Quantitative Assessment of Groundwater Within Paiko Sheet, North-Central, Nigeria

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Abstract

Quantitative assessment of groundwater within Paiko Sheet has been carried out to determine the sustainability of groundwater quantity of the area for the rising population. Empirical method that makes use of the multiples of saturated aquifer thickness, effective porosity and area extent was used to established the groundwater quantity of the area while groundwater recharge potential was determined with Total annual replenishable recharge *(TARR)* method. The population of the area was estimated with exponential growth equation. The minimum and maximum static water level above sea level for dry season was 138.27m and 534.43m respectively while the minimum and maximum static water level above sea level for wet seasons was 139.07m and 534.93m respectively. The minimum and the maximum groundwater fluctuation is 0.1m and 2.2m respectively with an average of 0.9m. The average depth of wells within the studied area was 5.6m. The groundwater flow predominantly in southern direction with local variation in flow as a result of topographic influence. The estimated groundwater quantity of the area is 3.10km^3 and the annual consumption for domestic purposes is approximately 0.014km^3. Groundwater recharge potential of the area is 0.28km^3. The groundwater quantity and groundwater recharge results show that the groundwater held in storage can sustain the domestic demand of the inhabitants of the studied area.

Keywords: *groundwater quantity, groundwater fluctuation, groundwater recharge, population, Paiko Sheet*

Introduction

Groundwater quantity and quality problems constitute a major set of challenges facing the world during this century (Luczaj, 2016)). Scanty or Lack of groundwater data (occurrence, distribution, movement, quality and quantity) in some areas has affected the exploration, exploitation, operation, control and management of groundwater resource. The United Nation Educational, Scientific and Cultural Organization (UNESCO) established International Hydrogeological Program (IHP) towards the middle of 1970s to provide solution to the gap in groundwater data. UNESCO-IHP along with the Commission for the Geological Map of the World (CGMW) launched the World-Wide Hydrogeological Mapping and Assessment Program (WHYMAP) with the aim of collecting, collating and visualizing hydrogeological (groundwater) information of the World (Richts *et al.* 2010). They produced WHYMAP of the world in 2004 (Figure 1) and a modified version in 2006 (Figure 2). It is a program that is ongoing as existing map is based on available hydrogeological information which is not detailed in all cases. Quantitative map of groundwater of Africa has been produced by (MacDonald *et al,* 2012), and (Akujieze *et al.* 2003) has estimated the groundwater quantity in Nigeria. These studies were also based on available scanty data and lot of assumptions. (Akujieze *et al.* 2003) acknowledged that lack of comprehensive knowledge of the quantity of, or current water demands for domestic, rural and industrial areas, is responsible for the significant shortage or complete absence of potable water in both urban and rural settings of Nigeria. (Akujieze *et al.* 2003) also noted the southern parts of the country that have an apparent excess of water are not left out these challenges. Adequate knowledge of groundwater quantity can enhance the proper planning and development of groundwater resources.

Paiko Sheet No 185 is witnessing surge in population due partly to the fact that these areas provide a cheaper alternative accommodation for people working within the cities of the Federal Capital Territory of Nigeria, fertile land for agriculture and the presence of some economic minerals in parts of the area despite the average annual growth rate of Nigerian population which is 3.02% (Adeosun and Popogbe, 2020). These mean that the demand for water will increase accordingly for industrial, agricultural and domestic uses. Several researchers have previously conducted researches in several places within the area. But none of these studies have been able to quantify the groundwater resources of the study area. It was for this reason that the groundwater quantity of the area research was carried out.

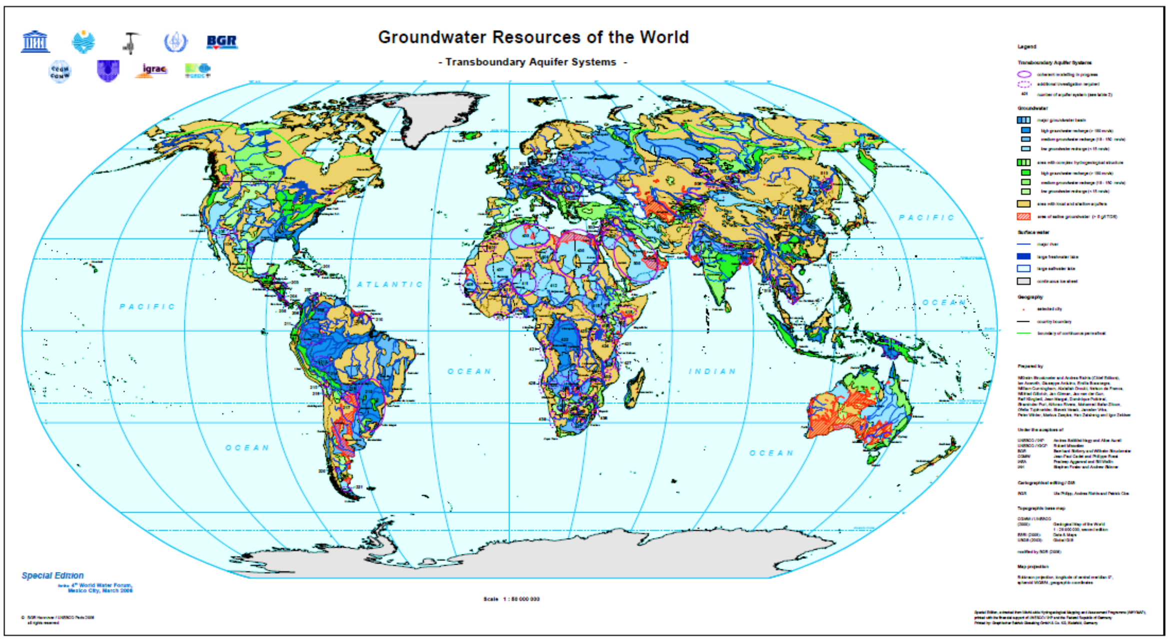

Figure 1: Groundwater resources of the World (BGR, 2004)

The study area

The Paiko Sheet No 185 is located on latitude 9º00' to 9º30' and longitude 6º30' to 7º00'' (Figure 3). It is a boundary Sheet (it cut across Niger State and Abuja) that is bounded to the north and south by Minna and Gulu Sheets respectively; and to the east and west by Abuja and Bida sheets respectively. The area is mainly accessible by Minna – Suleja road, Lambata – Bida road, Minna – Paiko road with other secondary and minor roads as well as paths (major and minor). River Gurara is the major river draining the area with dozens of tributaries. Notable among these tributaries are River Ekunu, River Wudna, River Jatau, River Zole, River Danko, River Gudna, River Kumi and River Kushama. The vegetation is the Guinea Savannah type while the climate of the area consists dry and wet seasons. The dry season usually lasted between November and April while the wet season usually lasted between May and October. The maximum daytime temperature is about 39.4ºC usually in the months of March and April, while a minimum temperature of about 24ºC is recorded usually in the months of December and January with a mean annual temperature is 33.15ºC (Nigerian Meteorological Agency [NIMET], 2006). The dry season is marked by influence of harmattan which is a result of North-East trade wind that blows across the

Sahara which is often laden with red dust between the month of December to the month of February (Ejepu *et al.* 2017). The wet season usually peaked in August of every year with a mean annual rainfall of 1354.26mm (NIMET, 2006). The major occupation of the inhabitants is mainly agricultural practice (Figure 4). Mining activities (mainly artisanal) is also common in the area although Baban Tsani in the south-western part of the sheet serve as the major hub.

Figure 2: Modified Groundwater resources of the World (BGR, 2006)

Geology of Paiko Sheet

85% of the area is underlain by Precambrian rocks of the North-Central Nigerian Basement Complex while 15% of the area is underlain by sedimentary rocks of part of Bida Basin in the south-western part according to (Ejepu *et al.* 2017). The alluvial deposits of gravel, coarse and fine sand, silt and clay is found in the central portion. The Older Granites series outcrop as isolated hills, inselbergs and low whalebacks. They range in size from plutons to batholiths. Circular to elliptical bodies occur in schist environment and more elongated bodies in migmatite-gneiss terrains. Contacts with pegmatites and gneiss, where exposed, are commonly sharp and contact metamorphosed according to (McCurry, 1976). The Older Granites lithologies consist mainly of coarse porphyritic granodiorite, tonalite, or granite and they are the most obvious manifestations of the Pan African Orogeny (Rahaman, 1988). Paiko Sheet No 185 is part of the area covered by (Russ, 1957), and (Truswell and Cope, 1963) in their reconnaissance geological survey of part of Northern Nigeria and (Woakes and Bafor, 1984) studied the area as part of a wider studies for gold mineralization. Jimoh, (2002) placed the overburden thickness between 9 – 14m and submitted that sulphide rich areas correspond to the part with thicker overburden from seismic refraction studies of south eastern portion of the sheet (Babban Tsauni). Okunlola *et al.* (2007) noted geologically, the area is underlain by Precambrian basement rocks such as migmatite - gneiss, ultramafics, pegmatized migmatites and pegmatites. Oladipo *et al.* (2011) reported high pH and conductivity in some wells in the area in Lapai (southwest of the area). Egbe *et al.* (2013) noted that multi-gravity method yielded the best result out of the three methods used (jigging, multi-gravity and shaking table separations methods) for the beneficiation of gold-zinc around Baban Tsauni in the southwestern part of the studied area. Amadi *et al.* (2013) recommended a 30m – 60m depth for borehole drilling in the area. Ako

(2015) reported elevated values for lead, potassium and magnesium from surface water around Kwakuti marble deposit. Ejepu and Omar (2015) noted that Very high and high potential zones correspond to areas composed of alluvial deposits, sedimentary rocks and high lineament densities of the studied area. Ejepu *et al.* (2017) also attributed thick regolith and highly fractured basement with better groundwater potential especially areas with high lineament density. Amadi *et al.* (2017) founded that iron, zinc, copper, total coliform and faecal strepp were in excess of the recommended standards for drinking water quality around lapai town.

Methodology

Secondary data used for this research include borehole logs sourced from Niger state Rural Water Supply and Sanitation agency, Nigeria. Rainfall and temperature data for 59 years and 37 years respectively were acquired from the Nigerian Meteorological Agency (NIMET).

Groundwater table measurement

Groundwater table measurement were determined from 172 hand dug wells during dry season and wet season in the 2019 to assess the difference in groundwater level for seasons. The coordinate of each well was also recorded. The result of this exercise was used to construct groundwater configuration map and groundwater fluctuation

Groundwater quantity, *Gs*

The groundwater quantity or, groundwater storage (*Gs*) of aquifers within Paiko sheet 185 was determined using the empirical formula of (Lezzaik and Milewski, 2017).

$$Gs = \mathrm{T_Y \, X \, \phi_e \, X \, AE}$$

Where T_Y is the saturated aquifer thickness, ϕ_e is the effective porosity, and AE is the areal extent.

A total of 48 borehole logs were used to determine the thickness of regolith and fractured aquifers. The difference between regolith thickness and water level was used as the saturated aquifer thickness. Porosity (Table 1) was derived from the porosity ranges of unconsolidated and consolidated rocks by (Driscoll, 1986)). The total areal extent covered by the research was 3080.25km^2 (this was determined from the topographical map of Figure 1.3).

Groundwater recharge potential

Groundwater table fluctuation method was used to determine the groundwater recharge potential of Paiko Sheet with the empirical formula of (Mahato *et al.* 2017) presented below:

$$TARR = \mathrm{A \, X \, W_a \, X \, S_Y}$$

TARR = Total annual replenishable recharge, A = the area of recharge, W_a = the average water table fluctuation and S_Y = the specific yield.

A was determined from topographic map (Figure 1.3) and 3D surface map (Figure 1.6) of Paiko Sheet by subtracting the dischargeable area from the total area of Paiko Sheet. W_a was determined from water level measurement of both seasons. The dry season average was subtracted from the wet season average to get W_a and S_Y was determined from the ranges of Specific Yields of Different Formations of unconfined aquifers composed of unconsolidated sediment (Johnson, 1967).

Population of Paiko Sheet

The current population of the areas within Paiko Sheet was calculated using the exponential growth equation by (Malthus, 1798) as follows.

$$P = P_o \text{ x } (e)^{kt}$$

Where P is the present population value, P_o is the initial population value which was the population of area as at 2006 Nigerian census, e is the constant which is equal to 2.71828, k is the rate of growth expresses as a decimal and t is the time or number of years which is 3.02% according to (Adeosun and Popogbe, 2020).

Annual expected domestic consumption demand (C) was calculated with the following formula:

$$C = P \times q \times d$$

Where P is the current population of Paiko Sheet, q is the quantity of water required per person per day and d is the number of days in a year which is mostly 365. This is to know if the groundwater quantity of Paiko Sheet can sustain the domestic needs of the inhabitants.

The amount of groundwater (D) available for other activities such as agricultural and industrial activities was derived from the difference between *Gs* and C.

$$D = Gs - C$$

Table 1: Porosity ranges of common unconsolidated and consolidated rocks (Driscoll, 1986)

Unconsolidated sediments	*n* [%]	Consolidated rocks	*n* [%]
Clay	45 - 55	Sandstone	5 - 30
Silt	35 - 50	Limestone/Dolomite (Original & Secondary Porosity)	1 - 20
Sand	25 - 40	Shale	0 - 10
Gravel	25 - 40	Fractured Crystalline Rock	0 - 10
Sand & Gravel Mixture	10 - 35	Vesicular Basalt	10 - 50
Glacial Till	10 - 25	Dense, Solid Rock	<1

Results and discussion

Groundwater configuration and seasonal groundwater fluctuation Maps

Groundwater configuration map of Paiko Sheet for dry season is shown in Figure 3 while the groundwater fluctuation map is presented in Figure 4. About 40% of the wells had apron while approximately 67% were covered. The minimum water level below ground level was 0.3m and 0.05m for dry and wet seasons respectively while the maximum water level was 11.4m and 9.9m respectively. The dry season and wet season average is 4.89m and 3.98m respectively. The minimum groundwater fluctuation is 0.1m and the maximum is 2.2m while the average is 0.9m. The average depth of wells within the studied area was 5.6m. The groundwater configuration map shows a southward direction of flow with visible influence of topography on the flow direction. The NNW-SSE principal joint direction (Abdulfatai et al, 2021) suggest that fracture pattern also have serious control on the groundwater flow direction.

The range of groundwater fluctuation in Paiko sheet is from 0.2m (Fiche A) to 2.2m (Gangare) with an average of 0.91m. Some area (such as Gbodna, Banado, Zuruh, Busupi, Daku and Bodna) in the northern half of Paiko sheet have the higher groundwater fluctuation. Moderate groundwater fluctuation occur in some areas in the northern (Shai,Piwowai, Bubuyi, Dnatopi and Gago) and south-western part (such as Pagada and Saminaka) of the sheet while the highest fluctuation occur in area around Gangare in the north-eastern part of the sheet.

Groundwater quantity

Borehole logs are represented by the locations in Figure 5. The average depth of borehole within Paiko Sheet is 45.32m, the average regolith thickness is 18.17m, the average water level below the ground surface is 3.11m, the average saturated aquifer thickness 15.06m, the average number of fractures is 1.74m and the average effective porosity is 6.7%. Figure 3 shows the groundwater storage (groundwater quantity) map of Paiko Sheet 185. Estimation of groundwater quantity was achieved with the following formula of Lezzaik and Milewski, (2017):

$$Gs = T_{\gamma} \text{ X } \phi_e \text{ X AE}$$

T_{γ} is the saturated aquifer thickness =15.06m = 0.015km, ϕ_e is the effective porosity = 6.7% = 0.067, while AE is area extent = 3080.25km^2.

$$Gs = 0.015 \text{ X } 0.067 \text{ X } 3080.25$$

$$Gs = 3.10\text{km}^3$$

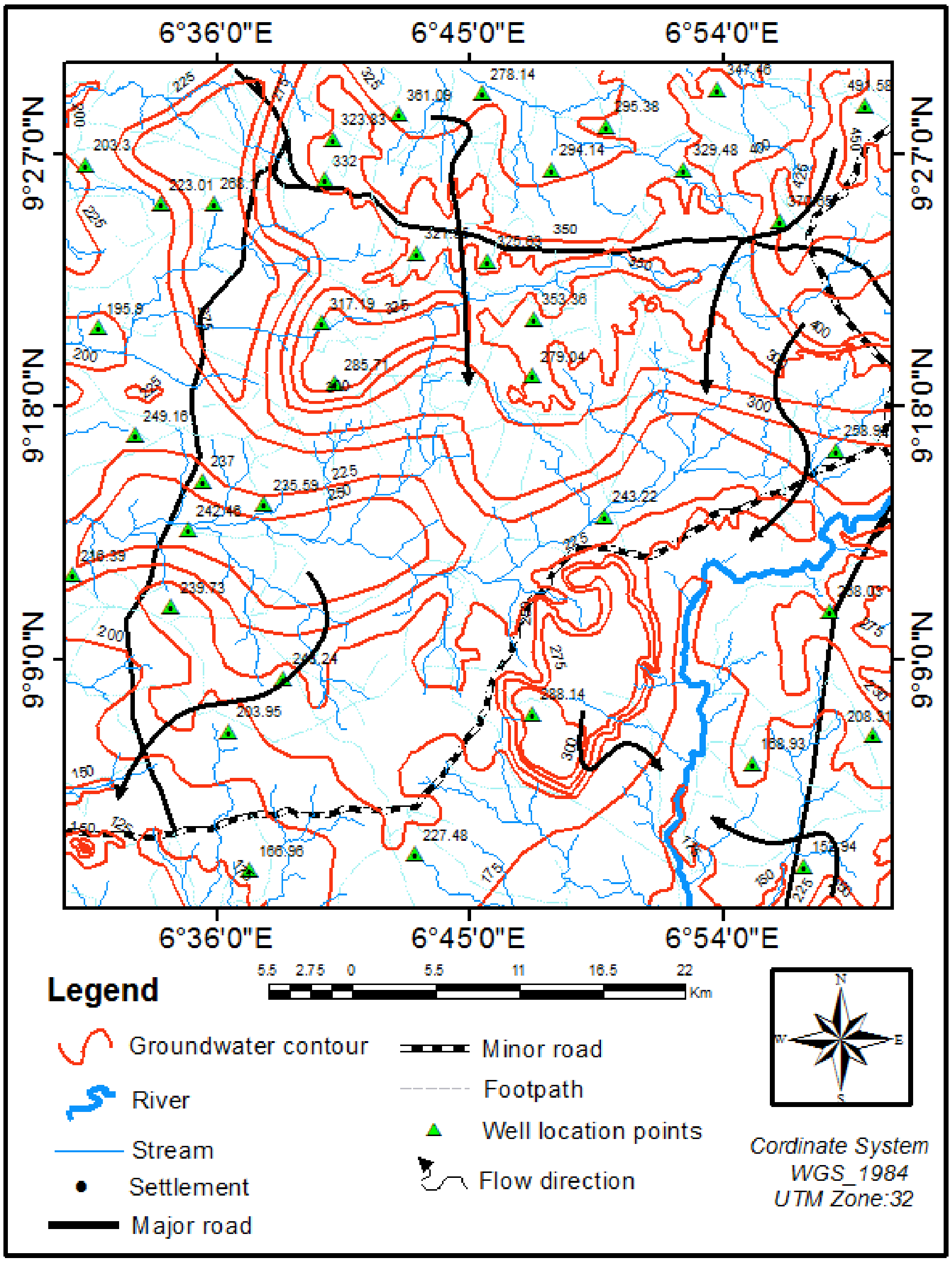

Figure 3: Dry season water level and flow map of Paiko sheet 185

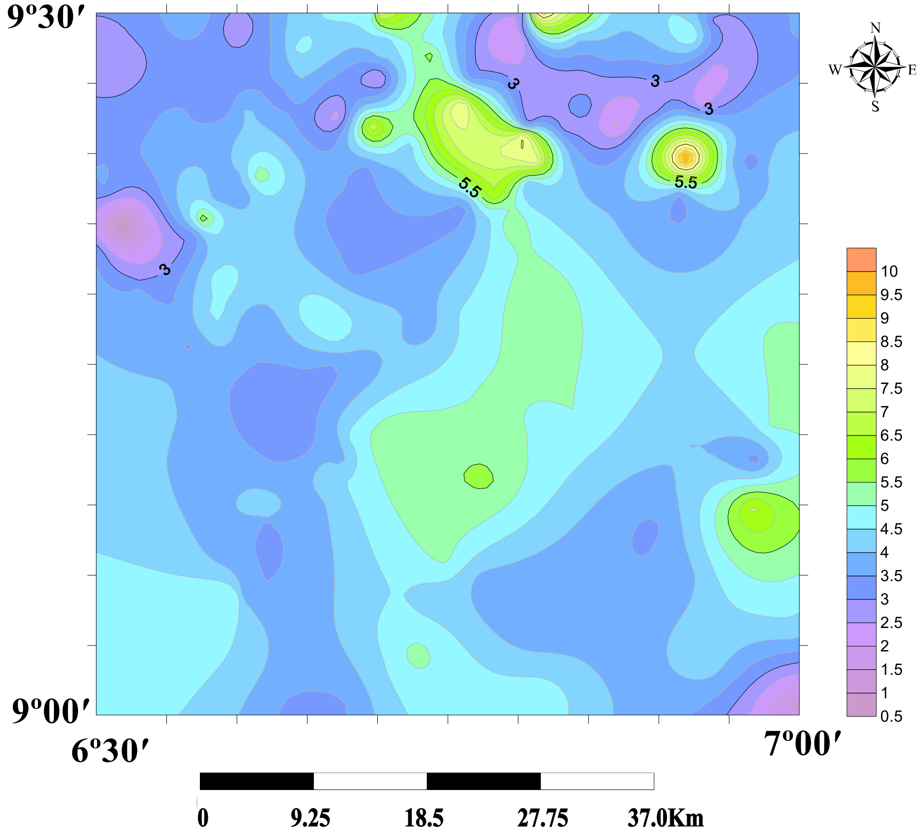

Figure 4: Groundwater Fluctuation Map of Paiko sheet 185

The current population of Paiko Sheet was calculated using the following formula:

$$P = P_o \times (e)^{kt}$$

P =? P_o = 492094 (Niger State Bureau of Statistics, 2012), e = constant = 2.71828, Average annual growth rate = 3.02%, k = rate of growth which is expressed as a decimal = 0.0302, t is time which is the difference between the year 2006 when the last population census held and the year 2021 which is 15 years.

$$P = 492094 \times (2.71828)^{0.0302 \times 15}$$

$$P = 492094 \times (2.71828)^{0.453}$$

$$P = 492094 \times 1.57302$$

$$P = 774076$$

Expected daily domestic consumption of water is 50L of water per person per day according to (Gleick, 2001). Therefore, the expected annual domestic consumption is:

$$C = P \times q \times 365\text{days}$$
$$C = 774076 \times 50\text{L} \times 365$$
$$C = 14{,}126{,}887{,}000\text{L/annum}$$
$$C = 0.014\text{km}^3$$

The available amount of groundwater, D for other activities such as agricultural and industrial activities is the difference between *Gs* and C.

$$D = Gs - C$$
$$D = 3.10 - 0.014$$
$$D = 3.08 \text{ km}^3$$

The south-western part of Paiko Sheet has the highest groundwater storage (Figure 5) followed by the north-eastern part and then the south-eastern part while the north-western part has the least groundwater storage. Estimated current population of Paiko Sheet was 774076 as at the end of 2021 year. The groundwater quantity (resources) of Paiko Sheet 185 calculated using the emperical formula of (Lezzaik and Milewski, 2017) was 3.10km^3 and with annual consumption for domestic purposes of approximately 0.014km^3, it means that it will take more than 200 years to exhaust the groundwater resources of the area if its use is restricted to domestic consumption. It also shows that the studied area can survive drought condition for a long period of time. These values also show that there will be approximately 3.08km^3 of groundwater available for other usage such as agricultural and industrial activities.

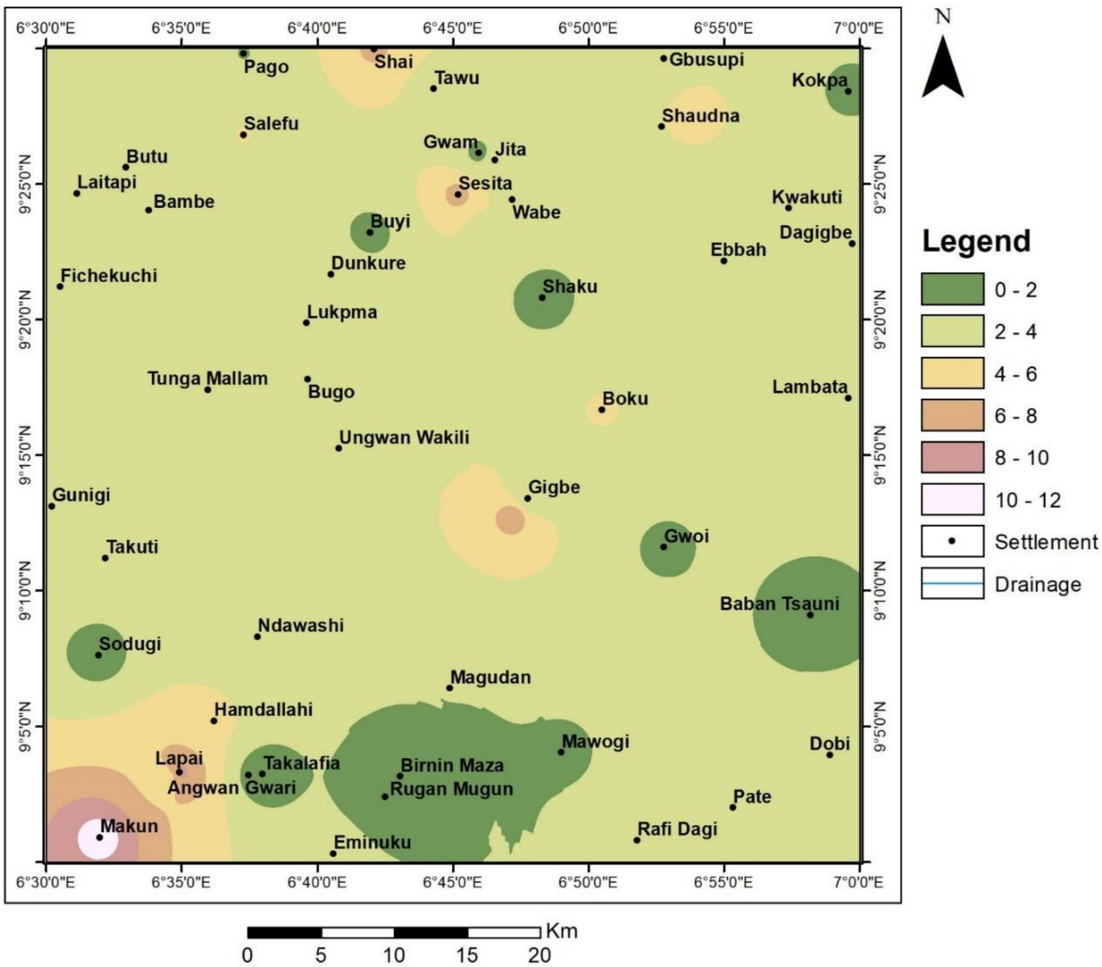

Figure 5: Groundwater storage map of Paiko Sheet 185

Groundwater recharge potential

The groundwater recharge potential of the studied area determined with the empirical formula of (Johnson, 1967) is presented below:

$$TARR = \mathrm{A\ X\ W_a\ X\ S_\gamma}$$

$$\mathrm{A} = 2371.79,\ \mathrm{W_a} = 0.00091 \text{ and } \mathrm{S_\gamma} = 0.13$$

$$TARR = 2371.79\ \mathrm{X}\ 0.00091\ \mathrm{X}\ 0.13$$

$$TARR = 0.28\mathrm{km}^3$$

TARR results is 0.28km^3 although some may be lost subsurface runoff or evapotranspiration or both. What is left is expected to be more than the estimated annual domestic consumption (0.014km^3). This implies that the groundwater held in storage (groundwater) is safe from depletion provided that there is no drought. However, groundwater quantity within Paiko Sheet can survive a long period of drought as shown by the groundwater quantity result.

Conclusion

The groundwater within Paiko Sheet flow southward majorly with local variation in flow directions and visible influence of topography. The average seasonal groundwater fluctuation in Paiko Sheet is 4.14m for the year 2019. The groundwater quantity (resources) of the area was calculated to be 3.086km^3 and with an annual consumption of 0.014km^3 for domestic purposes, there will be 3.14 km^3 of groundwater available for other usage such as agricultural and industrial activities. The *TARR* is 0.28km^3. The *TARR* results is twenty times more than the annual consumption. Therefore, the groundwater quantity held in storage is enough to sustain the domestic consumption of the populace of Paiko Sheet in the event of drought while the annual recharge can adequately take care of their annual needs without depleting the groundwater held in storage.

Acknowledgement

The authors wish to acknowledge the Tertiary Education Trust Fund (TETFund) for sponsoring this research.

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