Geographical Information System Assessment of Groundwater Potential Zones of Iju Town, Ondo State Nigeria

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Key words: Groundwater, VES, GIS, Topography

SUMMARY

The groundwater potential of Iju town in Ondo state was investigated using electrical resistivity and geographical information system to obtain the hydrologic/hydrogeologic conditions. A total of 230 hydrostatic level depths of existing hand-dug wells and 44 schlumberger vertical soundings were acquired in the study area to achieve the goals of the study. The VES data were interpreted both quantitatively and qualitatively by partial curve matching, computer iteration and visual inspection techniques, to obtain layer thicknesses, resistivities and geoelectric curve type, while the hydrostatic level depths data were processed to obtain groundwater head values. The 2-D/3-D topographic maps, weathered layer resistivity, bedrock resistivity, and overburden thickness maps generated from the acquired data, were used to establish the hydrogeologic/hydrologic conditions. The GIS analysis was used to produce digital maps from these coverage maps, which resulted to delineation into high, medium and low groundwater potential zones. From the composite maps, the major groundwater flow direction of the aquifer system was established as NW-SE axis, the recharge and discharge zones were also identified. Thus, from the composite maps, geoeletric sections and other relevant coverage maps, the northeastern, southeastern, part of central and northwestern portions were identified to be suitable locations for groundwater abstraction. The results provide geo-database from which groundwater potential could be assessed for groundwater development. It is recommended that the northwest-southeast axis of the study area should be free of refuse/waste dump site or landfill to avoid both surface and subsurface waters contamination/pollution problems.

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1. INTRODUCTION

Water is a source of life, and its importance to human existence on planet earth cannot be overstated. Even in the primordial days, establishment of any human settlement is usually centered on available sources of water supply. At the minimum subsistence level, most human beings generally use about 2.5 litres of water daily for direct consumption and much more for other daily activities (Odejobi, 1999).

The aggregate daily public water demand could not be satisfied in some parts of the world. Surface water supply seems to be the easiest and most convenient way to meet up with this water demand; but unfortunately, the supply from rivers, streams, springs and lakes sources are not evenly distributed all over the world. Where the supply sources are available, undisrupted supply could not be guaranteed due to some environmental factors (such as climate) that affect the quantity supply. Records of the world water balance given by Nace (1971) and UNESCO (1978) reveal that surface water sources account for less than 2% of the world's total fresh water, while ground water accounts for more than 98%.

Groundwater sources provide a reasonable constant supply that is not absolutely susceptible to drying up under severe drought conditions. All over the world, records of water balance reveal that groundwater has been a very good and important source of water supply for the industrial, irrigation and domestic consumptions. The source of groundwater supply is conveniently available in most cases at the point of need, and less vulnerable to surface contamination (Jacob, 1979).

The study area under investigation (Iju Township) falls within the tropical region of the basement complex of Nigeria, where water supply for rural domestic consumption and agricultural use depends primarily on the unevenly distributed rivers, springs, streams and low water yield hand dug well/boreholes. These sources of water supply could not adequately meet up with the water demands of the area.

Idowu et al. (1999) carried out investigation of groundwater occurrence in the southwest Nigeria basement complex. From the study, it was established that most weathered rock materials are clayey, and consequently have poor permeability. They asserted that the weathered rock materials characterized by lowest quartz content could not provide heritage for the quantities of extractable groundwater.

Bala (2001) carried out interpretation of fractures for the assessment of groundwater potential of Wudil and environs in the basement complex of northern-central Nigeria, using a GIS technique. From the study, it was established that fractures play an important role in the accumulation of groundwater in basement rocks and GIS analysis is an effective tool of groundwater study.

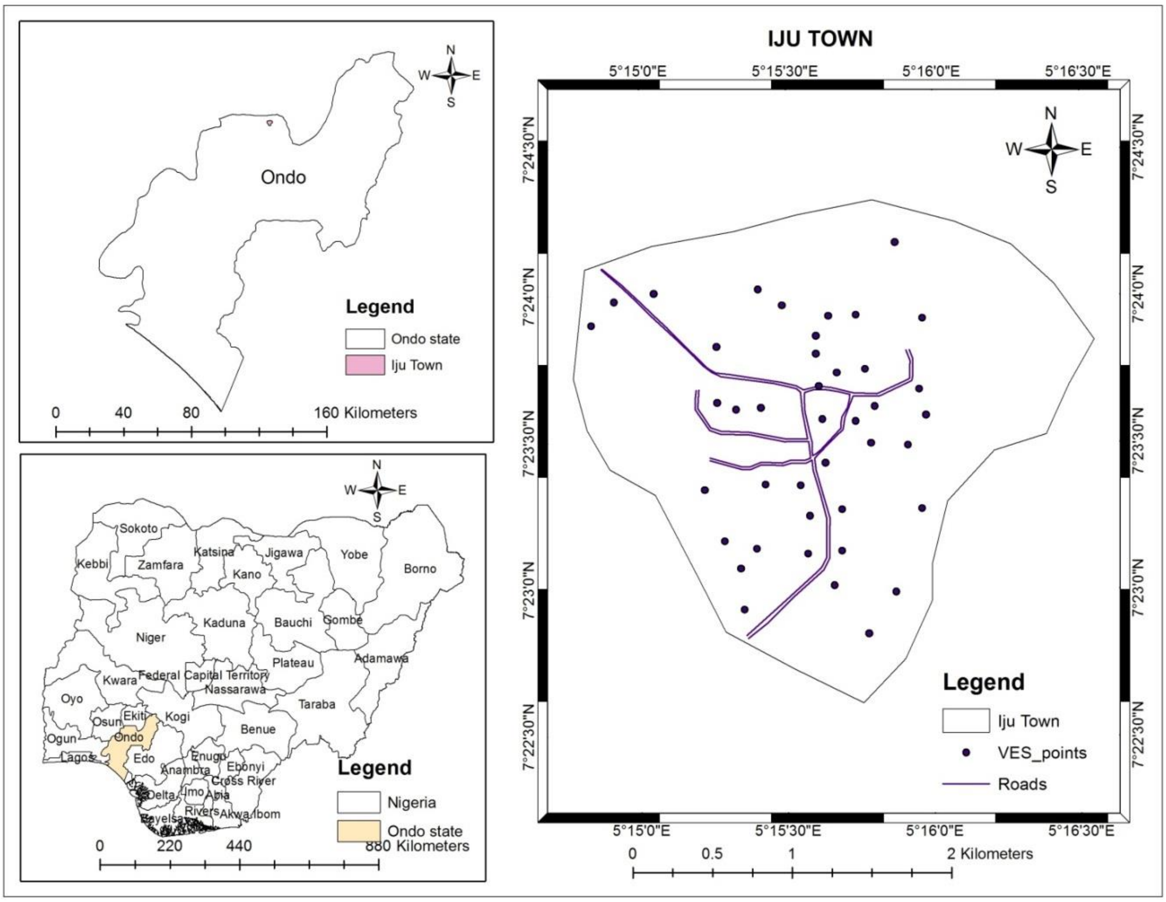

Figure 1: Map of the study area showing the VES points

Haskins and Croukamp (1999) utilized GIS techniques to identify suitable development potential terrains for a regional engineering geological mapping programme in South Africa. From the study, it was demonstrated that application of a GIS methodology could be used to derive development terrain.

Eduvie and Olabode (2001) carried out evaluation of aquifer potential in the basement complex of southern part of Kaduna state, Nigeria, using geoelectric sounding data. From the study, it was demonstrated that the groundwater potential is a combined function of the three geoelectric parameters: depth to bedrock, saprolite resistivity and fractured bedrock resistivity. It was also observed from the study that the difficulties in exploration and exploitation usually encountered in groundwater development in the basement terrains, where aquifer units are both isolated and compartmentalized, require the use of GIS technique approach, which could integrate relevant multidisciplinary hydro information for such groundwater development to ensure success.

In view of the above discussions, groundwater resources development scheme would provide a very suitable and reliable solution to the enumerated water resources problems. This kind of scheme is a cost effective one, which could be embarked upon and complete within a very short interval of time, if necessary geospatial database is available. Therefore, hydro geophysical and geographic information system (GIS) assessment of the groundwater resources potential of the study area is highly imperative.

2. AIM AND OBJECTIVES

This research work carried out a geophysical and GIS assessment of groundwater potentials of Iju township in Ondo State Nigeria and this was arrived at through the following objectives;

i. to generate geophysical, GPS and hydrostatic level data
ii. to delineate subsurface structures favourable to groundwater accumulation
iii. to delineate the potential aquiferous zones

3. METHODOLOGY

3.1 Geophysical, GPS and Hydrostatic Level Data

The data generated in this section includes geoelectric parameters, planimetric and altimetric coordinates and hydrologic parameters. An analogue resistivity meter (model R-50) was used for the vertical electrical sounding of the area under investigation. The resistivity meter is a direct current (DC) resistivity device, designed for depth probing surveys within a depth range of 150m (500ft) to 180m (600ft). The complete system consists of the separated transmitter and receiver units, and two cable reel assemblies with four pusher – type galvanized electrodes. The use of separate transmitter and receiver units eliminates the reading errors caused by mutual interference between the two electrical circuits associated with the transmitter and receiver. A 12-volt DC battery was used as a source of electric power supply to the resistivity meter.
Magellan promax X with an accuracy of 12m r.m.s for point positioning was used for fixing the horizontal and vertical positions of the VES stations and details of interest of the investigation. The receiver unit of the GPS interacts with the earth orbiting satellites in space through the inbuilt communication device and receive coded information, which is subsequently transmitted to the controller unit via the connecting cable for processing, to determine the GPS receiver position. The controller unit is powered by an external 12-volts DC rechargeable battery.
The VES technique was employed, using Schlumberger electrode array for the apparent resistivity data acquisition for this research. The depth of investigation is always a function of the total electrodes spread. The larger the electrode spacing along the basin, the deeper the effective depth of penetration. The apparent resistivity data obtained could be plotted as a function of the electrode spacing (half of the total electrode spread for Schlumberger array). The thickness of the subsurface layers underneath the VES station could be evaluated from this graph, using appropriate interpretation techniques.

3.2 Subsurface Structures Favourable to Groundwater Accumulation

The acquired heights above mean sea level of the VES stations, hand-dug wells, boreholes, and other details of interest within the study area, were plotted and contoured to generate the height contour map (a topographic map) of the study area. The topography (relief) of an hydrologic basin has effect on the groundwater flow pattern of the basin. Height contours on a topographic map are one of the forms of terrain representation use for terrain analysis to determine hydrologic parameters that go into groundwater flow model in GIS technique (Goodchild and Kemp, 1998). The topographic contour map of the study area therefore forms an important GIS coverage map in this study.

3.3 Delineating Potential Aquiferous Zones

In order to delineate the potential aquiferous zones, three maps were produced. Firstly the overburden thickness map of the study area was produced. Overburden thickness as used in this context is defined as the total depth from the surface to the top of bedrock at each of the VES station. This was done by plotting the overburden thickness of the VES station against their horizontal coordinates using the SURFER software. Secondly, the weathered layer resistivity map of the study area was produced by plotting the apparent resistivities of the weathered layer obtained from VES data preliminary interpretation against VES stations horizontal coordinates. In a similar way the bedrock resistivity map of the study area was produced by plotting the bedrock resistivity obtained from the VES data interpretation results against the horizontal coordinates of the VES stations.

4. RESULTS AND DISCUSSIONS

4.1 Geophysical and Geoelectric Data

A total of 44 depth soundings were made randomly to cover the area of study in the course of the geophysical field survey. Table 1 below shows the geophysical and geoelectric data obtained fom the field.

Table 1: Geophysical and geoelectric data

VES Stations	Northings (mN)	Easting (mE)	Height above msl (m)	Overburden thickness (m)	Weathered layer resistivity (Ωm)	Bedrock resistivity (Ωm)
1	749529.324	817555.244	379	7	1350	3964
2	749808.978	817686.146	372	6.7	1516	3250
3	750035.081	817674.246	378	14.3	2263	7835
4	750160.033	817852.748	377	8	600	8402
5	750100.532	818031.251	374	11.6	34	4501
6	750392.086	818055.051	342	11	1071	6250
7	750433.736	818293.055	375	8.7	1490	16695
8	750261.184	818376.356	379	20.7	263	3413
9	750136.232	818465.607	374	15.6	306	9618
10	749951.78	818953.514	371	16	91	8305
11	748452.359	818620.309	364	16.9	845	5525
12	748922.415	818471.557	367	8	0	9577
13	748196.505	818560.808	369	6.5	54	2841
14	748047.753	818412.056	388	23.8	204	5566

15	748999.766	817692.096	374	26.7	130	3282
16	749172.319	817680.196	372	19.2	6281	1345
17	748720.112	817596.895	382	15.8	845	13585
18	749398.422	817531.444	385	17.4	1004	5715
19	748916.465	816549.68	380	20.9	384	8748
20	749797.078	816484.229	377	7.6	822	7000
21	748851.014	816728.183	374	6.8	72	11555
22	749963.68	816746.033	373	8.5	4273	8179
23	749582.875	816793.634	364	7.3	26	3847
24	749618.575	817013.787	372	13.5	458	1410
25	749136.618	816936.436	373	9.3	168	14550
26	749291.32	816912.635	373	10	37	2600
27	749136.618	817204.189	379	15.6	793	1616
28	749624.525	817251.79	382	5.3	78	3433
29	750136.232	817287.491	372	6.3	78	2243
30	748398.808	817965.8	377	13.1	533	1355
31	748494.009	817698.046	375	10.8	456	1260
32	748529.71	817513.594	380	27.9	383	1769
33	749511.474	817840.848	379	35.5	1814	4858
34	749749.477	818025.301	376	18.1	523	2860
35	750528.938	817953.9	381	37.3	254	621
36	750499.187	818239.504	380	17.1	911	5111
37	749838.728	818066.951	379	19	1440	4367
38	749969.63	818108.602	381	14.7	147	3299
39	749945.83	818293.055	381	29.1	646	1042
40	749463.873	818239.504	391	16.4	880	461
41	749529.324	818465.607	382	16	450	2043
42	749713.776	818495.357	376	24	350	611
43	749463.873	818346.605	392	15.2	598	3504
44	749166.369	818388.256	371	37.2	100	1407

Authors' fieldwork (2019)

4.2 Geophysical and Geoelectric Data

Figure 2 and 3 shows the 2-D and 3-D height contour maps of the study area respectively. the southern and central-eastern portion of the maps of the study area depicts lowland – 2-D map is characterized by closed contour curves with a minimum elevation value, while the 3-D map depicts lowland which could be visualized directly from the 3-dimensional stereo view. The northwestern portion of the maps (2-D and 3-D) also display the same characteristic. It is generally observed that valley could be ground surface expression of subsurface depression or fault plane. Consequently, it could be adduced that the southeastern and northwestern portions are the major discharging zones of the groundwater flow system of the study area.

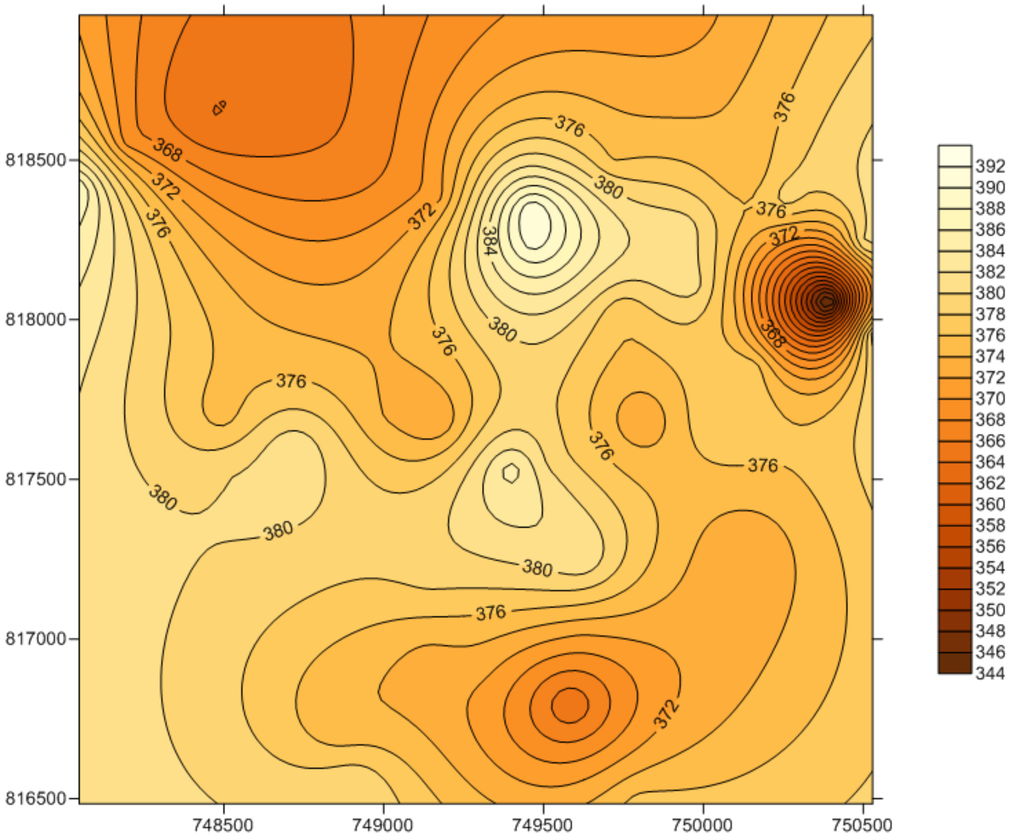

Figure 2: 2-D Height contour map of the study area

The northeastern, central and southwestern portions of the 2-D and 3-D maps depict highlands; the 2-D map is characterized by closed contour curve of maximum elevation values at these portions. Therefore, the northeastern, central and the southwestern portions could be considered as the groundwater recharge zones of the study area.

From the 3-dimensional stereo-view of the topographic map, it could be observed that the northwestern – southeastern axis (direction) depicts relatively flat topography (or valley) that slopes gently towards the southeastern and northwestern portions. It could be therefore deduced that this axis constitutes the major valley (drainage channel) of the study area, through which the groundwater drains out of the flow domains (i.e. the main groundwater flow direction).

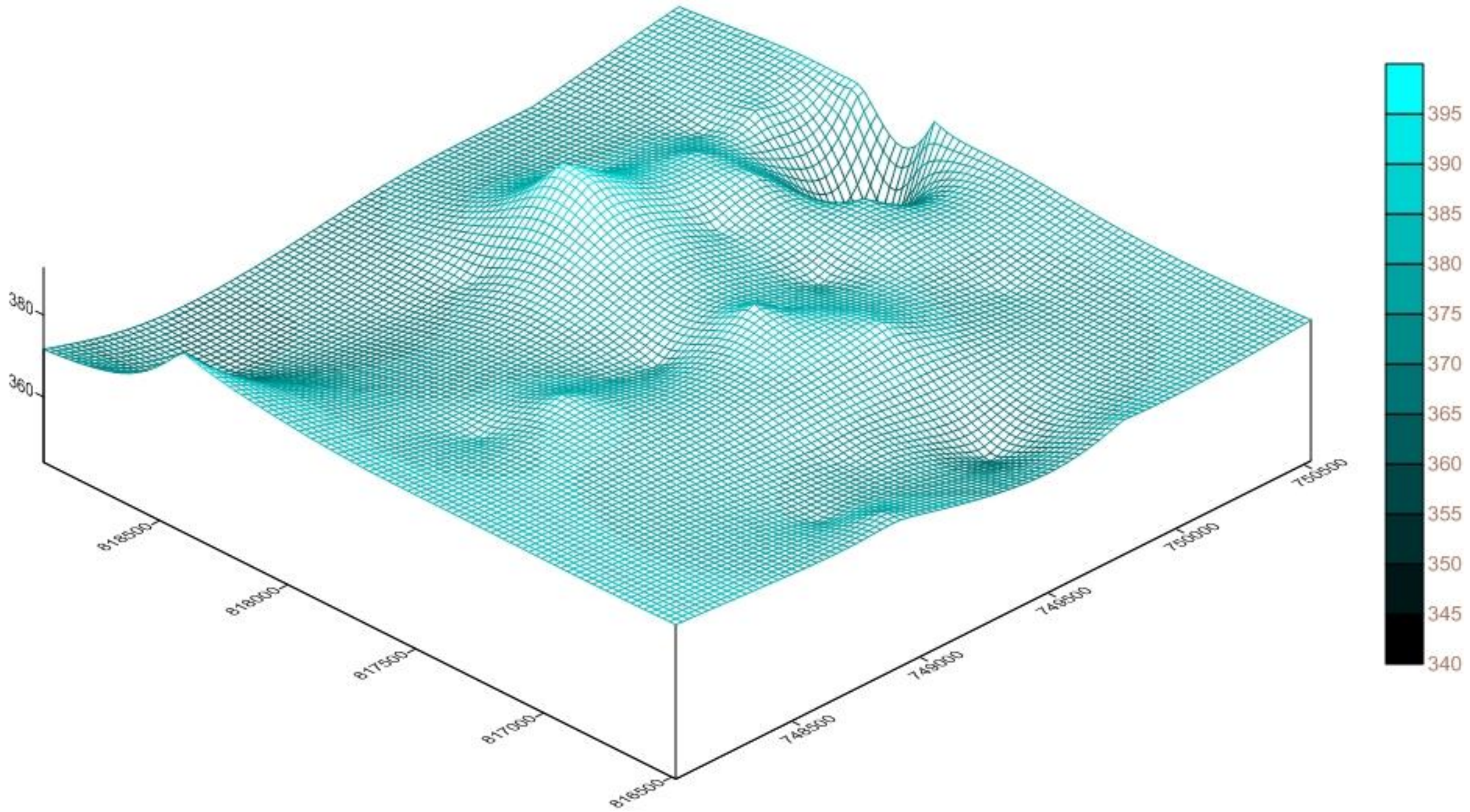

Figure 3: 3-D Height contour map of the study area

4.3 Aquiferous zones

4.3.1 Overburden thickness map

Generally in the study area, the map (Figure 4) shows overburden thickness values ranging between 5m to 38m. The map depicts the study area to have an appreciable overburden thickness in the northeastern direction (values ranging between 20m to 38m), fairly high thickness with values ranging between 16m to 19m in the northwestern flank, and relatively low thickness in the southern parts.

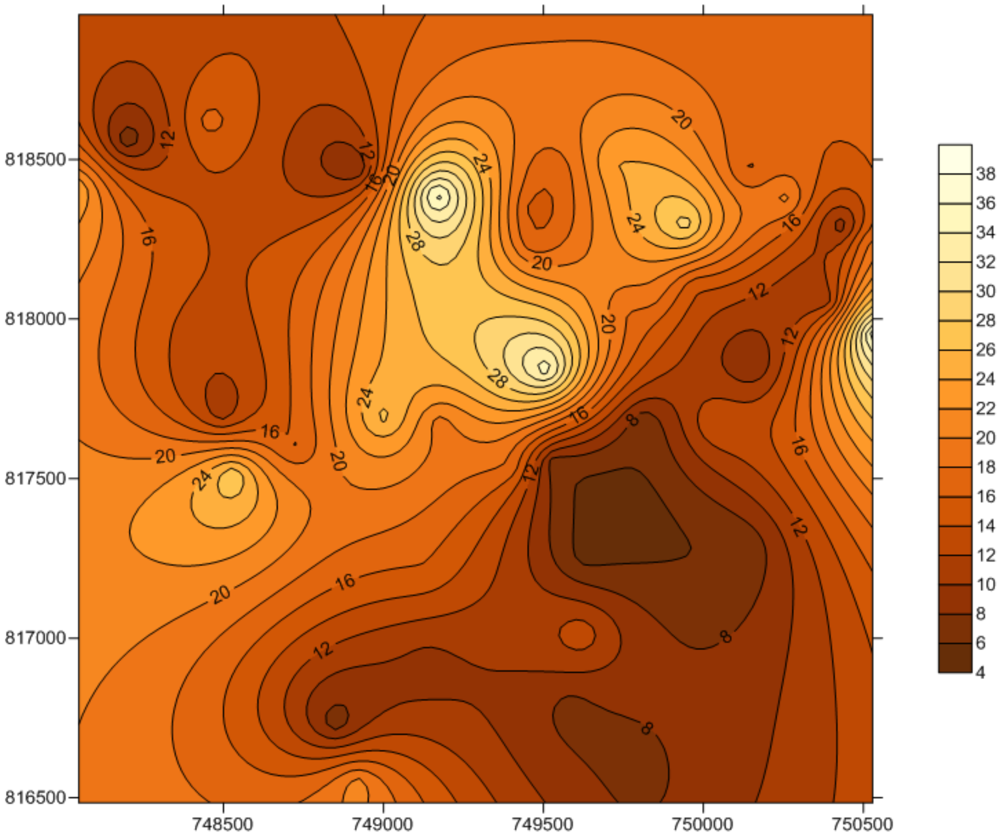

Figure 4: Overburden map

The high overburden thickness could be diagnostic of basement depression, which is a favourable condition for groundwater accumulation; while the low overburden thickness is diagnostic of basement ridge, which is relevant in engineering works. Pressure being a function of depth (i.e. pressure increases with depth) makes the pressure gradient in the parts of the study area with high overburden thickness suitable for groundwater development.

For a viable groundwater abstraction scheme in the study area, boreholes could be sited in the northwestern and northeastern parts; such boreholes would be productive with a reasonable yield, provided the aquifer thickness is reasonable and underlain by fractured or weathered bedrock of low clay content. The low overburden thickness could only support shallow hand-dug wells.

4.3.2 Weathered Layer Resistivity Map

From the weathered layer resistivity map of the study area (Figure 5), the south-central portion of the map is characterized with closely-packed resistivity contour curves (with resistivity values ranging between 700Ω to 4273Ω), which is the same resistivity characteristic displayed at the same portion of the bedrock resistivity map. This geoelectric characteristic is suggestive of the presence of a localized geologic structure such as fractured plane/basement depression, which is a favourable condition for groundwater development.

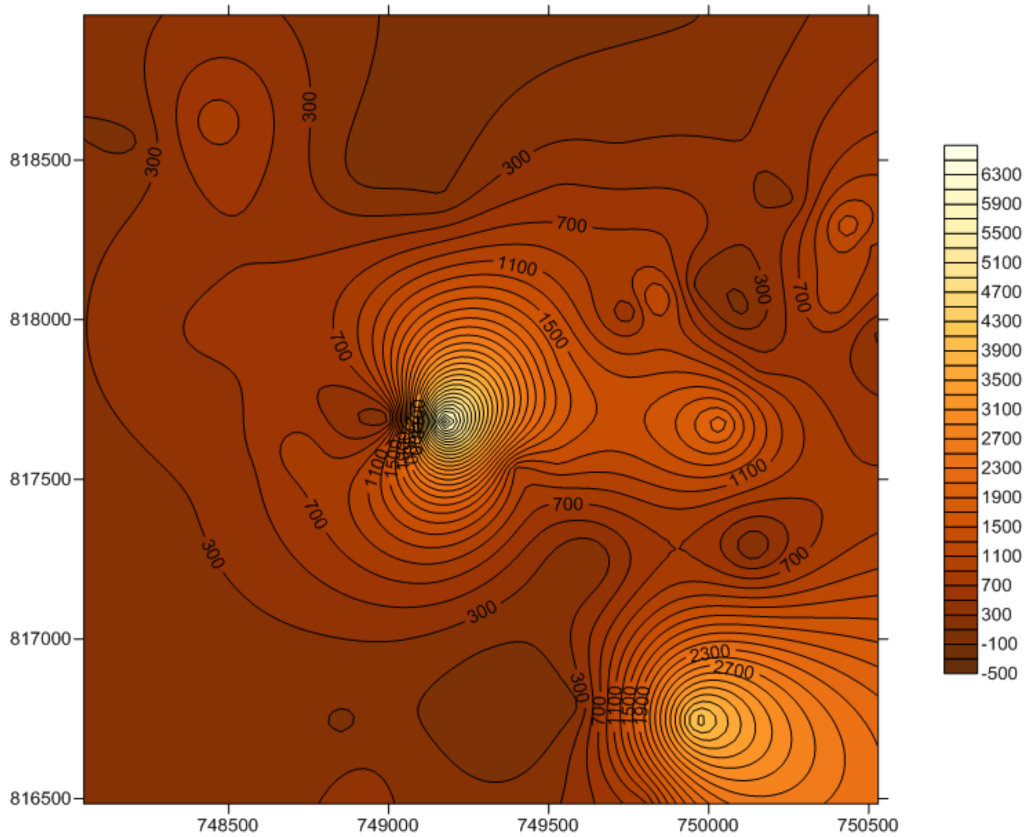

Figure 5: Weathered Resistivity map

The central portion of the northern flank and the southwestern parts of the map exhibits relatively low to moderate resistivity values (ranging between 10Ω to 300Ω). The relatively low saprolite resistivity values observed at this portion of the southwestern flank could probably be attributed to the high degree of saturation due to fractured underlain basement; while the relatively moderate resistivity values could be attributed to the high sand to clay ratio (i.e. very low clay content). These hydroelectric conditions are favourable to groundwater development; hence, the southwestern flank of the study area could be considered to be a good groundwater potential zone.

4.3.3 Bedrock Resistivity Map

Figure 6 shows the bedrock resistivity map of the study area. This kind of geoelectric map allows the assessment of resistivity variation of the underlain basement rock and its correlation with the expected degree of fracture/joining and permeability, which could be related to groundwater potential attribute of the overlain aquiferous unit.

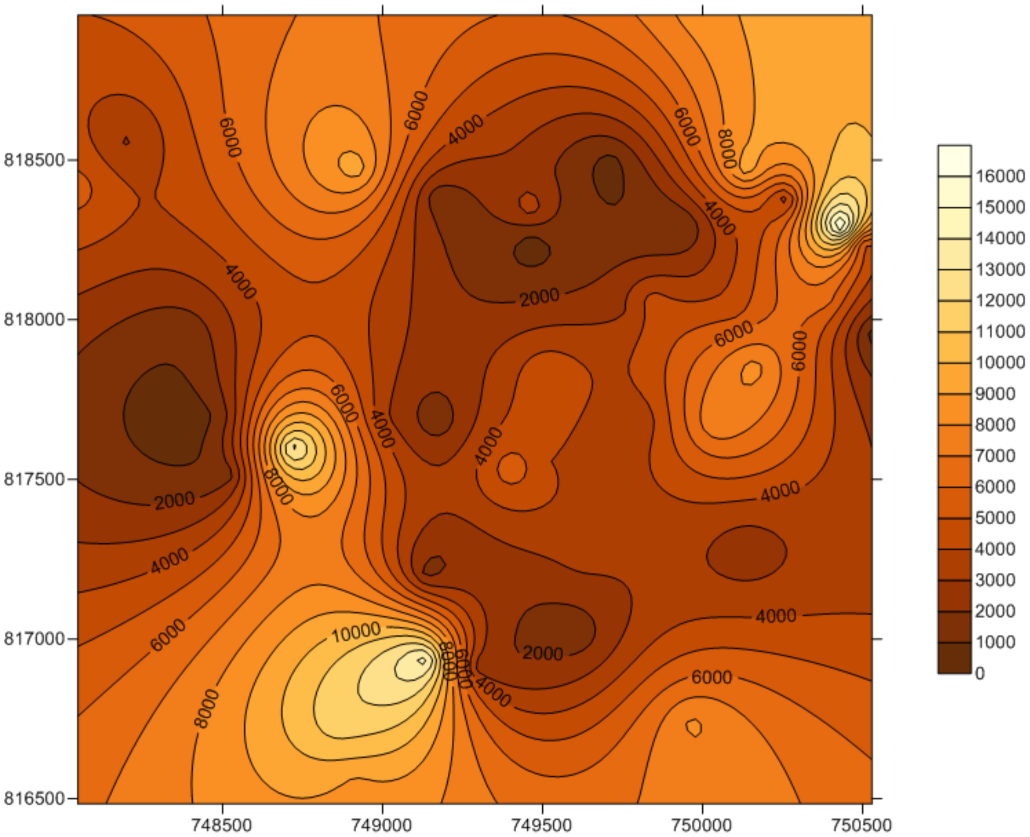

Figure 6: Bedrock Resistivity map

A simple criteria scheme (as shown in table 2) for preliminary evaluation of aquifer potential as a function of bedrock resistivity in the basement complex terrain (Olayinka et al., 1997) was used as part of basis of discussion and hydroelectric deductions in this section of the study. It is generally believed that if bedrock exhibits a relatively low/moderate resistivity value, this could be suggestive of high fracture/permeability of the bedrock (Eduvie and Olabode, 2001). Also, closely packed resistivity contour of bedrock is generally believed to be a signature of basement fracture or depression. Therefore, any overlain aquiferous unit of such bedrock could be accorded high groundwater potential attribute.

Table 2: Aquifer Potential as a function of fractured Bedrock Resistivity

Bedrock Resistivity (Ωm)	Aquifer Characteristics	Weighting
< 1000	High fracture/permeability as a result of weathering; high aquifer potential	10.0
1000-2000	Reduce influence of weathering; medium aquifer potential	7.5
2000-3000	Fairly low effect of weathering; low aquifer potential	5.0
> 3000	Little or no weathering of the bedrock; negligible aquifer potential	2.5

Modified from Eduvie and Olabode (2001)

The southern-central, north-eastern and central flanks of the study area are characterized by closely-packed resistivity contours; this geolectric characteristic is diagnostic of bedrock fracture/basement depression, which is a favourable condition for groundwater development. A portion of the southeastern flank exhibits relatively moderate resistivity values between 1000ohms to 2000ohms. This geolecetric characteristic suggests that the bedrock of this portion is fairly fractured/weathered; consequently, the southeastern portion could be considered to be a fairly good groundwater potential zone.
The central portion of the north-eastern flank is characterized by relatively low to moderate resistivity values ranging between 600ohms to 2000ohms. This is also a signature of high fracture/permeability of the bedrock. Therefore, this portion is suspected to be fractured, which is a good condition for groundwater development. In view of this, the northeastern flank of the study area could be considered to have good groundwater potential attribute.
The western, eastern, northern-central, south-western, flanks of the map are characterized with relatively high to very high bedrock resistivity values (ranging between 2500ohms to 14500ohms). This resistivity characteristic is diagnostic of fresh bedrock/bedrock ridge; which is not a favourable condition for groundwater abstraction in the basement complex terrain.

5. SUMMARY AND CONCLUSION

The investigation of groundwater potential of Iju township in Ondo State , Southwestern Nigeria has been successfully carried out by employing integrated hydrogeophysical and geographic information system (GIS) techniques. It was revealed that the northwest – southeast direction is the major groundwater flow direction for the study area while the the western and central flanks, northwestern, parts of eastern and southeastern portions are identified as the major recharge and discharge zones respectively.
The study hereby recommend that community borehole project scheme for protable water supply could be sited at the northeastern, central and southeastern portions of the study area. However, this recommendation could further be corroborated by pumping and drilling tests to enhance the evaluation stage of the groundwater development. Aslo the northwest – southeast

axis of the study area should be free of refuse/waste dumpsite or landfill to avoid both surface and subsurface waters contamination/pollution problems. If there is any landfill or dumpsite already located along this axis, in order to avoid problems of groundwater quality degradation, an appropriate and comprehensive chemical analysis of water should be carried out to facilitate appropriate remedial measures before any groundwater development project could be sited in the area.

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BIOGRAPHICAL NOTES

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