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Assessment of static water level and overburden pattern for sustainable groundwater development and management in Ilorin City, Nigeria

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Abstract

Basement aquifers are usually developed within the weathered, over-burdened and fractured bedrock of crystalline rocks which can provide a sizeable amount of groundwater if the overburden is relatively thick enough to store percolating water. This study assessed the static water level and overburden pattern for sustainable groundwater development and management in Ilorin city, Nigeria. The data on depth of boreholes, depth to water, water level of 100 boreholes and the Vertical Electrical Soundings (VES) data conducted before the borehole were drilled, were collected from Kwara State Ministry of Water Resources and Lower Niger River Basin Development Authority, Ilorin. All the Vertical Electrical Soundings (VES) data collected were conducted with ABEM SAS-1000 Terrameter using the Schlumberger electrode configuration, and the electrode spacing (AB/2) varied from 10m to 200m. From the manual interpretation of each VES curve, we estimated the overburden thicknesses. Field work was embarked on to get the coordinates (locations) of the sampled points using handheld GPS. Pearson Moment Correlation Coefficient was applied to determine the level of association between borehole parameters and thickness of overburden. The static water level and contour map were computed with the data on depth to water and the coordinates to show the pattern of water level in Ilorin, using ArcGIS 10.2 and Surfer 12 GIS software. The depth of overburden and the point location collected were also used to plot the overburden map using IDW interpolation. This study classified Ilorin into poor (overburden <10m), marginal (10m-19m overburden) and good or high zone (overburden ≥ 20m) of groundwater potentials. The spatial pattern of overburden depth revealed that the majority of Ilorin city was underlain by marginally thick overburden. The study concluded that sustainable groundwater development and management in Ilorin city could only be attained by controlling the indiscriminate drilling of boreholes (wells), continuous mapping and regular updating of the available records on groundwater resources.

Keywords: basement complex, groundwater development, groundwater management, Nigeria, overburden pattern, sustainable management

Introduction

The greatest importance of groundwater besides its eco-hydrological functions, is in sustaining human life. Groundwater provides a high proportion of withdrawals amounting to more than 20% in most countries mainly for domestic supplies, mines, industries and irrigation (Nyagwambo, 2006). The main advantages of groundwater are that it occur in-situ, often of potable quality and does not require expensive treatment and permits scaled development using infrastructure that is usually of lower cost in relation to surface water feed supplies, this factor makes groundwater more ideal for poverty alleviation than surface water (Taylor et.al, 2009, Nyagwambo, 2006). However, groundwater occurrence in any region of the world is largely dependent on the nature and type of aquifer in such environment (Ifabiyi, et. al., in press). This is because the nature and type of aquifer determines the quantity of groundwater that can be abstracted in a particular area to support her population. This is why it is extremely important to determine the groundwater potential of an area for sustainable development and management.

Available records shows that major aquifers in Nigeria are located in the sedimentary deposit basins which cover about 50% of the nation's land area. The remaining 50% is underlain by crystalline rocks of the basement complex (Nwankwoala, 2011). Aquifers within the basement are limited, their thickness ranges from 16 to 180 m. The depth of hand dug wells and boreholes are rarely more than 60 m with varied average static water level between 1 to 45 m below the surface. This shallow depth coupled with the poor hydraulic conductivity account for the general low yield experienced in most part of basement complex rock (Nwaogazie, 1995). Ilorin city is underlain by Precambrian Basement complex; comprising mostly gneiss, granite, schist, undifferentiated meta-sediments rocks and overburden that are composed mainly of clay, sand and silt soils. The nature of aquifer (shallow) in the study area, which is a function of the depth or thickness of overburden makes most of the shallow well to be seasonal and some of the deep wells failing at critical time (dry period).

Various water projects and planning have been undertaken in the city with the view to meet the increasing water demand of the populace. The first water supply scheme completed in 1952 was the Agba dam project even before the creation of Water Corporation with an output of 3,100 cubic meters per day (685,000 gallons). The output was raised to 1.2 million gallons per day in 1974. According to Kwara Water (2010) the water need at that time was about 7.2 million gallons which meant a deficit of 6.0 million gallons. This prompted the construction of Asa dam on river Asa which is a three phase project and currently has an output of 25.5 million gallon per day (Kwara Water, 2010). Recently various water projects has being developed in the study area ranging from automated bore hole to the traditional hand-pumped type; all these are in anticipation of supplying good potable water to the increasing population. Despite all these efforts, problem of water supply is still evident in Ilorin city. This however call for sustainable development and management of the groundwater resources of this area, to meet the need of the rapidly increasing population. Ifabiyi and Ashaolu (2013) reported that pipe borne water supply in the city is limited to some certain areas. In fact, the residents of this city depend on groundwater (borehole and Shallow Well) to augment the water supply from the Water Corporation, even in areas where there is pipe borne water coverage.

According to Sophocleous (2000) sustainability is a widely used idea that is not well understood. Consequently, different levels of development in different countries or different locations within countries, sustainability may mean different things from country to country and within country. Sustainable development of any form of natural resource as a concept, is the development that meets the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987). In this context, sustainable groundwater development and management in Ilorin and Nigeria at large means the development and management of groundwater resources to meet the present water need in the face of changing climate that is already affecting our surface water resources and not compromise the ability of the unborn generations to meet their groundwater need.

Sustainable groundwater management and development in Ilorin city and Nigeria at large is faced with series of problems and short comings which requires urgent attention. According to Nwankwoala (2011) suitable machinery for the effective and sustainable management of groundwater resources in Nigeria has not yet evolved. According to him, authorities have put up institutions for this purpose, but at the same time set up rival agencies to carry out very overlapping functions. This results in wastage of available resources, leading to lack of progress in groundwater development and management. He further stressed that the Nigerian water problem revolves round two critical issues, namely: Inadequate access/poor distribution of water resources in time and space in relation to the needs of the people, and inadequate planning and management of these resources (Nwankwoala, 2011).

Furthermore, unavailability of data such as geographical information on water quantity, hydrology, state of aquifers and withdrawal limits have contributed to the unsustainable use of groundwater in Nigeria (Omole, 2013). Data on groundwater levels are not widely published or made available outside government organizations in Nigeria. As a result, discussions on groundwater overexploitation and depletion are always based on unrealistic data. However, it is a fact that falling water tables and depletion of economically accessible groundwater reserves will have serious socio-economic consequences in a country like Nigeria and Ilorin city in particular. Therefore, it is needless to point out that there is an urgent need for conservation of this vital resource for sustainable groundwater development and management in Nigeria (Nwankwoala, 2011) and Ilorin city where study has shown that the corporation saddled with the responsibility of providing potable water supply from the surface water resources is faced with numerous challenges (Ifabiyi & Ashaolu, 2013).

Generally, one of the most important strategies for sustainable management of groundwater is regulation in critical areas. A study by Nwankwoala and Mmom (2006) has recognised over exploitation and development of groundwater resources as a major problem, especially in the Niger Delta region. Omorinbola as far back as 1982 reported a systematic decline in groundwater level in the regolith of the basement complex of some parts of southwestern Nigeria due to human activities (Omorinbola, 1982). According to Nwankwoala, (2011), the tendency towards over exploitation of groundwater resources is rooted in the rapid spread of energized pumping technologies, resource characteristics, demographic shifts and incoherent/inconsistent government policies. However, the problem of groundwater sustainability can be met through groundwater resources mapping. Not only can the information be obtained at regular intervals but their accurate state, can also be updated. In this context, efficient groundwater policy is imperative if sustainable groundwater utilization is to be realized (Nwankwoala, 2011).

As stated earlier, the nature and type of aquifer determines the quantity of groundwater that can be abstracted in a particular area to support the population of such area. In the basement complex rock, it is the depth or thickness of the overburden that determines if a sizeable amount of groundwater can be exploited, and if it can sustain the population concentrated around such aquifer. Therefore, the depth or thickness of overburden is an important factor that need to be considered in drilling of boreholes in the basement aquifer. Several studies have revealed the expected depth of overburden in a basement complex aquifer before a sizeable amount of groundwater can be obtained. Olayinka et al. (1997) is of the view that for a productive well, the value of overburden thickness should range between 20m and 30m.Other scholars suggested a minimum overburden thickness of 25m for viable groundwater abstraction (Oladapo, et al., 2004; Olorunfemi & Okhue, 1992). White et al, (1988) is of the opinion that a minimum of 10m of overburden thickness before an adequate yield can be ensured. Oladapo et al. (2009) also classified area with less than 10m thickness of overburden as poor groundwater potential and areas above 10m but less than 20m as areas of marginally thick overburden which they termed as shallow aquifer units. Wright (1992) reported that in the basement areas of Zimbabwe between 20m and 25 m of overburden is the minimum required before siting a borehole. From the submissions of these scholars, it is clear that a productive well cannot be sited in any area on a basement complex rock with less than 10m of overburden thickness.

From the foregoing, sustainable groundwater development and management can be met through groundwater resources mapping to identify zones of poor and good groundwater potential using the thickness or depth of overburden as a criteria. This will revealed the spatial pattern of groundwater resources, which will enable proper planning, development, control and abstraction of groundwater resources of Ilorin city and Nigeria at large to meet the needs of present and not sabotage the need of future. The specific objectives of this research is to assess the static water level and overburden pattern of Ilorin city, Nigeria, with the intention to identify and mapped areas of poor, marginal and high groundwater potential. This will enable us to give a recommendation for sustainable groundwater development and management in Ilorin city.

Study area

Ilorin city, the Kwara state capital is located between latitude 08°24'N and 08°38'N of the equator, and longitude 04°26' E and 04°37'E of the Greenwich meridian. Ilorin city is one of the fastest growing urban centers in Nigeria and has a tropical wet and dry climate. Wet season is experienced from April to Octoberer and dry season from November to March. Rainfall condition in Ilorin exhibits greater variability in time and space. The mean annual rainfall is about1200mm. The population growth rate is much higher than other cities at 2.8 percent of the national growth. The 2006 census put the population of Ilorin city to about 847,582 (NPC, 2006 provisional results). The city has a geological settings consist of Precambrian basement of south western Nigeria and is underlain by rock of metamorphic and igneous type (Ige & Ogunsanwo, 2009) complex with numerous patches of undifferentiated meta-sediment rocks and overburden that composed mainly of clay, sand and silt soils. This is same for more than 90% of kwara state with only a few areas in the northeast with cretaceous sediment underlay. The underlying pre-cambrian igneous-metamorphic rock of Basement Complex rock is neither porous nor permissible except in places where they are deeply weathered or zones of weakness. There are productive shallow wells and boreholes in this area but there are also numerous failing wells and boreholes especially during the dry season. Ilorin city has generally undulating land scape with an elevation of between 273m to 333m above sea level. There is an isolated hill (Sobi Hill) of about 394m above sea level towards the north of the western part and 200m to 346m in the east. The pattern of drainage system of Ilorin is dendritic due to its characteristics. The important rivers are Asa and Oyun which flows in south northern direction. It occupies fairly wide valley and divide Ilorin into two parts namely the eastern and western part. The rivers that drain into Asa are Agba, Alalubosa, Osere, Okun and Aluko. See Fig. 1 for the map of study area.

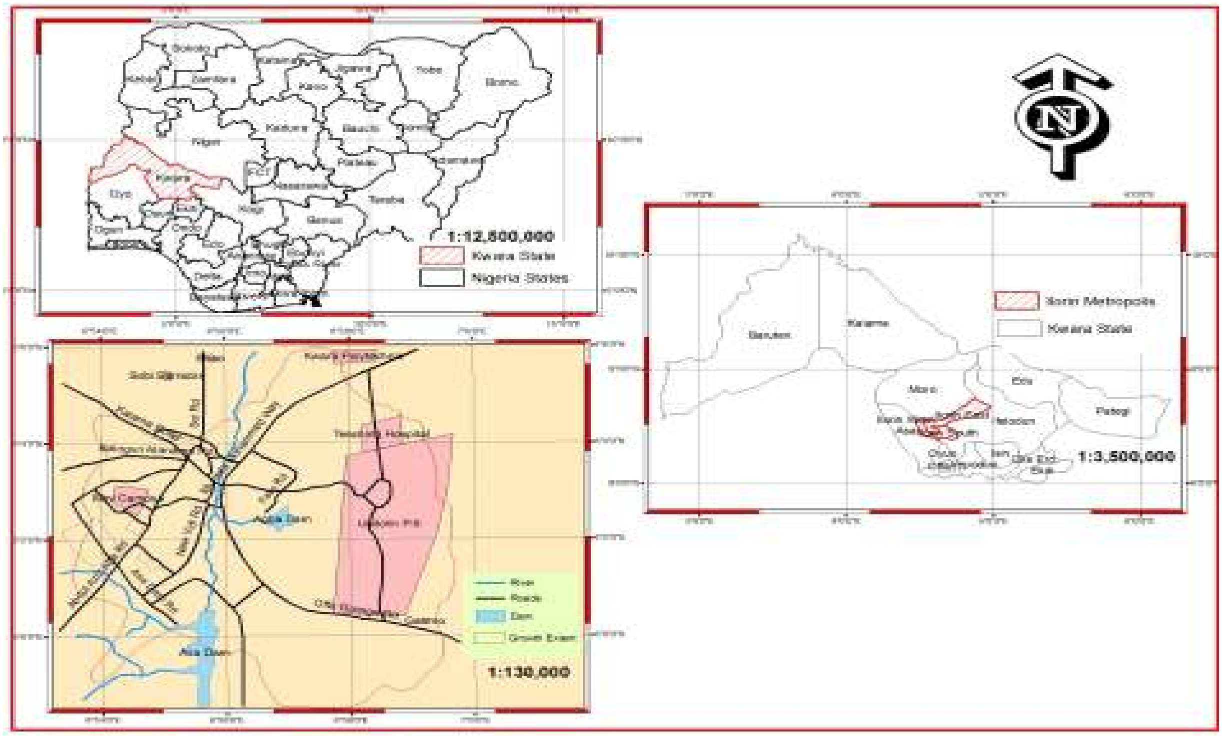

Figure 1. *Map of Nigeria showing Kwara State and Ilorin City*

Material and methods

The method adopted for the study is a combination of secondary and primary (field work) data. The secondary data include depth of borehole, depth to water, water level of 100 boreholes and the Vertical Electrical Soundings (VES) data conducted before the borehole were drilled. These secondary data were collected from Kwara State Ministry of Water Resources and Lower Niger River Basin Development Authority, Ilorin. All the Vertical Electrical Soundings (VES) data collected were conducted with ABEM SAS-1000 Terrameter using the Schlumberger electrode configuration, and the electrode spacing (AB/2) varied from 10m to 200m. The manual interpretation of the VES data collected was accomplished using the conventional partial curve matching technique (Koefoed, 1979) with two-layer master curves in conjunction with auxiliary point diagrams (Orellana & Mooney, 1966). From the manual interpretation of each VES curve, we estimated the overburden thicknesses, and these were refined using WINRESIST computer software, to reduce the interpretation error to acceptable levels (Baker, 1989).

The field work was carried out to get the coordinates (locations) of the sampled points using handheld GPs. This was carried out to get the coordinates of all the borehole used in the study, which facilitated the plotting of the data in ArcGIS and Surfer GIS software. Descriptive statistics such as mean, standard deviation and coefficient of variation were used to summarized and see the level of dispersion of the data, while inferential statistics such Pearson Moment Correlation Coefficient was used to determine the level of association between borehole parameters and thickness of overburden. The water level and contour map were computed using the data on depth to water and the coordinates (latitude, longitude and elevation) taken, to show the pattern of water level in the study area. This were carried out in ArcGIS 10.2 and Surfer 12 GIS software, this approach was also used by Ashaolu and Adebayo (2014). The depth of overburden and the point location collected were used to plot the overburden map of the study area. Point locations and depth of the overburden were plotted in ArcGIS 10.2 and Inverse Distance Weighted (IDW) interpolation was carried out to generate the overburden thickness map of the study area. The generated map was further classified into three categories of groundwater potential of Ilorin city.

Results and discussion

Descriptive summary and pattern of water level in Ilorin City and descriptive summary of borehole parameters and overburden thickness

Table 1 shows that borehole depth varies from 30m to 45m, with mean of 39.53m, standard deviation of 4.13m and coefficient of variation of 10.45%, which indicates that there is less variability in borehole depth across the study area. The water level varies from 20.13m to 38.60m, with mean of 31.52m, standard deviation of 3.95m and coefficient of variation of 12.53%, which indicates that there is also less variability in water level across the study area. The depth to water (static water level) varies from 2.06m to 10.30m, with mean of 7.08m, standard deviation of 1.77m and coefficient of variation of 25.00%, which indicates that depth to water varied slightly in the study area. The depth of overburden varies from 3.50m to 30m, with mean of 14.58m, standard deviation of 5.93m and coefficient of variation of 40.67%, which indicates that the depth of overburden varied across the study area. The variation in the depth of overburden falls within the range predicted by previous studies in the basement complex rock aquifer of Nigeria (Olorunfemi & Okhue, 1992; Olorunfemi et al., 1999; Oladapo et al., 2009; Oyedele & Olayinka, 2012).

Table 1. Descriptive statistics of borehole parameters and overburden thickness

Parameters	Minimum	Maximum	Mean	Std. Deviation	CV
Depth of Borehole	30.00	45.00	39.53	4.13	10.45%
Water Level	20.13	38.60	31.52	3.95	12.53%
Depth to Water	2.06	10.30	7.08	1.77	25.00%
Depth of overburden	3.50	30.00	14.58	5.93	40.67%

Relationship between borehole parameters and overburden thickness

Pearson Moment Correlation Coefficient was used to determine the relationships between borehole parameters (borehole depth, depth of water and depth to water) and depth of thickness of overburden in the study area. Borehole depth exhibits a very strong relationship with depth of water (r=0.781), depth to water (r=0.537) and thickness of overburden (r=0.519), which are statistically significant at 99% confidence level. All things being equal, these results on the one hand, indicate that the deeper the well, the deeper the depth of water, depth to water and thickness of overburden, respectively. On the other hand, as the depth of well decreases, the depth of water, depth to water and thickness of overburden decreases. These results are expected because the depth of well is a function of depth of water, depth to water. Also, depth of borehole and thickness of overburden are closely related because the thicker the overburden, the deeper the borehole. Depth of water exhibits a positive relationship between depth to water (r=0.394) which is statistically significant at 95% confidence. This suggested that as depth of water increases, depth to water also increases and vice versa.

Table 2. Relationship between borehole parameters and overburden thickness

	Depth of Water	Depth to Water	Overburden
Borehole Depth	.781**	.537**	.519**
Depth of Water		.394*	0.199
Depth to Water			0.154

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Pattern of static water level (depth to water) in Ilorin City

The static water level values calculated were converted to a Digital Elevation Model (DEM) using 3D analyst tools. This was used to generate the static water level contours and 3D model of Ilorin city using ArcGIS 10.2 and Surfer 12 software. The values of the static water levels were contoured on the map of the study area as shown in Figure 2. The highest elevation values ranges from 375m to 360m above sea level. This consists of areas such as Wonderland, Tanke area, and Olorunshogo, while the lowest elevation is Royal valley area which is 285m above sea level.

The pattern of static water level in Ilorin city are calibrated to show the range of the water level and which area in the study area falls within these ranges. The highest static water level range from 8.45-10.15m from the surface of the earth, while the lowest range from 2.89-5.6m. Static water level ranges from 2.89-5.6m from the surface in places such as Adewole, Ganiki sango area, Alagbado area among others, this shows that water level is closer to the surface in these area. While in places like Kilanko and Royal valley estate have static water level that ranges from 5.61-6.66m from the surface of the earth. In all these areas with static water level ≤ 6.66m, the groundwater will be vulnerable to contamination and people in this area will prefer shallow wells, since it is cheaper to drill using crude methods (digger and holes) than deep well that requires sophisticated equipment.

Further, places like Okelele, Banni, Oloje, Pakata, Fate-tanke, Al-Hikmah area, Asa Dam, Tanke area, Apata Yakuba, Oyun have water level that range from 6.67-7.51m. Static water level ranges from 7.52-8.44m in places such as wonderland, Olorunshogo area, Gaa-Akanbi and Asunnara area. In places like Bal Engineering area, Yebumot Hotel area, Okoolowo and Babooko, static water level ranges from 8.45-10.15m, this suggested that water level is farther to the surface in these areas compared to all other areas in Ilorin. Shallow wells located in these areas may not be very productive especially in dry periods. As revealed in Figure 2, the central part of Ilorin city with higher elevation coincides with the areas that have higher depth to water. This shows that, the depth to water or static water level on higher ground is always deeper compared to a lower ground. For example, Royal valley area with the lowest elevation, which is 285m above sea level falls within the areas with static water level that ≤ 6.66m. While places like Olorunshogo, Asunnara which are on higher elevation, have static water level that range between 7.52-8.44m from the surface.

The findings of this study revealed that water level is closer to the surface in places such as Adewole, Ganiki Sango area, Alagbado areas among others. The implication of this, is that there will be shallower well in these areas because of the closeness of the water level to the surface. However this shallow well in the basement complex of this areas may respond to vagaries of climate and weather, and they may dry up during the dry season. Consequently, the people of these areas will be faced with water shortage during dry season. This is because the larger percentage of the people in these areas depend on groundwater as the pipe borne water supply network do not cover most of these places. Further, in places like Bal. Engineering area, Yebumot Hotel area, Okolowo and Babooko where static water level is far from the surface. The static water level will dropped in the dry season, leading to an increase in the amount of energy required in hand pumping the water to the surface.

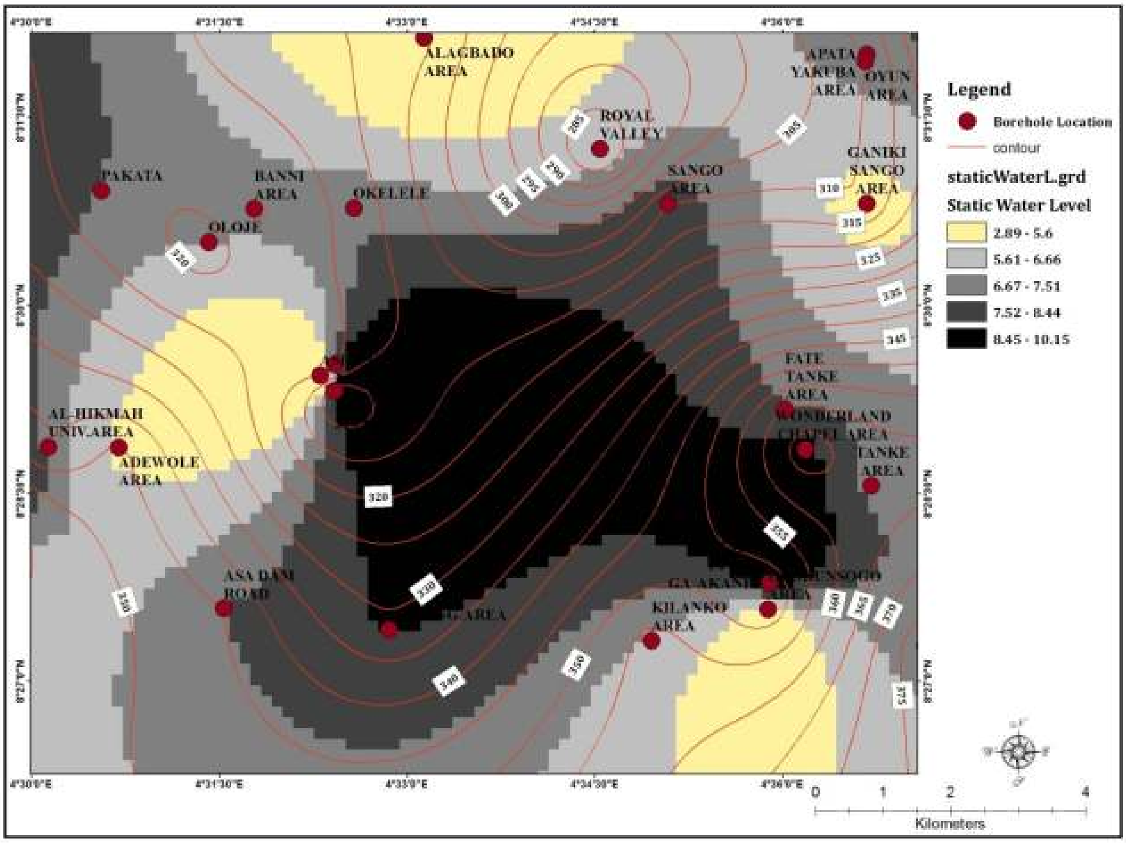

Figure 2. *Water level map of Ilorin*

Variation in depth (thickness) of overburden in Ilorin City

Thickness of the overburden in Ilorin city varies between 3.5m at Royal Valley area and 30m at Agbabiaka area and BAL-Engineering area. The overburden thickness map of Ilorin city is presented in Figure 3. The map was utilized for hydro-geologic characterization of the study area based on overburden thickness values. Several studies have revealed the expected depth of overburden in a basement complex aquifer before a sizeable amount of groundwater can be obtained. Olayinka et al., (1997) is of the view that for a productive well, the value of overburden thickness should range between 20m and 30m. Other scholars suggested a minimum overburden thickness of 25m for viable groundwater abstraction (Oladapo, et al, 2004; Olorunfemi and Okhue, 1992). White et al, (1988) is of the opinion that a minimum of 10m of overburden thickness is required before an adequate yield can be ensured. Wright (1992) reported that in the basement areas of Zimbabwe between 20m and 25 m of overburden is the minimum required before siting a borehole. Oladapo et al. (2009) also classified area with less than 10m thickness of overburden as poor groundwater potential and areas above 10m but less than 20m as areas of marginally thick overburden which they termed as shallow aquifer units.

Based on the submission and classifications of these scholars, Ilorin city is classified in to poor (overburden thickness < 10m), marginal (overburden thickness 10m-19m) and very high groundwater potential zones (overburden thickness ≥20m). The map generated and displayed in Figure 3, shows that Ilorin city is generally underlain by thin, marginal and thick weathered basement. Places such as Royal valley and Kilanko is categorized as a poor groundwater potential zone because the depth of the overburden is less than 10m. Bal engineering area, Adewole, Agbabiaka, Okelele Iqra College area are classified as very high groundwater potential zones (overburden thickness ≥20m). While majority of the area sampled falls between the zones of marginal groundwater potential because the depth of overburden in these areas falls between 10m-19m. These areas include Apata Yakuba, Ganiki Sango Area, Elekoyanga Area, Sango Area, Oyun Area, Alagbado Area, Olorunsogo Area, Tanke Area, Danialu Upper Gaa-Akanbi, Fate Tanke Area, Wonderland Chapel Area, Oloje, Asileke, Jooro, Okolowo Area, Yebumot Hotel area among others. From this classification, it can be said that majority of Ilorin city is underlain by overburden that is between 10m-19m, which signifies that majority of the study area is underlain by a marginally thick overburden which is a shallow aquifer. This is in contrary to Oladapo et al. (2009) that discovered that majority of Ilara-mokin in the south-western, Nigeria is underlain by thin overburden and pockets of marginally thick overburden, but lacking in terms of thick overburden which is a high groundwater potential. The majority of the study area been underlain by marginal overburden can be the reason for the seasonality in most of the wells in Ilorin metropolis. The implication of shallow aquifer is that it is vulnerable to contamination and pollution. Based on these, most of the groundwater resources in Ilorin city may be vulnerable to contamination which can have serious health implication on the residents of the areas located on the thin and marginal overburden aquifer.

Importance of the study for sustainable groundwater development and management in Ilorin City, Nigeria

The study identified and classified Ilorin into poor (Overburden thickness <10m), marginal (overburden thickness between 10m-19m) and good or high zone (overburden ≥ 20m) of groundwater potentials. The spatial pattern of the thickness or depth of overburden revealed that majority of Ilorin city is underlain by marginally thick overburden. Although, there are areas that are underlain by thick and sandy overburden (overburden ≥ 20m) which is described as high or good groundwater potential zones by Okhue and Olorunfemi (1991), Bala and Ike (2001). As the study revealed that majority of Ilorin is underlain by marginal groundwater potential, there is need for constant monitoring of the groundwater resources for sustainable development and management. This can however be achieved through the following:

i. Estimation of monthly groundwater recharge because studies have shown that recharge on basement complex rock is through rainfall. Monthly groundwater recharge estimation is the best practice because it would revealed the amount of rainfall that goes into the ground every month to recharge the shallow aquifer in the study area,
ii. Estimation and monitoring of monthly groundwater withdrawal is also important to know the amount of water that is being pumped out of the ground. This will enable us to balance the amount of water going into the ground and the amount of water pumping or drawing out of the ground,
iii. The rate of monthly groundwater withdrawal should be checked and not allowed to be greater than the rate of monthly recharge for sustainability,
iv. Indiscriminate drilling of boreholes and shallow wells should be checked in the study area, especially in areas of poor to marginal groundwater potential in order to curb overexploitation which may lead to groundwater depletion. This can be achieved through issuance of license before borehole or shallow well can be drill, after the necessary requirement such as the minimum distance between a well to another has been met. So that no new well should cause significant or noticeable drawdown to any existing well,

v. The development of motorized borehole should be targeted in areas of high groundwater potential. The groundwater abstracted in such area can be stored in reservoirs and distributed to every other part to augment water supply from the surface water resources, and

vi. The Kwara state ministry of water resources should be empowered to oversee the drilling of any borehole or shallow well. Prosecute any individual who do not follow the laid down regulations as regards well drilling and abstraction of groundwater in Ilorin City, Nigeria.

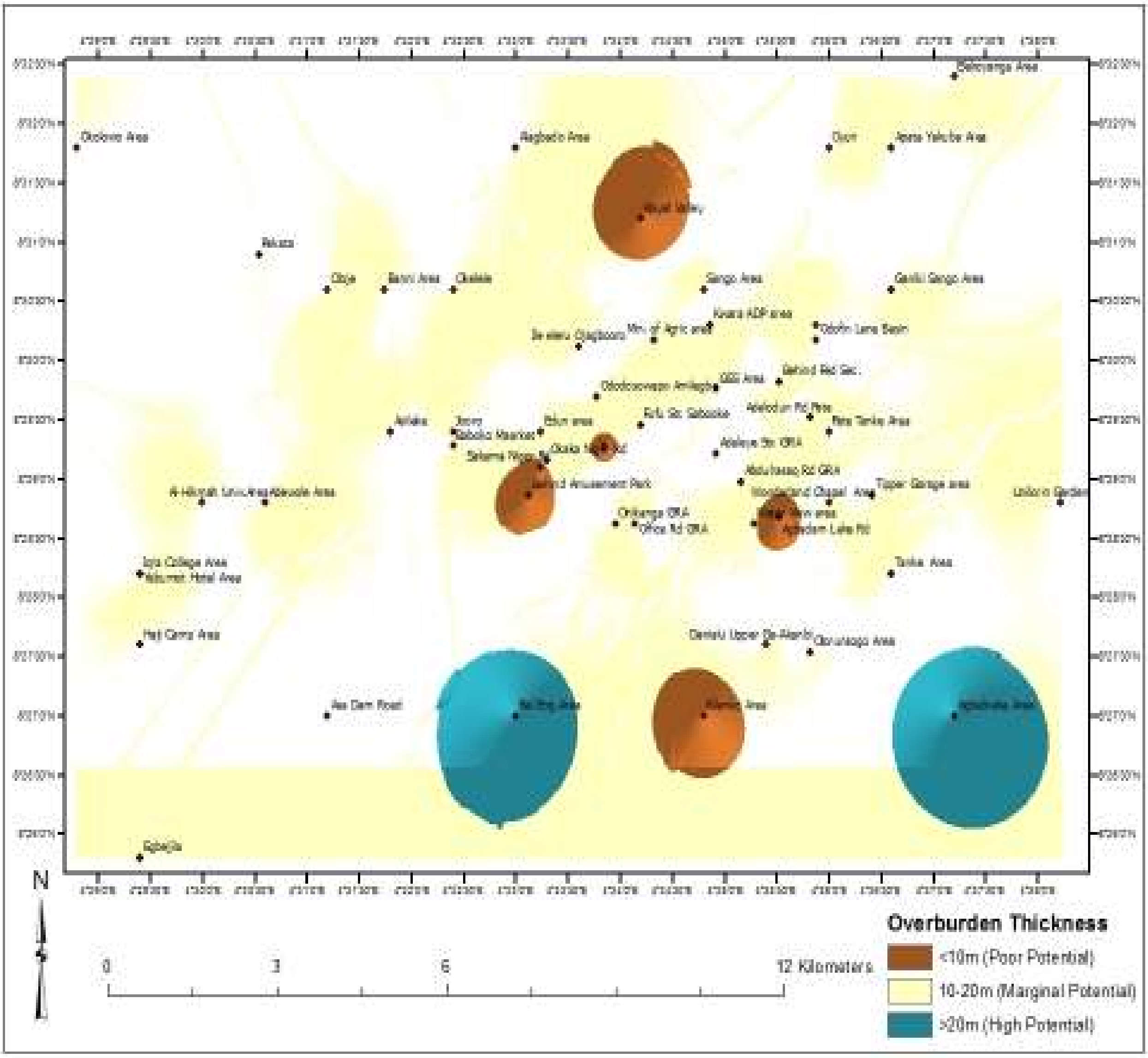

Figure 3. *Overburden thickness map of Ilorin City*

Conclusion

In conclusion, the study have succeeded in groundwater resources mapping of Ilorin city and discovered that the majority of the city is underlain by marginally thick overburden (Overburden thickness between 10m-19m) which is a shallow aquifer. It is clear that setting water rules and regulations to monitor and control the groundwater resources of this area is the only gateway to sustainable groundwater development and management. Therefore, sustainable groundwater development and management can however be attained by controlling the indiscriminate drilling of boreholes (wells), continuous mapping and regular updating of the available records on groundwater resources in Ilorin City.

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