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Geo-electrical Resistivity Assessment of the Groundwater Resources Potential of the Waradey Area, Eldas Sub-county, North Eastern Kenya

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***Abstract*—The Waradey Area is located in Eldas subcounty in the greater Wajir County. The area has lacked reliable water structures since independence and was the focus of a concerted geophysical mapping to help avail water to the local populace. To achieve this, Geoelectrical Resistivity Mapping and simulation Models using the GIS techniques were used. This achieved the goals of combining the geophysical models and the hydrogeologic models so generated to build a reliable picture of expectations of the proposed drilling program. The variables simulated using hydrogeologic modeling were aquifer transmissivity, flow-vectors showing direction of movement of water in the subsurface flow systems, salinity, and the aquifer geological material, as well as the water struck levels, which may be used to infer aquifer groundwater levels in the study area. The geoelectrical models were used to simulate fractures, weathering and moisture content of the underground. The IPI2WIN software was used to model the geophysical VES data so generated. When the two models were combined (ie. both geophysical and hydrogeological), a picture of reliable groundwater potential emerged. On the basis of the foregoing, a well was surveyed and was recommended for drilling, to be discharging up to 10 cubic meters per hour. At worst the models projected a discharge of 2-6 cubic meters per hour. The study has shown the reliability of Vertical Electrical Sounding probes and geospatial models, as powerful groundwater exploration tools for the Eldas area, given the limited actual data of hydrogeological drilling in the study locality.**

Keywords*—Resistivity, GIS, Surfer, Basement, Water Struck Levels, Flow Vectors, Groundwater Levels, Schlumberger

I. INTRODUCTION

Waradey Trading Centre is located some 220 Kilometers to the Northwestern sides of Habaswein Town, approximately 70kms away from WAJIR TOWNSHIP. The site lies 500M away from the township along the **Waradey –Anole stretch**. The Project targets a population of at least 2,000 persons and 30000 animal stocks, respectively for domestic and livestock use. No borehole site exists in this proposed settlement scheme. Earlier attempts at drilling in 2009 by the NWCPC operated unsupervised and generated 2 cubics per hour, which is way too little to be of much help. Even this limited help was short-lived as the well was located at a place with very unreliable recharge, compounded by the erratic rainfall patterns in the area. The rains would easily have recharged the upper aquifers.

Study team thus ventured some hundreds of meters away from the township, at a point with some acacias, shown to us by the area Chief. The geophysics data modeling intimated that some 2-6 cubic meters per hour discharge, or more, could come out of the hole. The well is a public the facility, and will be hand it over to the county government, for further development of infrastructure systems. The borehole will be developed upon drilling completion and should be preferably encased with steel casings. It successful, it shall free the locals of the stress of having to trek to Eldas nearly on a daily basis for watering of their livestock. Once the productivity of the borehole has been determined, a suitable submersible pump will be installed to pump water into the proposed storage tanks. The schematic design and the detailed itemization for the proposed borehole shall be the subject of phase two work for the planning and designing unit, but will be predicated on the borehole performance in terms of aquifer yields and recharge. In case the yield will be too low for a submersible motor powered pumpage, a hand pump or windmill driven pump system is suitable as well**.**

Project Ownership

The proposed site is a public facility owned by the local Waradey community and will be managed by a committee specifically designated to run the facility, on matters relating to borehole operations and maintenance.

II. Literature Review

Inverse resistivity modeling using Schlumberger array on geophysical d data formed the basis of a 2019 work, (Arifianto et al, 2019) study in an area situated in Jeneponto, located in the South Sulawesi Province, Indonesia. The study was part of the Indonesian Government's effort dubbed the 'Development Acceleration Program targeting the country's regions deemed underdeveloped as compared to the rest. Water had been identified as one of the main drivers of development, hence the decision to start with water exploration. The areas volcanogenic sediments comprised, amongst others, the volcanic breccia, tuffaceous sand, as clayey deposits. The geoelectrical probes were employed mainly to map out and determine both vertical and lateral extents of the active aquifers deemed available in the area, as it identified and mapped the relative variations between different rock and soil layers encountered with respect to moisture or water contents. Oyeyemi et al (2018) mapped the Iyana Iyesi area of the Ogun State using the Schlumberger arrays, with a view of delineating the most productive geological features that would clue them in, on the spots with the best probability of striking water. The geoelectrical resistivity arrays were undertaken using Schlumberger profiles, in the Ogun state. The study generated the aquifer hydraulic parameters, which included porosity, transmissivity, hydraulic conductivity and permeability, and whose favorable values ended up recommending the area for groundwater development, given the confidence boosting study s to the chances of striking underground water. Umar et al (2018) did a groundbreaking study using the Wenner-Schlumberger probe arrays, employing the resistivity exploration technique of geoelectrical mapping. The modeling of the data generated a 2D anomaly, which revealed the lateral spread of resistivity as well as the vertical components, and formed the basis of determination of how far apart the aquifer material was located away from the saline water interface which was deemed a risk, with time. On the basis of this study, it was established that the geological material that harbored the aquifer was an assortment of various forms of gravel, sand, clay, mud, and coral limestone, amongst others, in an alluvial environment. Dar Zarrouk profiles were used to critically study an aquifer in Indonesia (Nugraha et al, 2022)Bangka Belitung Islands Region. Water resources were identified as a key economic growth factor without which economy of the island could not grow and as a result had to be availed for the industrial momentum to be actualized. The Dar zarrouk Parameters mapped helped generate d a report giving road map as to how to develop the water infrastructure in the island. Hasan et al (2018) undertook a comprehensive mapping of geophysical components using the VES arrays, then did pumping tests and geochemical analysis, so that he could establish ground water correlation between the hydraulic variables obtained from geophysical method, as well as the aquifer test pumping data. Test pumping implies drilling, development and test pumping which is costed at millions. The Pakistani scientist's research aimed at helping one estimate the hydraulic variables generated via test pumping using statistical correlations between geophysical data and the hydrogeologic data analysed. To achieve, he had to undertake the traditions Dar Zarrouk Mapping.

In 2021, Kanoti et al undertook a comprehensive study on groundwater vulnerability, using an assortment of procedures, one of which was geophysical VES mapping.

The study involved undertaking field mapping to establish aspects relating to geology, insitu physical and chemical parameters of aquifers, thermo-tolerant, aquifer bacteriology, as well as interviewing the with the local community , to help identify suitable drilling and /or exploration spots.. The research work equally involved water sampling and lab analysis for the cation and anion contents dominant in the aquifers mapped. The traditional methods of Geological mapping and the VES probes, alongside XRD, and interpretation of software-aided analysis of the VES data helped determine and establish the aquifer geometry. Aquifer flow dynamic were subsequently inferred using available hydraulic data such as aquifer transmissivity and the likes of permeability. Test drilling for lithological samples, aquifer testing, and analyses of previously available data permitted delineation of aquifer dynamics, generalized transmissivity distribution, and interpretation of the groundwater flow system. Electrical geo-mapping helped develop the Kakuma Refugee camp in a study of 2017 by the ESGG group (Bauman, et al 2017).ERT The electrical resistivity tomography, abbreviated as the ERT, was instrumental in helping make distinctions of granular geological material from the fine-grained clay and the material from fractured lithologic units, as well as distinguish fresh from saline water. The procedure also helped map out faults. These are the lineaments usually searched for by Hydrogeologists using geophysical procedures, while looking for subsurface water. **Amimo et al** (2021) mapped the Landheer area of Dadaab in Kenya, using both VES geophysics and hydrological moles to delineate the best discharge point for drilling as well as the estimated water quality using both statistics and machine learning methods.

III. Hydrogeology

A. Geology and Stratigraphy

Recharge Mechanisms within the Aquifer Systems

Evidences abound of jointing and fracturing of the carbonate sediments on the surface, alluding to intense forces of fracturing, carbonation and quaternary tectonic faulting. Much of the south westerly – north easterly directed stress fields helped sculpture the terrain into its present geological state. The sedimentary material overlies the basement material. Recharge is via runoff infiltrations . The Jurassic limestone carbonates are fairly fractured and possess water at the shallow depths, though highly mineralized, via the fractures and karstification veins. Water also forms at the contact points between the carbonates and the Archaean metamorphic basement units. Groundwater in the upper sediments shall enjoy annual precipitation recharge through direct infiltration, while the deep-seated zones shall be recharged via regional flow aided by the karstification channels and plate tectonics in the Jurassic – cretaceous period. Evapo transpiration rates of up to 3,000mm per annum over shadow the annual rains of up to 400mm per annum.

B. Physiography

The area is endowed with a low/ unfavorable physiography. It stands at an average altitude **of 442** metres above sea level within a gently dipping terrain punctuated with several ant-hills and flood plains both on the south eastern and north western flanks.

IV. Project Location

A. Location

The project area lies in North eastern province within **ELDAS District.** It is located on the southwestern sides of the main catchments course way. The area is defined by longitudes and latitudes **defined already,** at an altitude of approximately **442m above sea level**. Oblique dipping sediments litter the terrain alongside some zero degree dipping units of flood-prone Miocene Pliocene sediments. These overlie basement Granitoids as from 63m bgl to 130m bgl.

B. Nature of the Project

This is a proposed communal water supply project meant to not only address the critical needs for livestock watering and human domestic consumption, but also to enhance the rapid settlement of the local population by having them practice small scale agriculture as well as enhanced rapid absorption of children into schools for academic and spiritual growth. The project shall have a daily requirement of approximately **100 cubic meters,** computed from the population figures. This is possible if the well ends up with a discharge of 7 to 10 cubic meters per hour as its safe yield during test pumping and well development. This is a figure computed to include daily domestic requirements as well. The completed borehole/shallow well will be developed upon drilling completion and should be preferably encased with steel casings. Once the productivity of the borehole has been determined, a suitable submersible pump will be installed to pump water into the proposed storage tanks. The tanks should bear capacity of at least 50 cubic meters storage or more-preferably 100 cubic meters, for the simple reason that the well will get lots of water all at once and the time people shall be utilizing the storage, the well will have sufficient time to efficiently recharge, hereby prolonging the lifespan of the facility. A schematic design and the detailed itemization for the proposed borehole shall be the subject of phase two work for the planning and designing unit, but shall be predicated on the borehole performance in terms of aquifer yields and recharge. Several watering troughs are desired way distant from the proposed well drilling point so that the process of watering the animals don not end up polluting the aquifers being abstracted as the formation is highly fractured and weathered, admitting surface fluids into the subsurface.

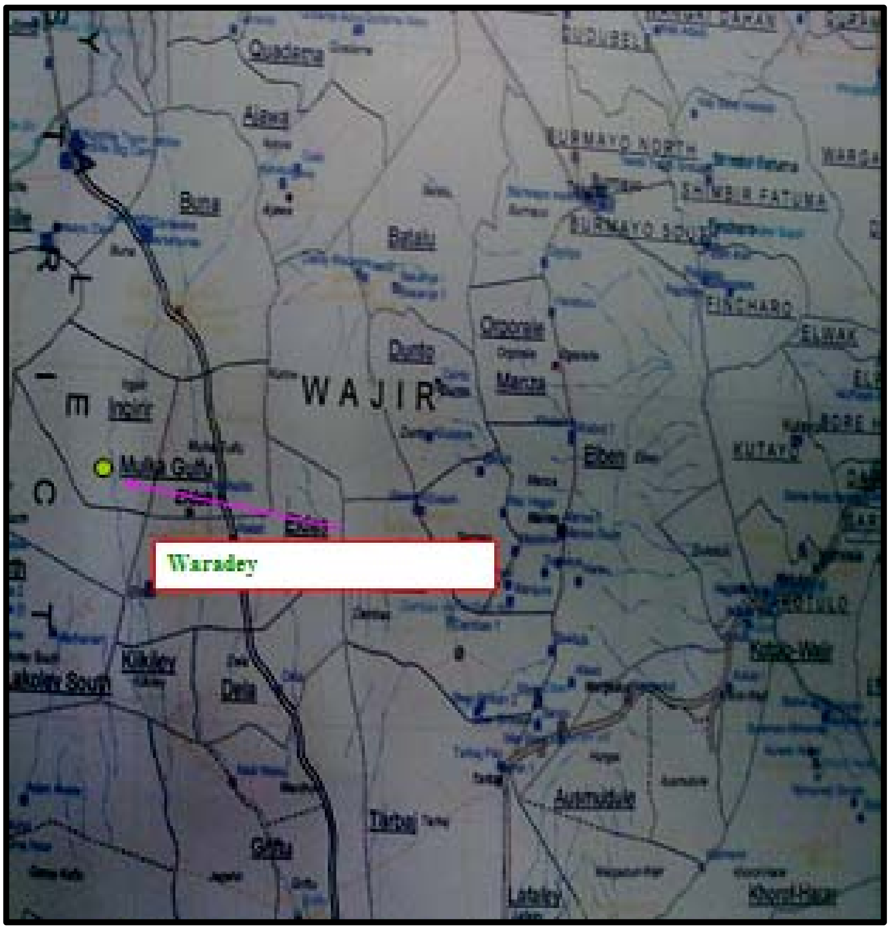
The proposed site is a public facility owned by the un-registered **Waradey- Community Water Supply Project.** The well point proposed is located in an area highly rich in anthills and indigenous tree variety of acacias which are synonymous with moist underground geology. At an appropriate stage, the community will be trained on management related issues pertaining to sanitation, as well as borehole operations and maintenance. Basic record keeping and plant operator skills shall be imparted onto the selected community members whose work shall be closely supervised by the committee.

C. Geology, Geomorphology and geostratigraphy

The flow of water in the surface and the shallow subsurface is a product of the geomorphology or **the Anole and Waradey** plains, and the geomorphic factors active in the area are soils, slope, rocks, vegetation, river hydraulics, amongst many others. The soil mechanics determines the rate of infiltration of run-off waters from rainfall and slope determines the recharge flow velocity of flood waters from Buna plains rivers, as well as Malka Gufu and Masalale areas. Vegetation protects the soils from erosion, hence area a useful check for siltation of material into the small Earthpans present in the area.

The slopes, soil types, vegetation and drainage of the project area is not conducive for perennial flow from the annual rainfall runoff. The topography is undulating, and is enriched in laterites and allied weathered material as well as some loamy/clayey material, thereby promoting rapid infiltration. The geology is defined by **dark to light toned sandy clayey sediments, the weathered granitoids and sandstones,** and limestone-rich material, which overlies the fresh to slightly weathered basement gneisses. Groundwater in the upper sediments shall enjoy annual precipitation recharge through direct infiltration, while the deep-seated zones shall be recharged via regional flow aided by the karstification channels and plate tectonics in the Jurassic – cretaceous period. Evapo transpiration rates of up to 3,000mm per annum over shadow the annual rains of up to 400mm per annum.

Map 1-Map Showing The Location Of Waradey Study Area In The Eldas Subcounty



D. Hydrology, Hydrochemistry and Structural Geology

1. *Recharge Mechanisms within the aquifer systems:* There are minor evidence of limited lineaments in the study area. Biogeography happens to be the only means available of inferring the presence of water in the study area. The biogeographic indicators of watering, fracturing and recharge happen ot be vegetation type and the numerous aligned anthills forever present in the study area. Much of the south westerly – north easterly directed stress fields helped sculpture the terrain into its present geological state.

2. *Drainage:* Owing to the relative flat nature of the terrain, there is flood rampancy. There are, however, no permanent civil structures on the ground to stand the risk of destruction added to the occasional loss of lives for both livestock and human persons. Most of the housing units, all at Hadado, are constructed through shrubs and dry acacia trees locally available, lightening the task of evacuation in the event of impending flood disasters.

3. *Physiography:*The area stands at an average **altitude of 442 metres above** sea level within a gently dipping terrain punctuated with several ant hills and flood plains both on the south eastern and north western flanks. The lagha water flows in the northwest-southeastern azimuth.

4. *Climate:* The project area falls within zone 7 of the classification of climatic/ecological zones of Africa, that is to say arid to semi-arid with temperatures averaging 30 to 34 degrees per day and occasioning evapo -transpiration rates of up to 3000mm per annum. The rainfall average falls well below 500mm per year.

V. GEOPHYSICS:

In order to determine the Projects Area's hydrostragraphy and aquifer suitability, a total of 5**No. Vertical** Electrical Soundings were undertaken using an **ABEM SAS 4000B** Terrameter. Schlumberger arrays were used so that current electrode spreads of up to 250m against potential spreads of between 5m and 25m were employed to conduct the surveys. Copper electrodes were used for the potentials, while steel iron electrodes were used for the currents.

The geonalysed data is presented hereunder for the best site.

VES 001-IN ELDAS TOWN FOR THE JUKALA-WARADEY WATER SUPPLY. DRILL TO 100M BGL

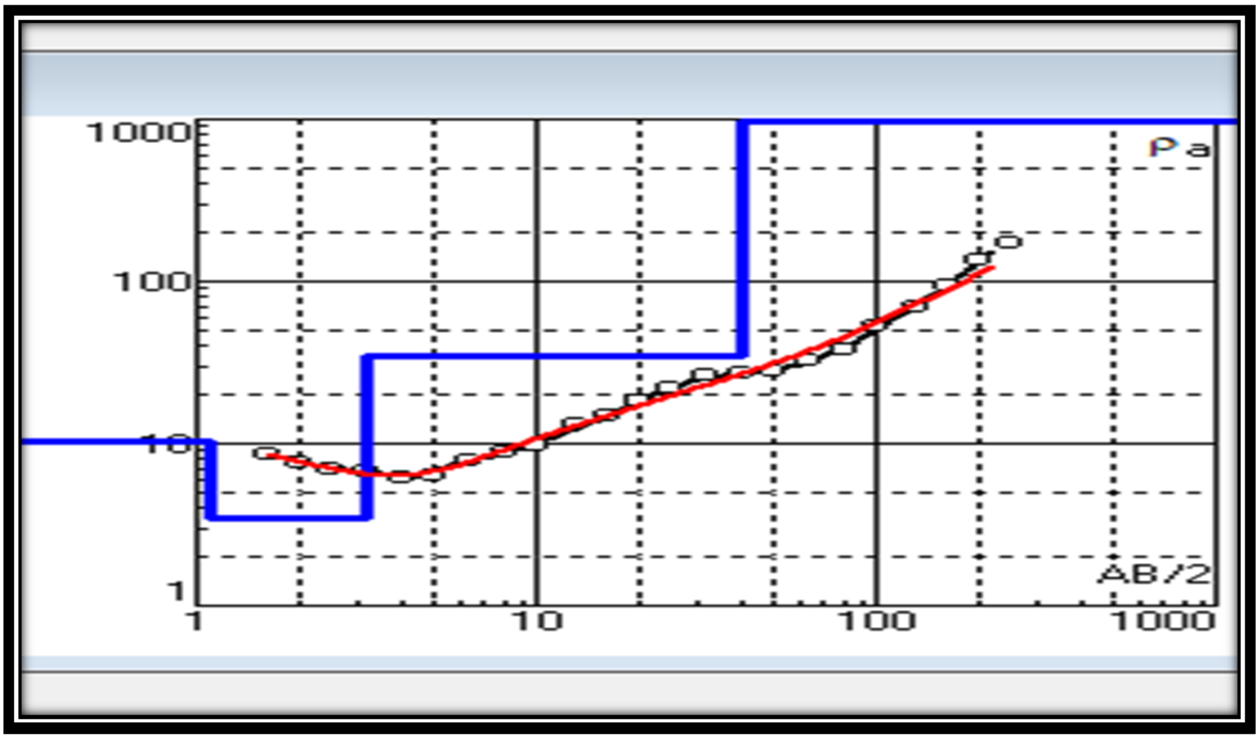


TABLE 1. Model output table FOR VES 001

RESISTIVITY CURVE NO.(R)	FORMATION'S DEPTH INTERVAL(M)	RESISTIVITY (OhmM)	EXPECTED GEOLOGICAL FORMATION
SITE 001 –the first site conducted in Eldas to drill and ferry water to Jukala and waradey	0-1	11.2	Top Soils
	1-5	8	SubSoils
	5-20	24	Clays and gypsites/corallites
	20-25	26	Clays and sandstones
	25-40	36	Fresh Sandstones
	40-50	36	Medium& coarse sst
	50-63	42	Fine sst and clays
	Over 63	infinity	Clays /Shales

VES 002: IN ELDAS TOWN FOR THE JUKALA-WARADEY WATER SUPPLY. RECOMMENDED NOT TO DRILL

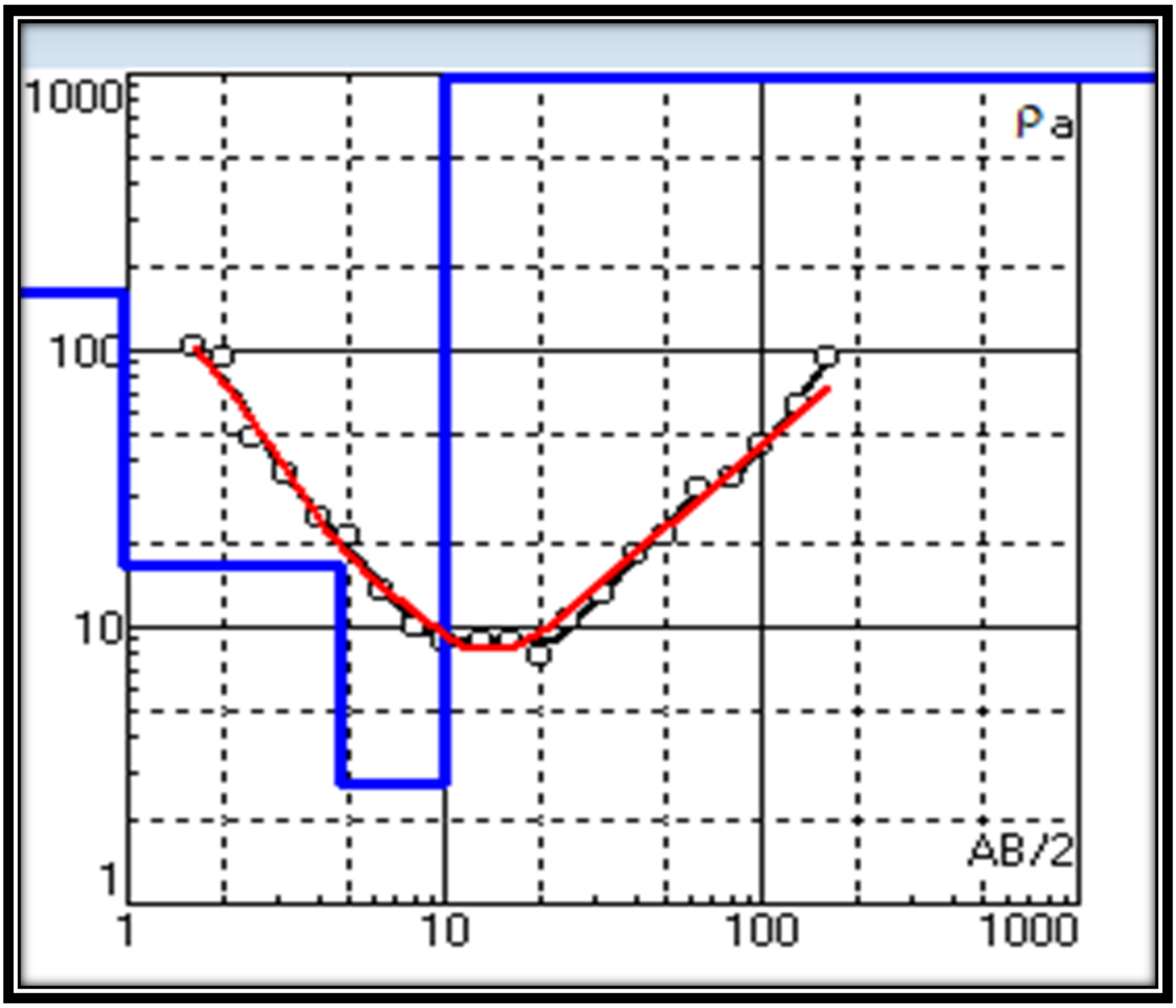
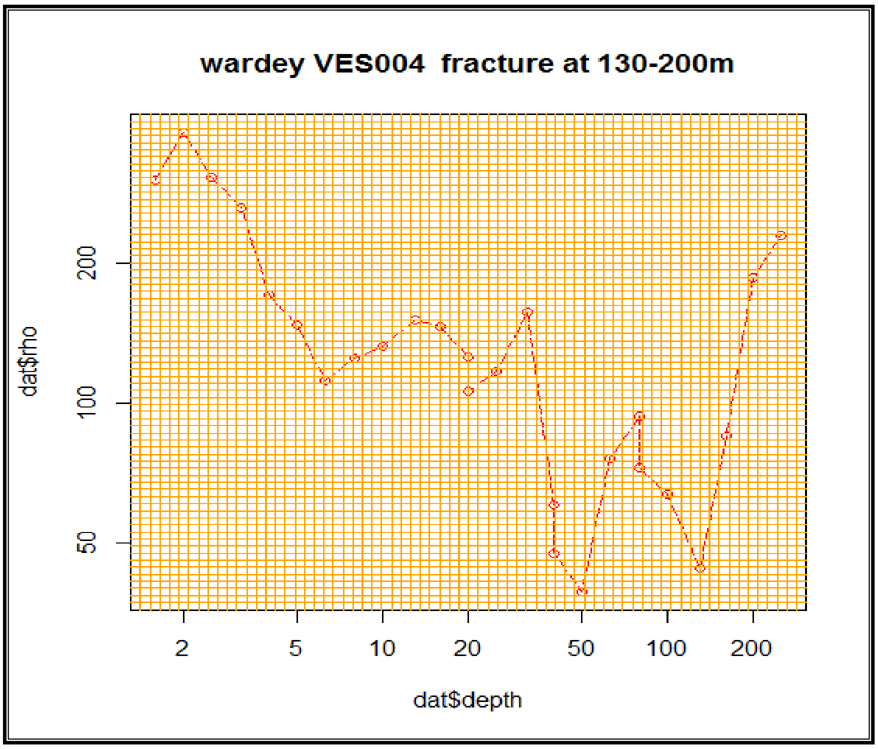


TABLE 2: MODEL OUTPUT TABLE FOR VES 002

RESISTIVITY CURVE NO.(R)	FORMATION'S DEPTH INTERVAL(M)	RESISTIVITY (OhmM)	EXPECTED GEOLOGICAL FORMATION
SITE 002 –the second site conducted in Eldas to drill and ferry water to Jukala and waradey	0-1 1-10 10-20 Over 20	112 10.4 11.2 infinity	Top Soils SubSoils Clays and gypsites/corallites Clays /Shales

VES004 FOR WARADEY VILLAGE WELL. DRILL TO 200M



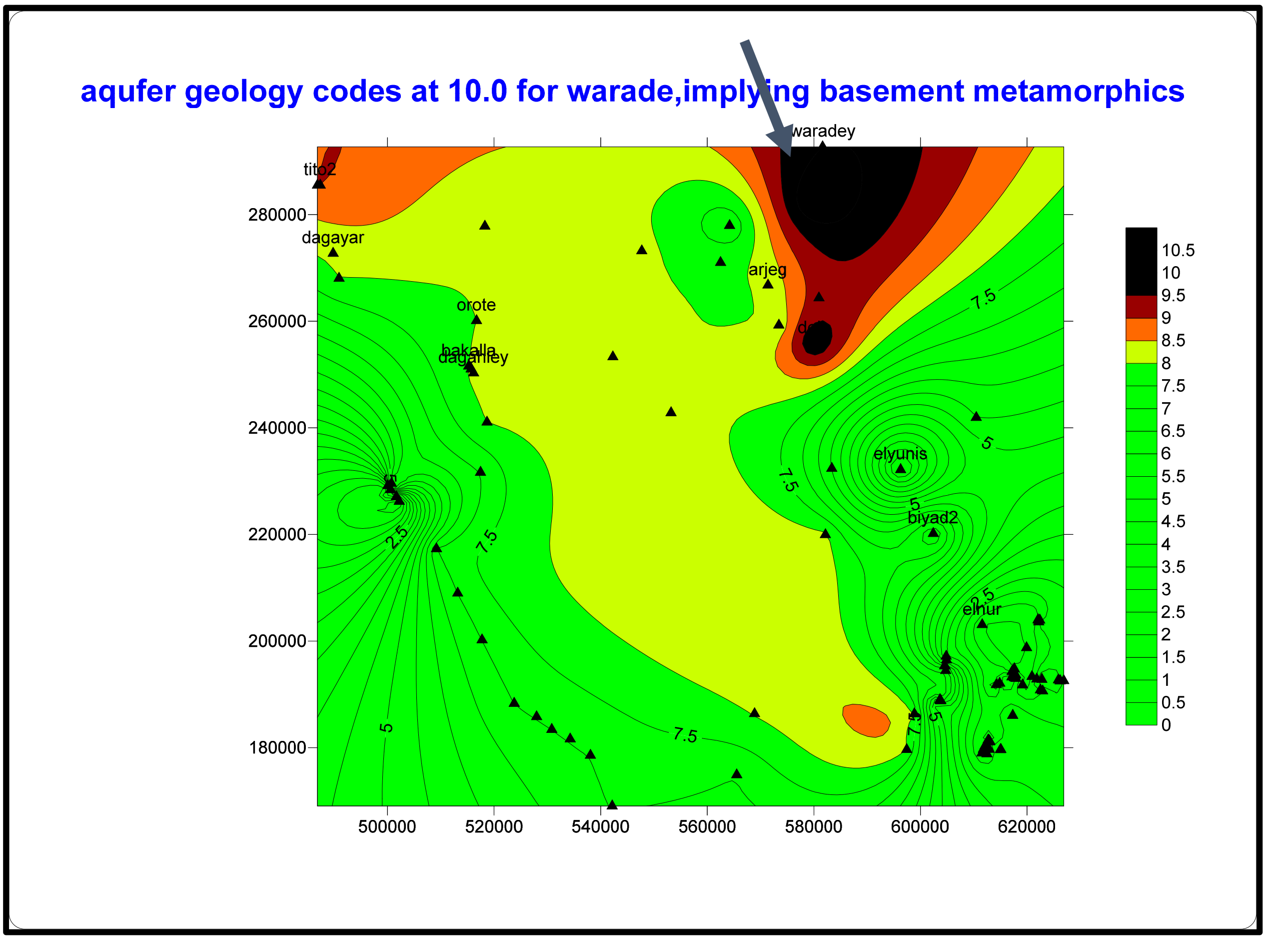
VI. Hydrogeological Modeling Using Surfer & G.I.S. Data

The GPS data may be plotted using the kriging and inverse distance weighting procedures and the output is a geospatial model showing the distribution in 2D of the variables being mapped. The basis of such an undertaking is that longitudes and latitudes shall respectively form the X and he Y axes, so that the hydraulic or hydrochemical variable being mapped firms the Z axis, and is actually the output being so mapped. The end result is a 2D model easy to follow and use for decision making. The different geologic materials in various parts of the greater Wajir west from **which Eldas** was carved out were coded in numeric values ranging from 1 to 10, and these were plotted in the excel table, so that each existing well had its coded geology plotted, aided by addition to a simulated random value. The geophysics was undertaken using s a series of Vertical electrical Soundings and the data generated formed the basis of depths arrived at from the Schlumberger model kinks formed and that have traditionally informed the suitability of the sites. This was followed by Hydrological Modeling of existing data which is tabulated next, alongside brief description of each GIS/Surfer model.

1. *Simple GIS-Based Hydrogeological Models*

Hydrological Simulation Models

Plate 1: -geological aquifer model for Waradey area. The color coding plots **on 10,** representing granitoids rocks, on the basis of which airrotary drilling is hereby proposed, for the centre/area. See the arrow on the top Top RHS of the model pinpointing the town by name.



KEY	
1	sandstons and loams
2	coralites and gypsite
3	coralites and sandstones
4	coralites, loams and sandstones
5	clays, loams and coralites
6	coralites and shalestones
7	medium & coarse grained sandstones
8	sandstones, coralites and gypsite
9	volcanics
10	basement granitoids

Fig 1: shows the names and codes of geological aquifer materials encountered between Wajir West , Wajir North, Wajir east and Eldas sub counties.

Plate 2: WSL levels in the Waradey area. The model estimates 130m to 160m bgl as the main aquifer depths for the waradey area. The first aquifer is between 63 to 80m bgl, and shall be easily struck. With these values predicted, one may easily estimate the groundwater levels as well. The handicap in getting very accurate estimates is that much of the data used to generate these models are actually sources from wells located dozens of kilometers away, and the estimates merely provide a general working figure for the researcher. The groundwater levels are a function of the site elevation in meters above sea levels and the water struck levels, and play an essential role in estimating the aquifer hydraulics of the area (T,K and B, respectively representing Transmitivity, Hydraulic Conductivity and aquifer thickness).

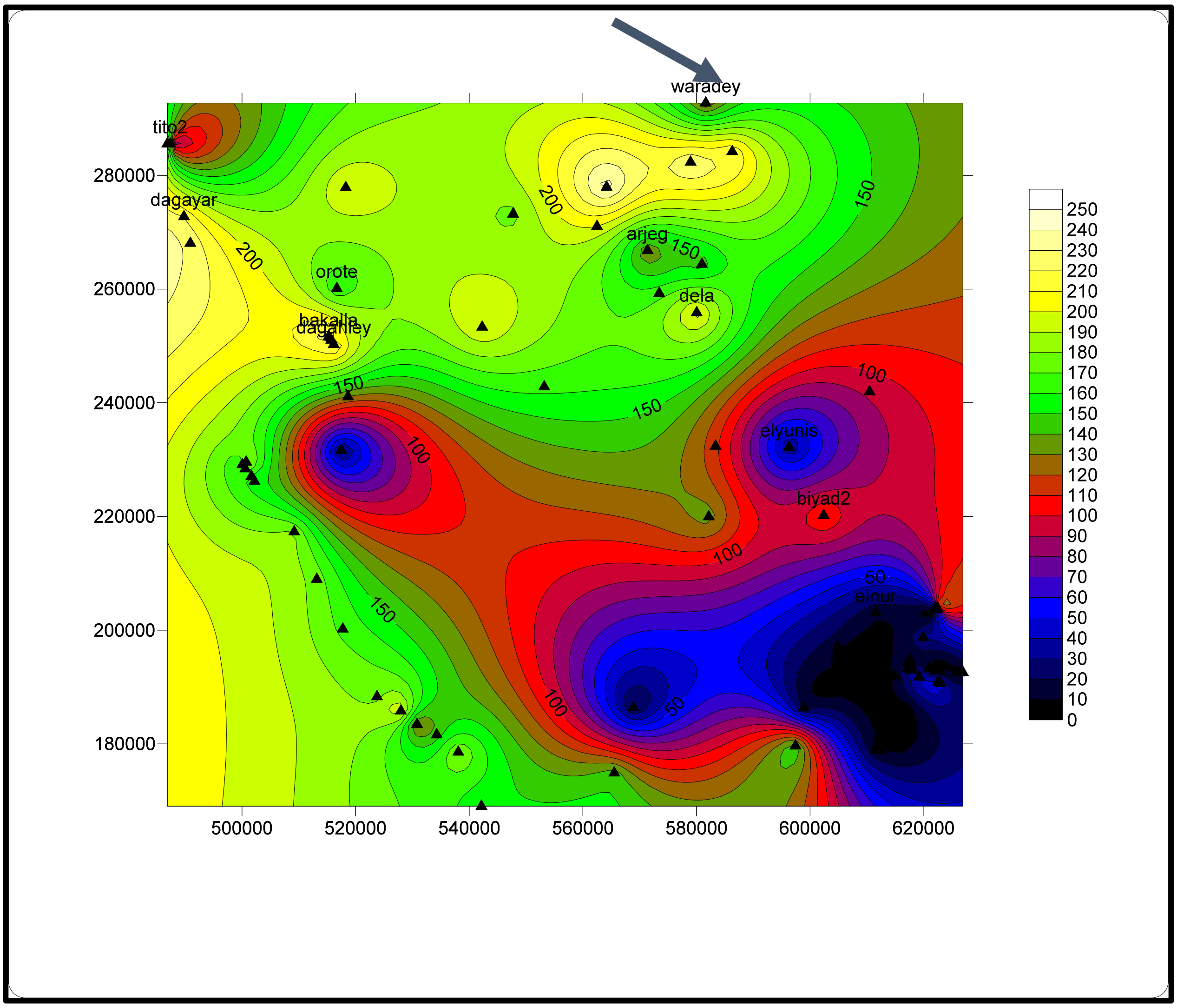


Plate 3: Values of water struck levels in **Waradey village**, as highlighted in the models. The values the first water tables are felt as from 63 to 80m bgl and these are the aquifers at which the first water tables are to be felt. The geophysical curve evidently offers additional hope for more aquifers in the depths beyond 130m bgl from the analysis of the geophysics data of aquifer pore-water resistivity. The water struck levels in the locality is a function of several factors, namely, mean annual rainfall, soil and rock mechanics with respect to infiltration speeds, vegetation cover available and the geometry of the contact zones between the sedimentary beds and the metamorphics prevalent the locality's geology. One readily notices that the water struck levels predicted range from 130m onwards, and this may be for the second or third aquifer unit anticipated in the locality. This shall be the main aquifer. The study area is far away from any river hydraulics structures like ephemeral flow and will enjoy its recharge primarily from the limited precipitation inflow into the upper beds and also the flood waters coming in from Buna plains which area a product of rainfall events in the Ethiopian Highlands.

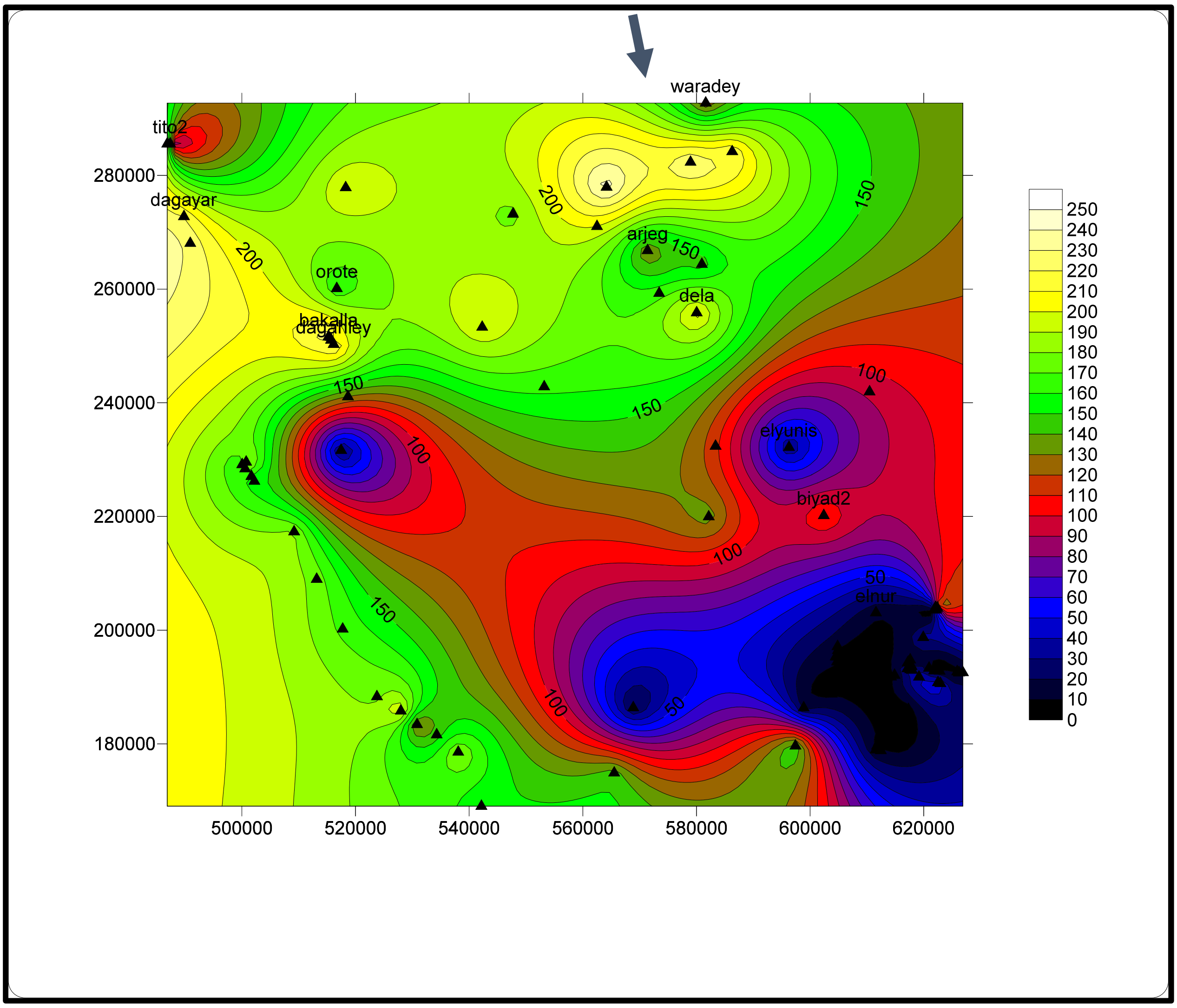


Plate 4: The discharge model as measured in cubic meter/hr, with the model showing estimated quantity of water expected at Waradey Village, upon drilling. see the RHS tip of the mode and take note of the color coding of the hydrological model. Estimated discharge is between 2-6 cubic meters per hour. This quantity shall be sufficient to address the immediate needs for both livestock and humans if a good storage is worked out fro the community, so that at least 100 cubics is pumped into the storage of hundred cubic meter tank every two days, giving aquifers sufficient time to recharge / replenish. Institutions like schools and health centre may also benefit, in retrospect.

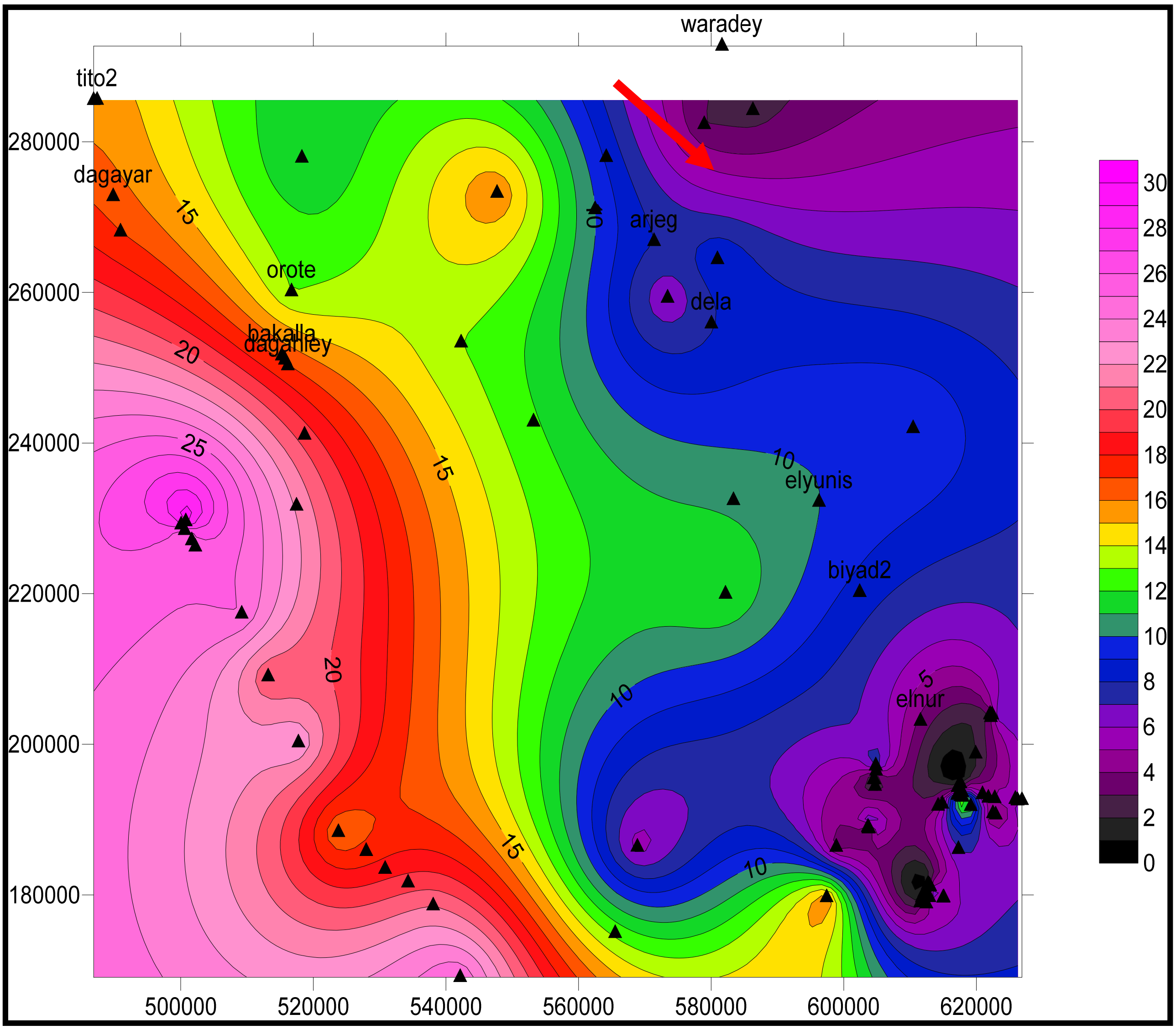
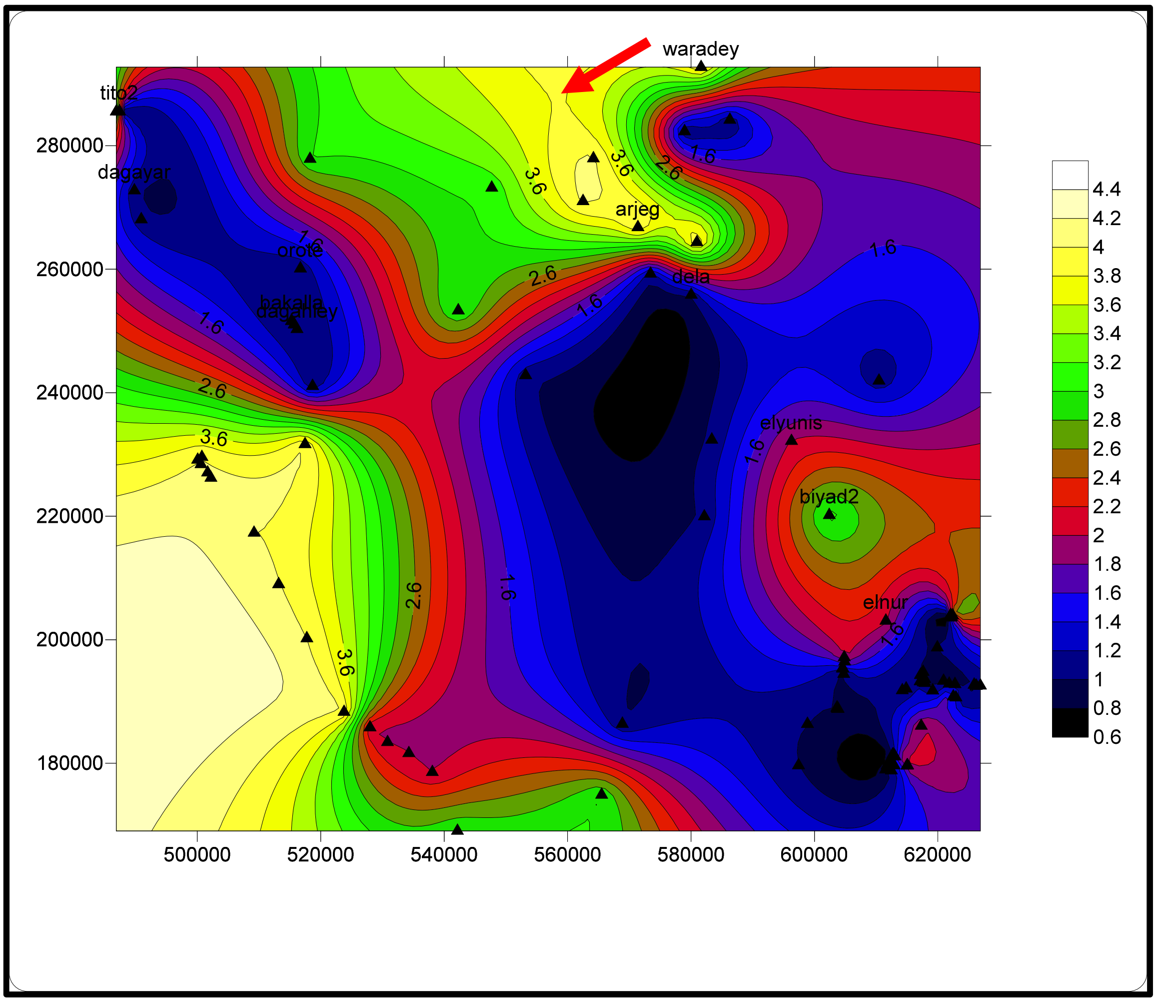


*Plate 5: W*e now highlight water quality from the hydrogeological simulation models and it goes thus: The Waradey water quality expected plots at 3.8, almost 4.0. The quality implies that the groundwater species thus encountered is fresh to taste and at worst; the water should be hard, **and n**ot saline, from this prediction model. The water is predicted to be hard-water and this is acceptable as it represents the general picture of water quality in the whole project area.



NOTE

Here the coding is as thus:

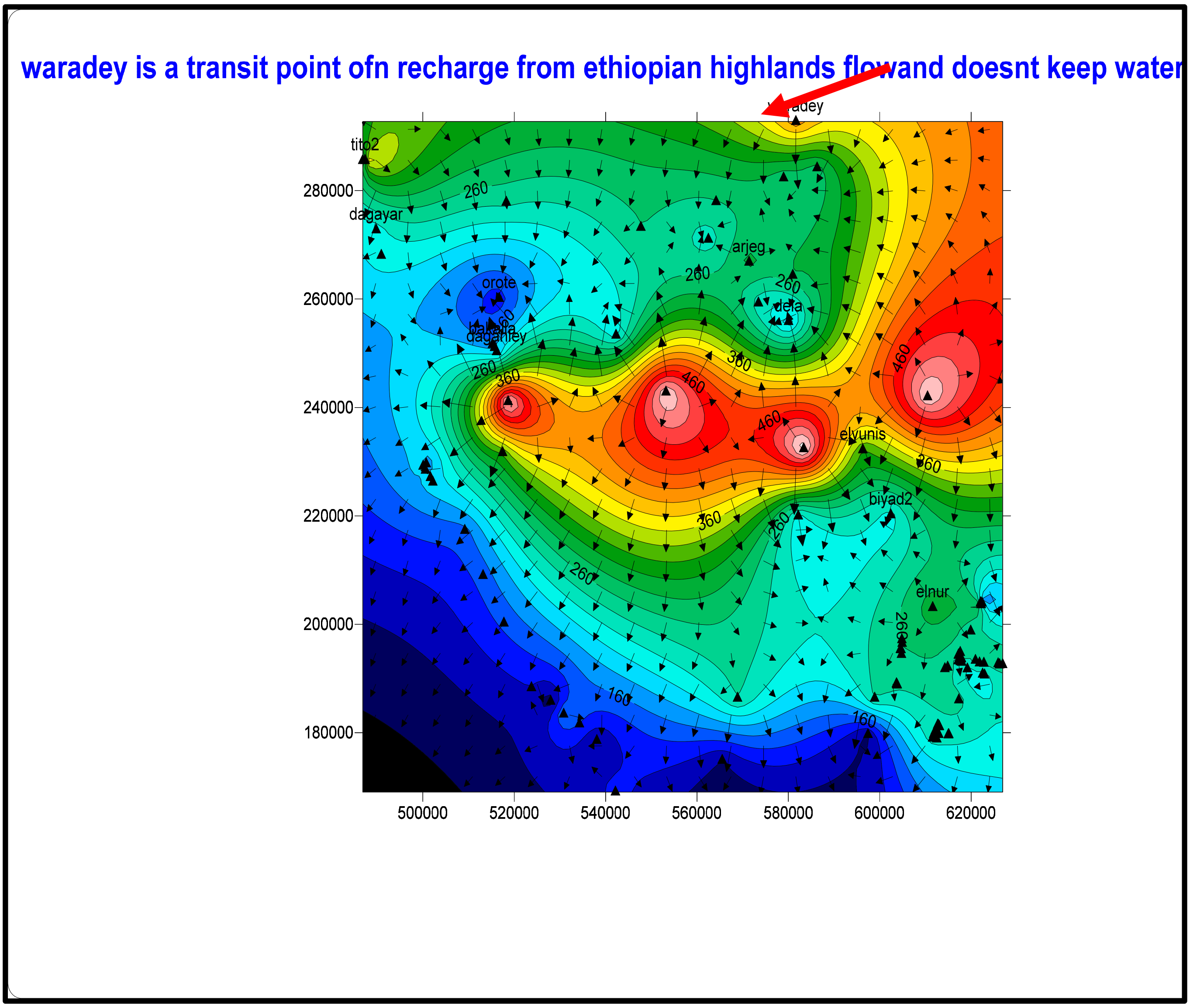
1-hard water

2-hard or fresh

3-saline

4-freshwater

Model 6: The Waradey center has all the arrows of flow vectors moving away from it. This explains the low yields in the area. Flow vectors ion the model indicate that much of the subsurface flow radiates from the north, flowing southwestwards towards Wajir township. Since the flow is overwhelming away from the project locality, the groundwater potential is moderate and is not quite high. This explains the ,limited number of wells sunk in the area and its surroundings so far. The central portion of the model showing places like Biyaad are most endowed with recharge on the account of the heavy concentration of the vectors displayed.



Comments

From the foregoing hydrological models, the Waradey centre possesses a well recharged aquifer – the detailed analysis of field geophysics results confirm the area is endowed with a reliable aquifer. Drilling is thus recommended here. The drilling should be undertaken by a hybrid of the drilling methods, since the upper sediments are primarily sedimentary materials and best suited to mud rotary methods. The point at which harder material will be encountered is the contact zone between metamorphic(bottom underlying sediments) and the younger sedimentary beds –which forms the main aquifer units for the project area.

VII. Recommendations And Conclusions

From the foregoing synthesis of the Project Areas hydrology, geophysics, hydrogeology and stratigraphy, the Waradey sites investigated bear moderate groundwater potential. Other deductions from the study are as thus:

(i) Resistivity Mapping has proved to be a useful tool in mapping the aquifer in the Waradey Area and the aquifer should generate better aquifer than the one drilled in 2009-2010 period.

(ii) The surfer mapping GIS software has helped predict aquifer hydraulics and expected water quality in the locality way before actual drilling was undertaken.

(iii) The water may be struck earlier than this depth of 160m as the first aquifers are visible from 63 m to 80m bgl.

(iv) Water quality will oscillate between hard and fresh, but mostly be leaning on the side of hard/bicarbonate water quality on the carbonate and limestone geology of the locality, which are mainly sedimentary beds.

(v) A borehole may be drilled upto a depth of 160m bgl and be used for watering sanitation , livestock and domestic purposes, apart from cooking and drinking.

(vi) The aquifer will lay between sedimentary and basement material, at the contact point.

VIII. Acknowledgements

The area MP (Eldas) facilitated this Study of groundwater exploration for his people who really struggle to make ends meet in terms of water acquisition efforts. He financed the surveys and the detailed data modeling and analysis of the field info, to ensure his people get water.

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