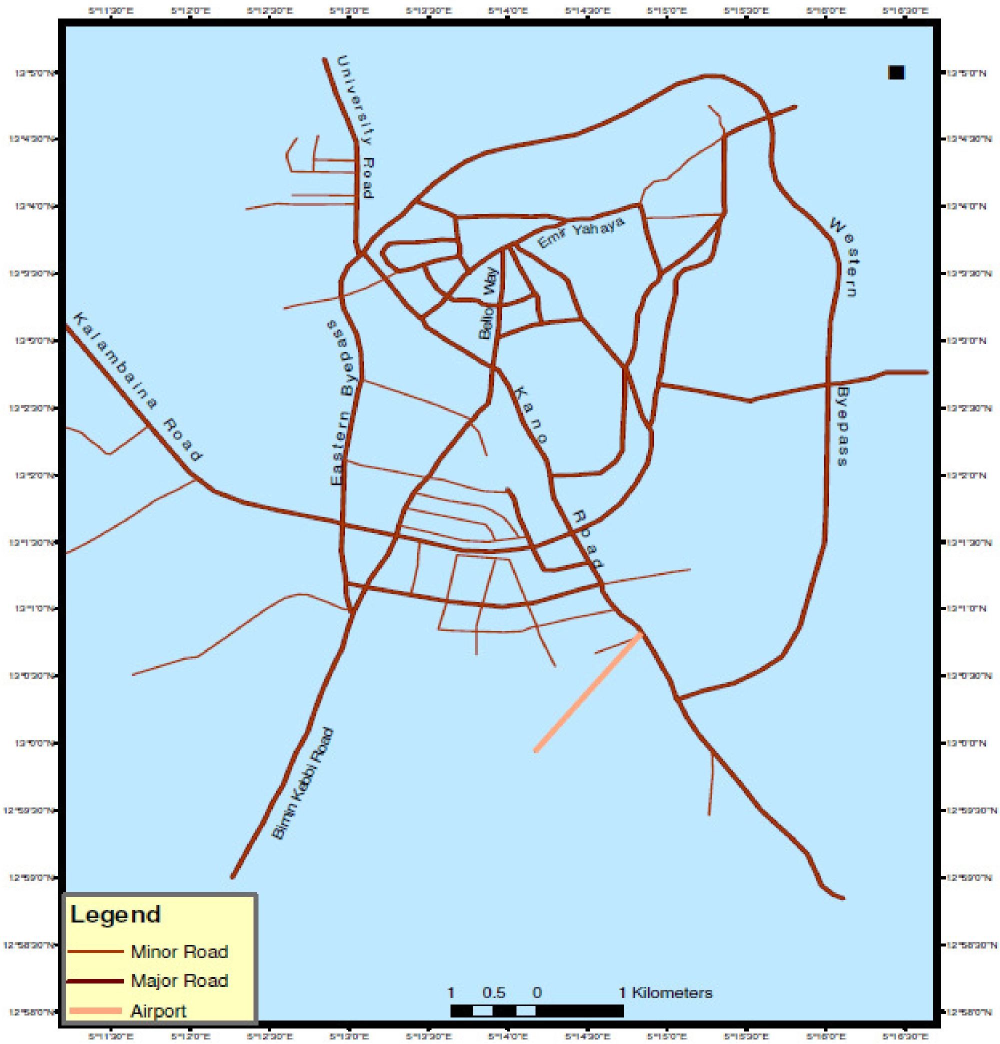

Figure 1: Street Layout in Sokoto Metropolis

The sediments of the Sokoto basin were deposited during three (3) main phases of deposition: continental Mezoic and Tertiary phases, with an intervening marine Mastrichlian to Palaeocene phase (Adelana and MacDonald (eds),2008). Overlying the Precambrian basement uncomfortably is the Illo and Gundumi formations, made up of grits and clays forming part of the "continental inter calarie" of West Africa. These are overlain by the mastrichlian Rima group, consisting of mud stones and friable sandstones (Taloka and Wurno formations): separated by the fossiliferous shaly Dukamaje formation. The Palaeocene Denge formation (mainly shales) is separated by the calcareous Kalambaina formation. The overlying continental Gwandu formation (continental terminals) is of tertiary age. These sediments dip gently and thicken gradually towards the North West, with a thickness of over 1200m near the frontier of Niger republic (Kogbe, 1989.). The principal water bearing beds in the Sokoto sediments are the surface laterites, sandstones, and grits in the Gwandu formations, limestone beds in Kalambaina formation, sandstones in the Wurno and Taloka formations as well as grits and sandstones in the Gundumi and Illo formations. Groundwater occurs under water table conditions throughout the area. Moreover, the association of inclined impervious beds alternating with water bearing horizons which gives rise to pressure water conditions in some parts of Sokoto basin. Perched bodies of groundwater also exist in the area. In the valley depression along the water courses, alluvial aquifers up to 20m thick can be found consisting of intercalations of gravels, sand, silt and clay causing locally confined conditions. The depth of groundwater in the alluvium, of Wurno area is about 1-3m but reaches several tens of meters under topographic highs. The fluctuation of the water table in the *fadama* area may be about 2-3m throughout the year

The Sokoto sedimentary basin in North-Western Nigeria consists of predominantly gentle undulating plain with an average elevation varying from 250-400m above sea level. This monotonous plain is occasionally interrupted by steep-sided, flat-topped hills with a low escarpment called the Denge escarpment as the most prominent feature. The escarpment itself is closely related to the geology of the area and has undergone intensive erosion to the extent that the Denge Scarp is no longer recognisable today (Udoh, 1970). Sokoto is drained by river Rima and its tributaries, which rises from Kaduna state and empties its water into river Niger.

Water is supplied to the metropolis from the Rima dam, owned and managed by the Sokoto State Water Board. In addition, numerous privately owned bore holes and hand dug wells are available from where people fetch water for domestic use. The water vendors also play a major role in water supply in the city

Materials and Methods

The data required in this study consist of: information on the coordinates of the selected hand dug wells, information on surface elevation of the selected wells, data on well depth, information on water levels of the wells, information on rainfall incidences and rainfall amount and finally the digitized map of the study area. These were obtained from primary sources, mainly field work. These data were collected at different times namely; the period before the rains, after the first rain and after the second rain. Twenty sampling points were selected within the metropolis. This was done after a careful study of the base map. Sample points were representative of the entire landscape of the metropolis. Hence, Sokoto metropolis was demarcated into 3 zones namely; Western Bye pass, Old airport road, and Runjin Sambo area.

The data collected were interpreted using 2 methods, namely: Geographic Information System (GIS) approach and statistical methods. The coordinates and elevation data were obtained through the use of Global Positioning System (GPS). These primary data formed input into Surfer 10 Mapper software environment. The variables were converted to Point data in ArcGIS environment. Using 3D analyst tools, the static water level values were converted to a Digital Elevation Model (DEM), from which the static water level contours and 3D model of the study area were generated in ArcGIS and ArcScene environment respectively. These were contoured on the map of Sokoto environment. According to Buddermeier and Schloss (2000), ground water would flow from the highest values of contour lines to lowest values in a direction perpendicular to the contour lines.

Both descriptive and inferential statistical methods were used in this study. The descriptive method includes mean, standard deviation, coefficient of variation, graphs and tabulation method. The inferential method involves the use of one way ANOVA which was used to find out if significant differences exist in rainfall incidences and ground water level fluctuations in Sokoto metropolis.

Results and Discussion

Rainfall Incidences and Onset

The first rain in 2011 was recorded in 12th May 2011; the next rain to this was recorded in 22nd May. According to Table 1, about six events were observed before the second sample was taken. These make a total of 130.8 mm antecedent moisture content. However, it must be noted that Sokoto is in a semi arid region where soil moisture in May is almost nil after about 9 months of dry season. The second group of samples were taken after the rain of 21st June, 2011, however, unlike what obtains in the case of the second sample, there were 3 incidences of rainfall before the last or 3rd samples were taken, but only the rain of 20th June was significant with 45.8mm to groundwater seepage, the other 2 were trace events. Hence, one may not expects significant response in groundwater levels, as the level of recharge was rather low as at May; as June mark the onset of rain in Sokoto (Table 1 and Figure1).

Table 1: Rainfall Incidences and Rainfall Onset in Sokoto (2010)

May	1	Date	Rainfall Amount (mm)
	2	12 May	14mm
	3	22 May	0.4mm
	4	25 May	24.1mm
	5	27 May	51.0mm
	6	28 May	3.2mm
June	7	10 June	38.1mm
	8	11 June	TR
	9	13 June	21.3mm
	10	17 June	TR
	11	18 June	TR
	12	20 June	41.4mm
	13	23 June	45.8mm
	14	26 June	TR
	15	29June	14.6mm

Source: NImet, Sokoto Airport, Nigeria

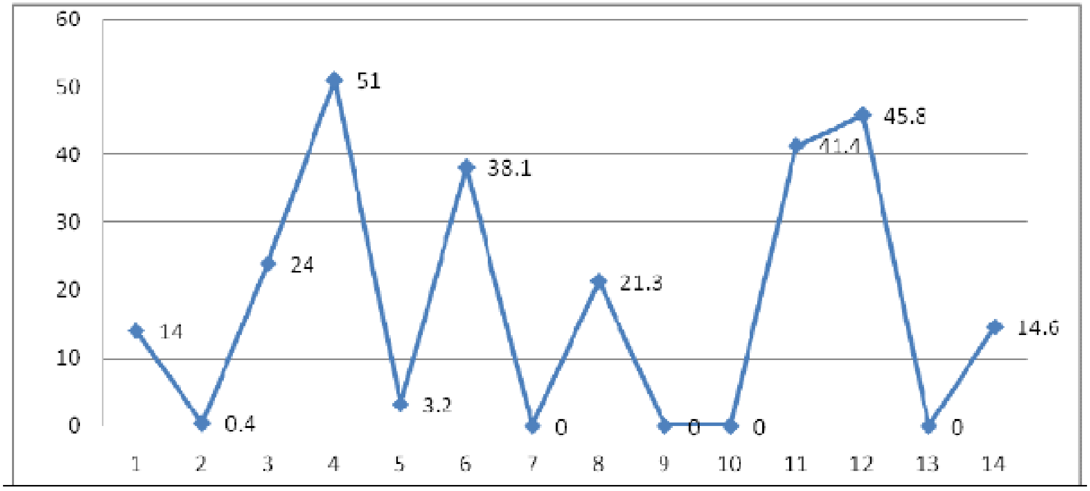

Figure 2: Rainfall Amount and Incidences (May 12 – June 29, 2011)

Differences in water level with rain fall incidences

According to Table 2 the lowest water level was recorded in Mabera/Eastern bye pass area where water level before the first rain was 17.2meters, this is followed by the period after the first rainfall having 17meters, while after the second rainfall water level increased to 16.9meters. The lowest water level was recorded in Kara where shallow water level of 1.7m was recorded in the period before the rain, after the first rain and second rain water level increased to1.4m and 1.2m respectively. With the exception of locations such as Dan Dutse University road, Adua road/Gidan Dutse and University road/Gidan Magaji all other 17 locations have a progressively increasing water level. Suggesting that water level only increased with rainfall incidences in these wells.

Table 2: Groundwater level at different rainfall incidence scenarios

Location	1st sample 6-May-2011	2nd sample 14-June-2011	3rd sample 21-June-2011
1. Mabera M. Idi Eastern Bye Pass	17.2	17	16.9
2. Mabera Idi	10.5	8.5	5.0
3. Dan Dutse Univ. P-site	9.2	9.8	9.75
4. Yahaya Yusau Old Airport	8.7	7	6.6
5. Dutsen Taila Gidan Igwe	8.4	0	0
6. Line G. Polo Club	8.4	7.8	7.0
7. Federal Low-cost Arkilla	7.71	7.25	6.40
8. Unguwar Rogo Kuyan Bana Road	6.8	6.55	6.0
9. Adua Road Gidan Igwe	6.7	7.10	6.5
10. University P-site 1 Gidan Magaji	6.77	6.8	6.8

11. Gagibi Ward Mabera M. old Airport	6.5	5.5	4.9
12. Sahara, Off Emir Yahaya Road	6.1	5.8	5.3
13. Western Bye pass Gidan Dare	6.1	4.6	4.55
14. Lokoja Road,Anguwan Rogo	5.8	5.5	5.2
15. Hajiya Halima Off Fodio Road	5.5	5.4	5.2
16. Western Bye Pass Site II	3.7	3.0	2.8
17. Gravel Market Opp. GT bank	3.1	2.9	2.7
18. Waziri A. Magaji Gari A	2	1.45	1.21
19. Kara Off Eastern Bye Pass (Gada)	1.7	1.42	1.20
20. Kuppa Eastern Bye Pass	1.75	1.6	1.40
Groundwater Total	**132.63**	**114.97**	**105.41**
Mean (m)	**6.625**	**5.74**	**22.37**
Standard Deviation (m)	**28.15**	**24.39**	**22.37**
Co-coefficient of Variation (%)	**21**	**21**	**21**

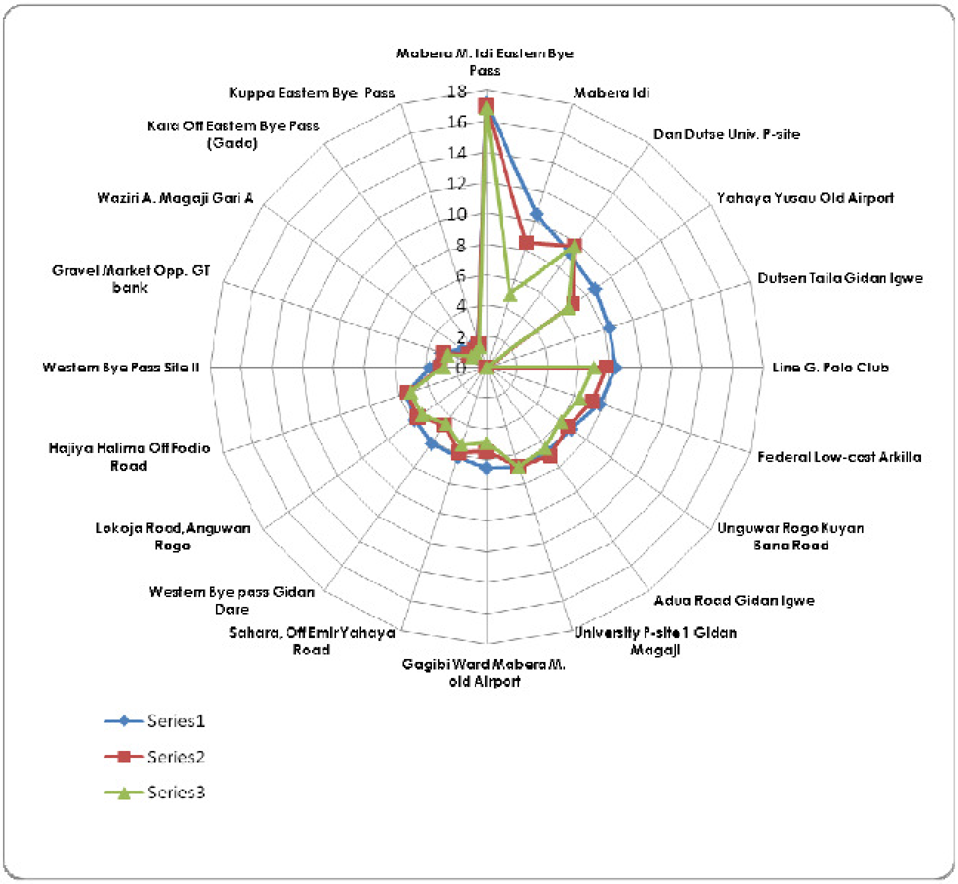

Figure 3: Pattern of Groundwater Fluctuation by Rainfall Incidences

The result of the ANOVA statistic presented in Table 3 shows that no significant difference exist between water levels in shallow wells in the 3 scenarios.

Table 3: ANOVA Table showing differences in groundwater level with rainfall events

F_{cal}	F tab	Decision rule
0.034	6.110	No significant difference exist in the level of water in shallow wells with rainfall events

The type of rainfall experienced around Sokoto metropolis is referred to as line Squall falling by the direction of wind (Easterlies) and mostly in form of shower and the duration of rainfall lasts for between 30-50mins. This rainfall is normally of high intensity, this therefore suggests that rate of infiltration will be low hence; groundwater recharge will also be low. The relatively low rainfall may be responsible for the similarities experienced in groundwater levels in the 3 scenarios of the study area.

The trend recorded by groundwater levels is expected, and this can be explained in the context of the fact that dry season rainfall in May and June are rather too little to have any significant impact on groundwater level. This is because in these months, the soil moisture deficit is little for any significant impact; therefore any additional water into the soil matrix will be absorbed by the soil matrix. The water level recorded after the first 2 rainfall incidences were insignificant to recharge the soil. The geological structure of rapid response to rain or flood events may indicate conduit dominated intake, whereas response delayed by weeks or months indicates recharge through homogeneous porous media (Mazor, 2004). This suggest that the homogeneity experienced in the 3 scenarios may also be partly due to the nature of the geology of the metropolis; whereby underground pipes are not likely, indeed, the materials of the study area are largely sandy and clayey, with limited chances for piping.

Groundwater Direction of flow

The one grid vector map produced for the study area indicates direct control of elevation on groundwater supply. Water flows from areas of higher elevation towards those of lower elevation. The result of the vector analysis shows that groundwater movement in Sokoto metropolis are in four directions. These are:

West-Northeast direction: The areas affected are mainly Lokoja Road- Angwan Rogo Western Bye Pass, Gidan Dare road and Uguwan Rogo Kuyan Bana Road. .

West-East direction: The areas in this category are University Permanent Site –Gidan Magaji (268m), Dan Dutse- University Permanent Site 2 (266m).

South-Northwest direction: This direction of flow of groundwater affect such as Line G, Polo Club, Gwiwa Low-Cost Arkilla (303m), Sahara Off Emir Yahaya Road (279m).

North-South direction: This category of groundwater movement include Gagibi Ward, Mabera Mujaya Old Airport Road (250m), Yahaya Gusau old Airport Road (237m) both are found at the southern margin of Sokoto metropolis.

This information is quite relevant to groundwater development and planning, especially it will provide baseline data for groundwater monitoring and groundwater development, as direction and points of contamination will easily be monitored.

Zones of Groundwater Levels

The results of the analysis showed that water table in Sokoto metropolis can be classified into 5 groups.

Extremely High water level: The Table 3 shows that wells in this zone have an average water level of 1.7 to 3.7m. These areas include: Karra off Eastern By Pass (1.7m), Kuppa Eastern By Pass (1.75m), Waziri A.Magajin Gari (2m), Gravel Market opposite GT Bank (3.1m), Western By Pass Site 2 (3.7m) Most of the wells in this locations are shallow. They have more quantity of water and are likely to last longer. However the disadvantage they might have is that they will be exposed to surface pollution and the intrusion of soak-away seepage.

High water level : Shallow wells in this zone ranges between 3.7 to 6.5m include Hajiya Halima off Fodiyo Road (l 5.5m), Lokoja Road Angwan Rogo (water level 5.8m), Gidan Dare off Western By Pass (6.1m), Gagibi Ward Mabera Mujaya Old/ Airport Road (6.5m). Wells in this location are shallow and have appreciable quantity of water.

Moderately High water level: Wells that fall into this category 3 range between 6.5 to 6.8m deep. They include: Gidan Magaji/University Permanent Site 1 (6.77m), Adua Road//Gidan Igwe(6.7m), Kuyanbana Road Anguwan Rogo (l 6.8m). These wells are quite deep and narrow in width in order to raise an appreciable quantity of water specifically during dry season.

Low Water Level: Range of wells in category 4 include: Federal Low-Cost Arkilla (7.71m), Line G Polo Club Gwiwa Low-Cost (l 8.4), Dutsen Taila/ Gidan Igwe (8.4m). These wells are deep.

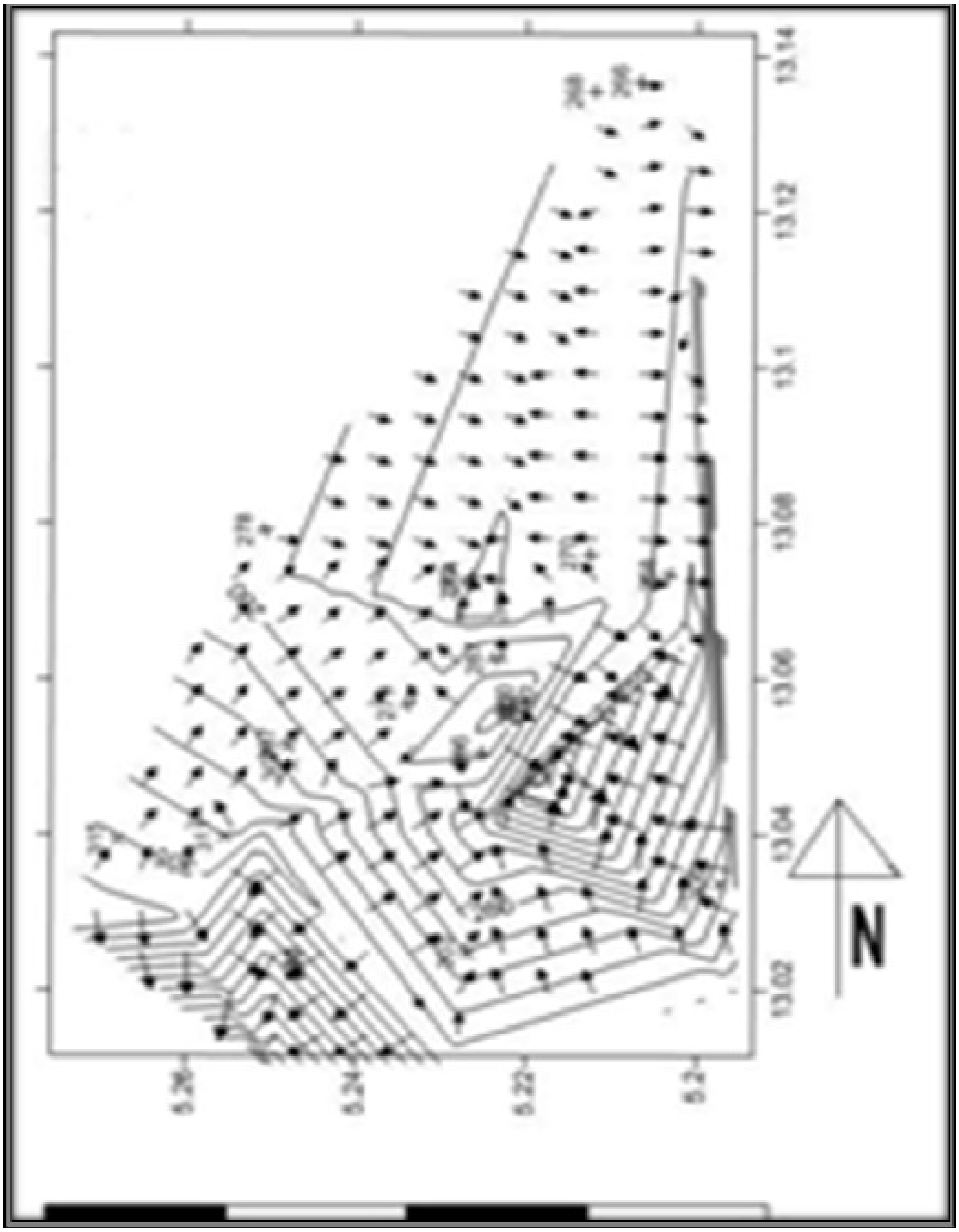

Figure 3: One Grid Vector Map Direction of Flow of Groundwater in Sokoto Metropolis, Nigeria

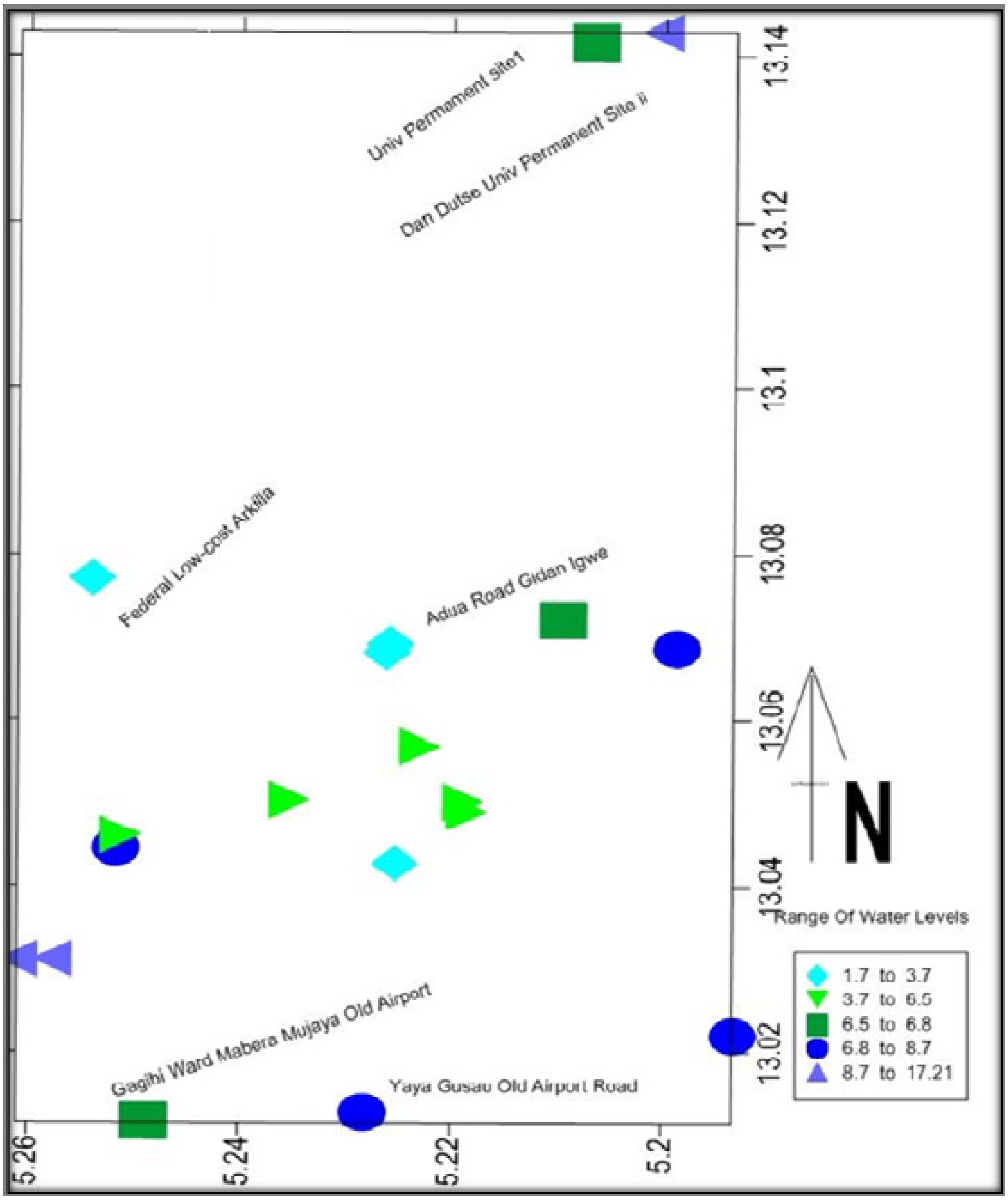

Figure 4: Zones of groundwater in Sokoto

Table 4: Zones of groundwater levels

No	Range		Well Sites
1	1.7-3.7	◆	Karra off Eastern Bye Pass, Kuppa Eastern Bye Pass, Waziri A.Magaji Gari .A,Gravel Market off GT Bank, Western Bye Pass Site 2.
2	3.7-6.5	▼	Hajiya Halima off Fodiyo Road, Lokoja Road Unguwan Rogo, Gidan Dare off Western Bye Pass, Sahara off EmirYahya Road, Gagibi Ward Mabera Mujaya Old Airport Road.
3	6.5-6.8	■	Gidan Magaji University Permanent Site 1, Adua Road Gidan Igwe, Kuyanbana Road Anguwan Rogo.
4	6.8-8.7	●	Federal Low-Cost Arkilla, Line G Polo Club Gwiwa Low-Cost, Dutsen Taila Gidan Igwe
5	8.7-17.2	▲	Yaya Gusau Old Airport, Dan Dutse University Permanent Site 2, Mabera Idi,Mabera Mujaya Eastern By Pass.

Extremely Low water Level: wells in this zone are the deepest in the study area, they have very low water level. They range from 8.7 to 17.2m. They are found in Yaya Gusau Old Airport Road (8.7m), Dan Dutse/University Permanent Site 2 (9.2m), Mabera Idi (10.5m), Mabera Mujaya Eastern by Pass (17.2m). These wells are found to be the most deepest among all the shallow wells surveyed in the study area with Mabera Mujaya (Eastern by pass with the deepest (17.2m) during raining season and (16.9m) during dry season. Wells in this zone are likely to be of better quality as they are somehow protected from surface pollution because of their depth.

Implication for Water Resource Management

Sokoto metropolis experiences 3 months of rainfall and 9 months of dry season, it is experiencing increasing population, high evapotranspiration, high rate of poverty, and low rate of female school enrolment. All these have implications for water supply.

Shallow groundwater plays significant role in water supply in cities, particularly in Nigeria, where urban water supply infrastructure are overstretched due to poverty, poor regional development and overpopulation. Hence, they consequently take to digging of hand dug well, which is cheaper, affordable, and available at the point of demand.

The result obtained in this study shows that early incidences of rain have little impact on ground water level. This is because dry season rainfall just as what was recorded in the study area is too little to effect significant effect on groundwater level, especially at the immediate period. For most part of the year, soil moisture deficit predominate and therefore soil matrix absorbs the first few events of rain and consequently prevent it from participating in groundwater flow or seepage. This suggests rainfall incidences particularly in the months of May and June are not strong enough to influence groundwater water level significantly.

The result of the vector analysis has also categorized groundwater flow into flow directions. The pattern displayed by the direction of flow is quite surprising in view of the relatively rolling topography of Sokoto. However, this pattern is expected in sedimentary aquifers. The implication of the direction of flow is to assist in conserving groundwater from pollution, when such direction is understood; effort will be made to control groundwater contamination along such corridors, since direction flow assist in identifying the zones of groundwater recharge of wells, stream, etc it will also assist land use management.

Furthermore, groundwater level was also grouped into 5 regions. This regionalization on the basis of water level is to assist better water management in Sokoto metropolis. In areas of extremely high water table effort should be made to check faecal pollution, as surface pollution and soak-away effluents will contaminate groundwater. Furthermore, in this area time spent in fetching water will be reduced. In areas with extremely low water level the quality of water will be quite high and little faecal pollution is expected. In addition, there will be a need for storage facilities.

This paper therefore concludes that rainfall may not be a good determinant of water level at the rainfall onset period. Hence, explanations of groundwater fluctuation at the onset period will only be explained in the context of other variables such as rate of evapotranspiration, change in atmospheric pressure, direct abstractions, etc.

It is hereby recommended that, in view of the relevance of shallow groundwater to urban water supply there is need to embark on public enlightenment on the best practice of sitting hand dug wells, this will assist in preventing indiscriminate digging of hand dug wells and their subsequent contamination by soak away pits. The information on direction of low and groundwater regions could form a basis for a straight forward feasibility project for holistic groundwater development efforts for Sokoto metropolis.

References

Adelana, S.M.A. and MacDonald, A. (eds) (2008). *Applied Groundwater Studies In Africa*, London. 507pp.

Alaku, S.O. (1991). Conservation and management of water resources in the semi arid areas of northern Nigeria. In Arid *Zone Hydrology and Water Resources,* N.M. Gadazama (ed) University of Maiduguri press, Nigeria. Pp.179-195.

Bredehoeft, J.D. (1967). Response of well-aquifer systems to earth tides. *Journal of Geophysical Research,* 72(12): 3075–3087.

Brodie, R.S. and Hostetler, S. (2005). 'A review of techniques for analyzing base flow from stream hydrographs'. http:/www.connect.iwater.gov.au/document/IAH05_Baseflow.

Brodie, R.S. and Hostetler, S. (2005). 'A review of techniques for analyzing baseflow from stream hydrographs'. http:/www.connect.iwater.gov.au/document/IA H05_Baseflow.

Buddermeier, R.W. and Schloss, J.A. (2000). Groundwater Storage and Flow.

http://www.kgs. Ukans.edu/Hight plains/atlas//apgengw.htm.

Chleq, J.L. and H. Dupriez. (1988). *Vanishing Land and Water. Soil and Water Conservation in Dry Lands*. MacMillan/ Terres et Vie, London.

Flügel, W.A. (1995). Delineating Hydrological Response Units (HRU's) by GIS analysis for regional

Griffiths, G.A. and Clausen, B. (1997). Stream flow recession in basins with multiple water storages. Hydrological modeling using PRMS/MMS in the drainage basin of the River Bröl, Germany . *Hydrological Processes*, 9: 423-436.

Hsieh, P.A., Bredehoef, J.D. and Rojstaczer, S.A. (1988). Response of well aquifer to earth tides : Problem revisted, *Water Resource Resaerch,* 24 (3): 468-472.

Ifabiyi, I. P. (2011). Response of Groundwater to Basin Variables in The Upper Kaduna Catchment, *Global Journal of Human Social Science*, 11 (6) Online Issn: 2249-460x & Print Issn: 0975-587x *Journal of Hydrology*, 190: 60-74.

Kogbe, C.A. (1989). *Cretaceous and Tertiary of the Iullemmeden Basin in Nigeria*. In: C.A. Kogbe (eds.), Geology of Nigeria, 2nd edn, Rock View, Jos.

Mazor, E. (2004). *Chemical and isotopic groundwater hydrology*, 3rd Edn. Dekker, New York, 453 pp

Ndubuisi, O.L. and Ujuanbi, O. (2006). Assessment of water well efficiency in Eshan district of southern Nigeria. *Journal of Engineering Science Application,* 4: 140-151.

Neal, B.P., Nathan, R.J. and Evans, R. (2004). 'A survey of base flow in unregulated stream of the Murray- darling basins'. *Proceedings 9th Murray Darling Basin Groundwater Workshop*, Bendigo.

Quian, J., Zhan, H., Weidong Z. and Sun, F. (2005). Experimental study of turbulent unconfined groundwater flow in a single fracture, *Journal of Hydrology,* 311: 134–142

Singh, R.B. (2001). Impact of land use change on groundwater in the Punjab-Haryana plains, India. *IAHS publ.* 269:117-121

Smatkin, V.U. (2001). Low flow hydrology: a review. *Journal of Hydrology*, 240: 147-186.

Tianqi, A.O. (2003).'Effects of sub basin scale on runoff simulation in distributed hydrological model: BTOPMC. Weather radar information and distributed hydrological modeling' *Proceedings of symposium HSO3* held during IUGG 2003 at Sapporo, July 2003 *IAHS publ.* 282: 1-7.

Todd, D. K. (1980). Groundwater Hydrology, 2nd edition. 535 pp