Hydraulic Head Analysis and Groundwater Flow System in part of Otukpo, North-Central Nigeria

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ABSTRACT

The use of hydrogeological methods for groundwater studies has efficiently reduced the risk associated with poor groundwater exploration and exploitation in geologically difficult terrains. Groundwater inventories of shallow hand dug wells were the approach used in the current investigation in Otukpo. Well inventories were collected within the area of study. The coordinates, depth to water level and the total drill depth of about 200 hand dug wells were used in the study. The surface elevation of the study area in meters ranges from 142 m to 208 m above the datum sea level. The minimal total depth of well in the area is 2.3 m with a maximum well depth of 14.2 m from field measurements. There exists a trend of downward and upward change in water levels in the individual wells randomly sampled across the study area. The depth to static water level in the wells ranges from 1.8 m to 14.0 m. Wells completed nearer to the surface in the northern region of the study have similar water levels while wells completed in the southern region show higher relative heads. The hydraulic head of the well in the study ranges from 113.0 to 201.9. The hydraulic head of groundwater in the area mimic the topographic variation of the area. Groundwater flow direction as computed from the hydraulic head of shallow hand dug wells in the area shows a northward flow direction.

Keywords: Groundwater, Inventory, Well, Flow direction, Hydraulic Head, Otukpo.

1. INTRODUCTION

Groundwater is a part of the hydrological cycle. Within the hydrological cycle, groundwater flow patterns are influenced by geological factors such as heterogeneity in aquifer lithologies, topography and structure of confining lithological strata (Todd, 1980; Dawei, 2010) and hydrogeologically by porosity, permeability, and hydraulic conductivity of the aquifer system (Idris-Nda, 2013; Amadi *et al*, 2017). Other factors that influence groundwater flow are the elevation of recharge areas in regions of aquifer outcrop, the degree to which river systems influence the landscape and the location and extent of lowland areas experiencing groundwater discharge. These factors determine in totality the configuration of groundwater flow system (Fetter, 2007; Chilton and Seiler, 2006).

Groundwater is not usually static but moves slowly and laterally through aquifers. Groundwater flow is driven by difference in potential energy associated with pressure. Potential energy cannot be measured directly, however it can be derived by measuring the hydraulic head (level to which water rises in a well). Groundwater flow is expressed as closed three-dimensional system containing flow paths from the point at which the aquifer is recharged to the topographically lower point at which water leaves the aquifer through stream, spring or river (Freeze and Cherry, 1979; Allen and John, 1979; Offodile, 2002; Kelvin, 2005;).

The flow of water to the well is dependent on the hydraulic head gradient represented by the height of the water level in a well which is the mechanical energy that causes groundwater to flow (Nwankwoala, 2015; Seiler and Lindner, 1995; Chilton and Seiler, 2006). The water table in an unconfined aquifer can be determined from the depth of water in a well that is not yet pumped. To establish groundwater flow direction through geological units, individual measurement of hydraulic head from wells has to be combined to generate contour map of water level. Groundwater moves from regions of high hydraulic head to regions of low hydraulic head obeying Darcy's law. Two components makes up the total hydraulic head, these includes the elevation head being the height of the midpoint of the section of the well that is open to the aquifer, and the pressure head, which is the height of the column of water above this midpoint. The first component reflects location and topographic position of the well and the second reflects conditions in the aquifer, which includes longer-term and seasonal changes in water levels. Hydraulic heads are normally measured with respect to an arbitrary datum, which is often above sea level (Chilton and Seiler, 2006; David and Larry, 2005).

After moving slowly through the aquifer down the hydraulic gradient, groundwater leaves the aquifer geogenically through springs, wetlands, base flow to rivers or discharge to lakes or the oceans and anthropogenically by constructed wells or boreholes. These are known as groundwater discharge areas (UNESCO, 2004). The hydraulic head increases with depth and the net saturated zone flow is upwards towards the water table. In a recharge area, the water table can be at depth, with a considerable thickness of unsaturated zone above it. In a discharge area, the water table is usually at, or very near to, the ground surface (Michael and Plummer, 2004; Chilton and Seiler, 2006).

Water well is a hole, a shaft, or an excavation bored into the subsurface used for the purpose of extracting groundwater from the subsurface for domestic, municipal, agricultural or industrial use (Thomas, 2003). Water may flow into the well surface naturally after excavation of the hole or shaft depending on the nature of the subsurface lithology. Such a well is known as a artesian well. The hydrogeological assessment to determine whether and where to locate water well should always be done by a knowledgeable hydrogeologist (Amadi et al, 2017; Idris-Nda et al, 2015; Thomas, 2003).

Water wells are usually classified on the basis of their method of construction. Wells can be constructed in a number of ways. Well construction and designs assume a different dimension with regards to the location attributes. Wells may be dug by hand, driven or jetted in the form of well points, bored by an earth auger, or drilled by a mechanized drilling rig. Hand dug, bored, jetted and driven wells are limited to shallow depths, unconsolidated deposits or regoliths subsurface. The final design of a well is subject to site-specific observations made from the geological investigation (Thomas, 2003; UNESCO, 2004). Water enters the well through porous and permeable lithologies in sedimentary environment and through weathered and fractures rocks in the basement areas.

When water is pumped from a well, the head in the well is lowered, creating a drawdown and setting up a localized hydraulic gradient which causes water to flow to the well from the surrounding water bearing aquifer. The grouping of geological materials into aquifers, aquitards and aquicludes, is an effective means of characterising groundwater flow (Idris-Nda, 2013; Tim, 2005).

The laboratory experiment by Henry Darcy (1856) suggested that groundwater moves rather slowly in primarily horizontal or lateral directions. This movement is governed by established hydraulic principles that can be expressed by Darcy's law which states that $Q = KA\frac{dh}{dl}$ where Q is discharge, K is the hydraulic conductivity, A is the bulk cross-sectional area of flow and dh/dl is the hydraulic head gradient. Darcy's law is applied in determining groundwater flow velocities and directions. It was established that the rate at which water flow for a given aquifer is directly proportional to the difference in vertical elevation between the places and inversely proportional to the horizontal distance travelled. The rate of flow is also proportional to the hydraulic gradient. Hydraulic conductivity k, is an important coefficient of proportionality describing the rate at which water can move through a permeable medium.

Analysis of groundwater flow direction is essential to solving most hydrogeological problems, hence the need for this research. This research is aimed at providing basic information about water wells in the study area which will enable effective well placement and well water management.

1. STUDY AREA DESCRIPTION

Otukpo is part of the southern Benue province of Nigeria. It bounded by latitude $7^{0}08'$N to $7^{0}15'$N and longitude $8^{0}05'$E to $8^{0}15'$E on an average surface elevation of 270m above sea level (Fig. 1). Otukpo is part of topographic sheet 270 SW and classified under the Lower Benue River Basin, hydrological area of Nigeria. The area is majorly drained by Okpokwu River which is a tributary of the River Benue. Otukpo owes its origin to the Cretaceous sediments of the Benue Trough, underlain by intercalation of mudstone, shale, sandstone and limestone (Nwajide, 2013).

It lies within the Guinea Savannah vegetation zone and has an annual rainfall range of 1500 mm to 1800 mm and a monthly temperature range of 25°C to 33°C (https://www.gismeteo.com/city/daily/2019). The prevalent climatic condition in the area comprises the rainy season (March to October) and dry season (November to February) characterized by high temperatures, low pressure and high relative humidity all year round. According to the 2006 Census by the national population commission, Otukpo has an estimated population of 266,411 with a landmass of about 390 sq. km.

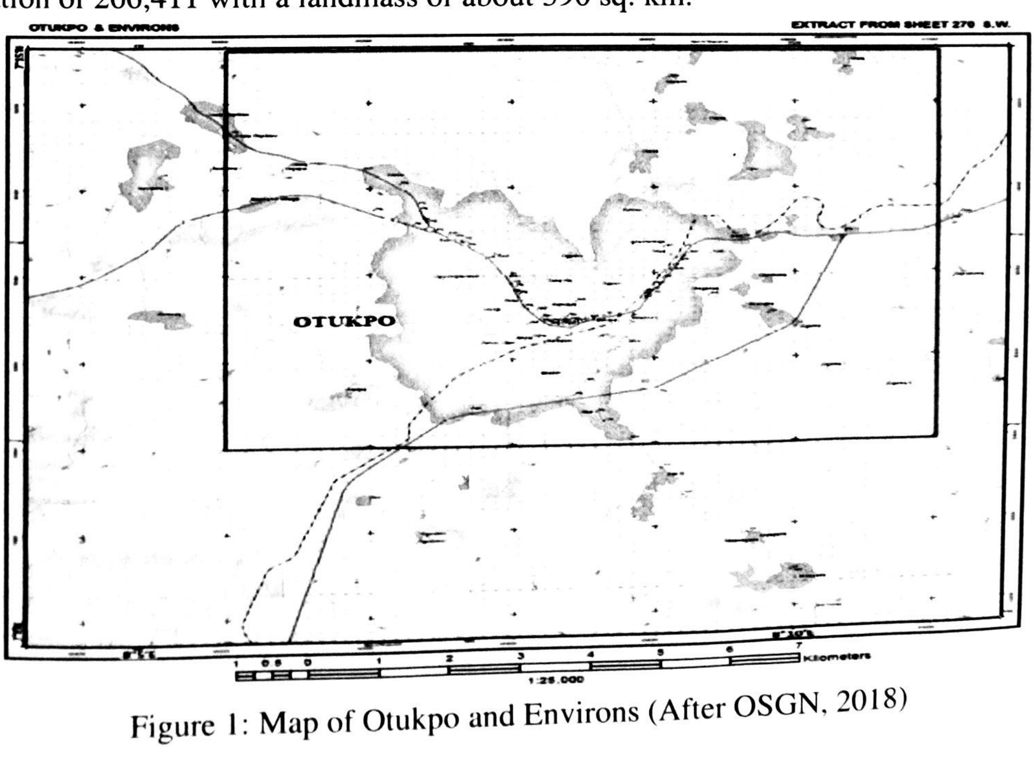

Figure 1: Map of Otukpo and Environs (After OSGN, 2018)

1. METHODOLOGY

Well inventory (200 well) which includes water level measurements in wells, depth of wells, well elevation and well coordinates were used in this study. The data were accessed with the aid of Global Positioning System (GPS) and water level dipper (Dip Meter) respectively. The coordinate (longitude and latitude) of the each well was recorded in degree, minute and seconds format. The surface elevation of the well position in metres was recorded.

The basis for determining the direction of groundwater flow is based upon hydraulic head of individual wells measured from the static water-level data. Water levels data was collected manually with a portable field device at every well encountered. The static water level measurement were taken very early in the day time before the wells were disturbed, this was done to allow the wells recovery to equilibrium conditions before taking the measurement. A water level dipper comprising of a length of twin-core electronic tape (E-tape) insulated copper cable, graduated in centimetres and metres, wound on to a drum or reel with a pair of electrodes attached to the end of the E-tape. The E-tape is lowered into the well, when the static-water surface is encountered; an electrical circuit is completed, which activates an audible buzzer. The total depth of the wells was also measured. The static water levels can be measured to a precision of ±0.005 m (Brassington 1998).

The depth to static water level in the well is recorded from top of well lining or ground surface. The common datum used is the mean sea level. All data would be collected from the wells were reduced to elevations above mean sea level. The hydraulic head was determined by subtracting the depth to static water level from the land surface elevation above sea level of the well positions. The obtained coordinate and the derived hydraulic head were used to determine and construct the groundwater flow direction of the study area.

1. RESULTS AND DISCUSSION

The surface elevation of the study area in meters ranges from 124 m to 208 m above the datum sea level. The minimal total depth of well in the area is 2.3 m and a maximum well depth of 14.2 m as obtained from the field measurement. There exists a trend of downward and upward change in water levels in the individual wells. The depth to static water level in the wells ranges from 1.8 m to 14.0 m. Wells completed nearer to the surface in the northern region of the study have similar water levels whereas wells completed in the southern region show higher relative heads. The hydraulic head of the well in the study ranges from 113.0 in the northern section to 201.9 in the southern section of the area (Table 1). Well in the southern region of the study area shows higher hydraulic heads while well in the northern region shows lower hydraulic head (Fig. 2).

The groundwater flow direction as computed from the hydraulic heads shows an approximate southwest to northeast groundwater movement (Fig. 2). The water level data collected indicate that the unconfined aquifer is being recharged by precipitation events. All water wells completed in the unconfined aquifer show an immediate response to precipitation during the rainy season events.

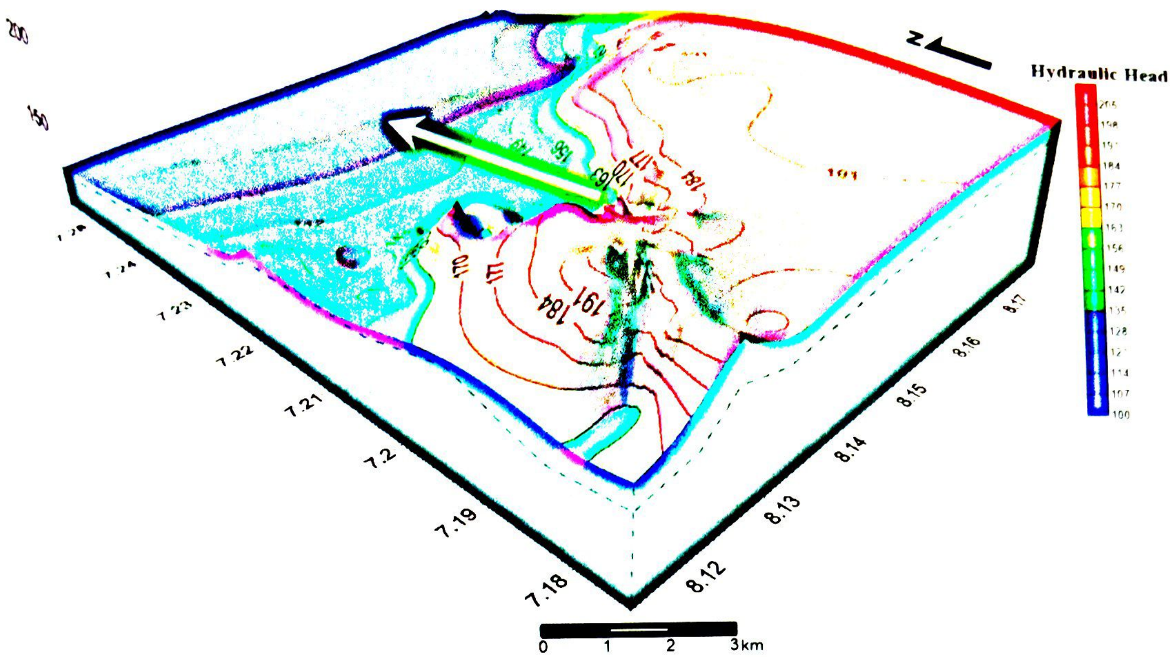

Figure 2: Groundwater Flow Direction of Otukpo

Table 1. Otukpo Hydrogeological Well Inventory Data

S/N	Co-ordinates N(°)	Co-ordinates E(°)	Altitude (m)	SWL (m)	Well Depth	Hydraulic Head
W101	7°12′17.8″	8°07′40.8″	157	7	7.2	150
W102	7°12′16.0″	8°07′39.9″	165	6.6	6.9	158.4
W103	7°12′21.0″	8°07′36.3″	190	7.4	7.8	182.6
W104	7°12′22.6″	8°07′35.8″	189	6.2	6.7	182.8
W105	7°12′23.3″	8°07′35.1″	182	4	5.4	178
W106	7°12′20.6″	8°07′30.2″	183	6	6.9	177
W107	7°12′21.4″	8°07′28.5″	177	6.1	7	170.9
W108	7°12′19.1″	8°07′24.7″	169	6	6.3	163
W109	7°12′19.6″	8°07′21.7″	177	6.1	6.7	170.9
W110	7°12′17.7″	8°07′13.7″	167	6.1	7.4	160.9
W111	7°12′18.3″	8°07′10.8″	159	6.6	7.5	152.4
W112	7°12′16.7″	8°07′06.1″	155	5.4	6.6	149.6
W113	7°12′18.3″	8°06′59.8″	159	4	8	155
W114	7°12′20.8″	8°06′52.6″	157	4.2	5.7	152.8
W115	7°12′21.5″	8°06′54.8″	155	3.7	3.9	151.3
W116	7°12′20.6″	8°06′59.3″	155	3	3.5	152
W117	7°12′28.1″	8°07′07.6″	153	6	7.1	147
W118	7°12′34.2″	8°07′09.6″	158	5.1	6.1	152.9
W119	7°12′39.2″	8°07′16.6″	147	4.3	7	142.7
W120	7°12′43.0″	8°07′21.0″	152	5.9	8.6	146.1

			156	6	7.2	150
W121	7°12′47.2″	8°07′21.3″	142	4.9	5.5	137.1
W122	7°12′51.8″	8°07′19.0″	149	5.5	6.2	143.5
W123	7°12′56.3″	8°07′26.1″	151	5.5	7.7	145.5
W124	7°12′55.8″	8°07′28.6″	153	4.8	5.8	148.2
W125	7°12′56.9″	8°07′31.5″	152	4.8	5	147.2
W126	7°12′49.2″	8°07′37.0″	158	3.5	3.9	154.5
W127	7°12′46.3″	8°07′38.0″	152	9.5	10.3	142.5
W128	7°12′43.4″	8°07′39.7″	170	4.7	4.8	165.3
W129	7°12′31.6″	8°07′42.1″	169	4	4.7	165
W130	7°12′28.3″	8°07′48.0″				

1. CONCLUSION

The use of well inventory to establish the groundwater flow direction has been carried out in Otukpo, North-Central Nigeria. The study has established that groundwater flow in the study area is in the direction of maximum change in hydraulic head (northward). The change in the water levels of the different well implies that the subsurface lithology and water bearing capacity of the area varies with locations.

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