ROLE OF VERTICAL ELECTRICAL SOUNDING (VES) FOR GEOLOGICAL, HYDRO-GEOPHYSICAL INVESTIGATION FOR SITTING WATER WELL: A CASE STUDY OF UKE, EAST WOLLEGA ZONE, WESTERN PART OF ETHIOPIA

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ABSTRACT

Groundwater is precious resource for life growth and development of country. Hence, reliance on the groundwater has increased greatly. This research was conducted in the Uke town, East Wollega zone, western part of Ethiopia. The study catchment is a watershed area drained by a small stream that joins Anger river from southern direction. The topographic variation in the study catchment ranges from 1287 to about 1337m. The occurrence of Paleozoic sedimentary rocks in the study area and this includes fine grained sandstone which is variably exposed in stream cut and at the bank of Anger river. Bedding structures that reaches as thick as 25cm are observed on the sandstone, however, thinly bedded with evident lamellae are abundantly exposed at the bank of Anger river. The regional stratigraphic sequence suggests that the Paleozoic sandstone overlays the eroded surface of Precambrian basement rocks. The major hydro geologic unit in the study area is the sandstone rock which covers the major portion of the study area. The sandstone is subjected to fracturing, jointing and local faulting processes.

This paper presents the results of geological, hydro-geophysical investigation carried out over the study area and the objective of this study for sitting water well in water bearing horizon, correct location, depth of aquifer well, and good discharge rate. This is possible by a systematic exploration of groundwater using by different scientific tools and also using geological, hydro geological and geophysical methods provides valuable information with respect to distribution, thickness, and depth of groundwater bearing formation zones. In this research, using in geophysical methods, only Vertical Electrical sounding (VES), because it is low cost and relatively high reliable accuracy in results. Vertical Electrical Soundings (VES) survey was carried out by using the symmetrical Schlumberger expanding spread. In this method, the resistivity measurements were taken by progressively increasing the Potential Electrode (MN) along with a relatively large increment of the Current Electrode (AB/2). The Potential Electrode (MN) separation ranges from 1m to 90m whereas; the Current Electrode Separation (AB/2) of 500m was stretched to achieve maximum depth of penetration. Signal Average System Terra meter300C was used for the resistivity measurement of resistivity survey. Like the model for VES1 the model for VES2 also represented 5 geo electric layers. The first layer has resistivity value of about 27Ωm. and this represents dry silty alluvial soil with thickness nearly 2meter. The second layer with significantly reduced resistivity value of about 16Ωm can possibly be interpreted to be sandy to silty soil of thickness nearly 10m. This succession gradually grades to fractured sandstone bedrock as it is manifested by relative increment of resistivity value to about 640Ωm. The study area, the major identified potential aquifers are the fractured bedrock, it comprises fractured, jointed and bedded sandstone. Groundwater Potential sites (proposed well sites) are selected based on converging evidences of litho logy and structures.

Keywords : Aquifer, Groundwater exploration, Paleozoic sandstone, Resistivity, Vertical electrical sounding

I. INTRODUCTION

Location of the study area

The Uke town is situated in the western part of Ethiopia, East Wollega zone (fig.1). The study area for water source investigation is a catchment that stretches northward and drained by a small stream that is tributary of Anger River. This paper presents the results of geological, hydro-geophysical investigation carried out over the study area. Groundwater is precious resource for life and growth and development of country. Hence, reliance on the groundwater has increased greatly. Accordingly, substantial increments in the groundwater withdrawals have occurred in almost every part of the country. One of most fundamental condition for the growth and development of nation is certainly to fulfill its urgent water needs hence; along with this are demanded good scientific and technical capabilities for the assessment and substantial development of the country for water resource potential particularly the groundwater. To develop the existing groundwater potential in the country, the first attempt is to identify the main difference of surface and subsurface by geological and hydro-geological and geophysical investigation of the study area and to characterize the aquifer systems of different geological formations.

This is possible by a systematic exploration of groundwater using by different scientific tools and also using geological, hydro geological and geophysical methods provides valuable information with respect to distribution, thickness, and depth of groundwater bearing formation zones. In this research using geophysical methods only Vertical Electrical sounding (VES), because it is low cost and relatively high reliable results generate. The weathering and fractured degree of the geology, geomorphology, tectonics and climate of the regional setup have a great role on the groundwater occurrence. The variability of these factors in the area strongly influences the quantity and quality of the groundwater in different parts. The geology of the area and the surrounding provides usable groundwater and provides good transmission of rainfall to recharge aquifers, which produce springs and Anger river. The total study area is highly vegetated and the type and amount of vegetation cover depends on the physiographic and climatic condition. It is mainly covered by grass, bushes, and large trees.

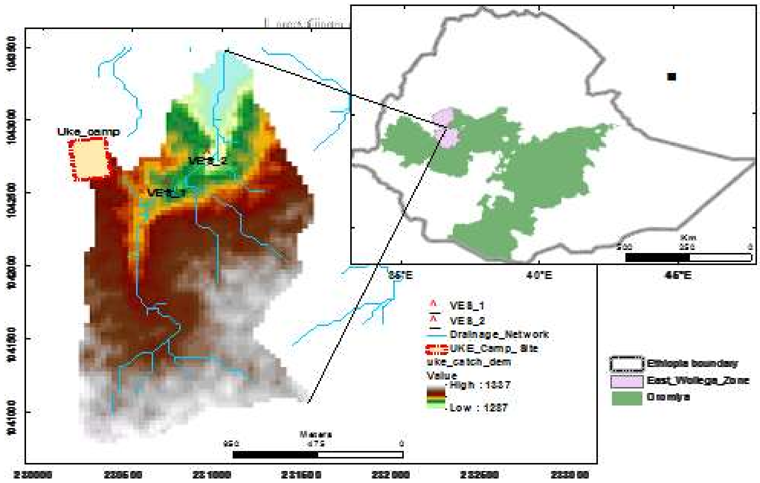


Figure-1: Location of study area

Topography and drainage Pattern

The project area is situated in the low land known as Anger depression also called Anger graben. The Anger graben is a distinct low land physiographic feature bounded from north, south and east by highlands (Gera, S. and Hailemariam, M.2000) The elevation is generally well below 1500m a.s.l. with generally low relief and is drained by Anger River. The study catchment is a watershed area drained by a small stream that joins Anger River from southern direction. The topographic variation in the study catchment ranges from 1287 to about 1337m a.s.l (Solomon and Mulugeta, 2000). Topographic highs are in the southern direction forming surface water divide (fig.2). Consequently, this has resulted in undulating topography that gradually slopes down in northern direction establishing base level in the northern periphery particularly at Anger River (fig.2). Because of the establishment of base level in the northern periphery, all the drainage networks emanate from the southern periphery of the catchment area and flow northward to join the Anger River. In the study catchment, relief is generally lower to instigate deep incision. Consequently, stream channels are generally shallower and meander in plain (fig.2). However, the linear reach of the stream segments can manifest the structural control over the drainage system (fig.2).

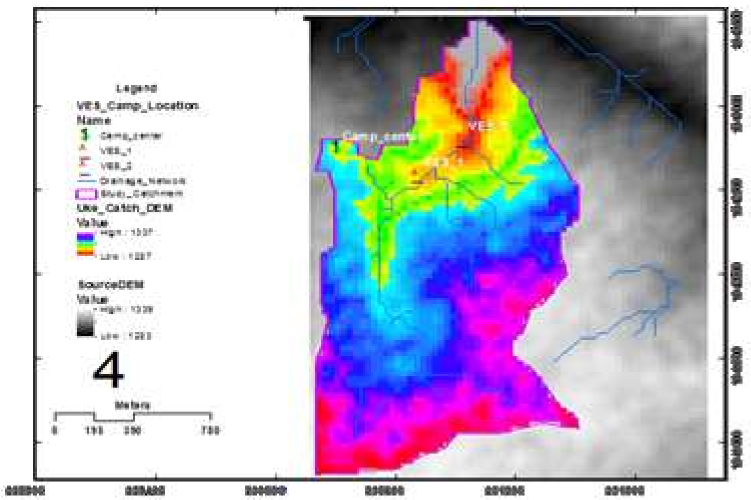


Figure-2: Topography and drainage network of the study catchment

II. METHODOLOGY

In the study area data have been collected from different source, which includes primary and secondary data to present the research. The method of data collection includes discussion with expert, beneficiary and field observation. To interpret the field data, analytical method is used. With the proliferation of fast and cheap personal computers, now day's analytical methods have largely replaced curve-matching procedures. Typically, this is inversion approach requiring an initial guess for a starting model and then refines that model by iteratively reducing the error between forward calculations from the current state of the model and the field data.

The iterative process is stopped when the error meets a specified criterion. This fast, effective approach produces a solution in a short time. However, as with any inversion process, the resulting final model is one of many possible models. The result must be compared to existing geologic information to determine its feasibility. The software used for the inversion process is a package called IPi2 WIN. Plot of resistivity value versus current electrode separation for all soundings (fig.6) are made to get a preliminary overview of vertical heterogeneity of the resistivity of the underlying geo-media. Resistivity values in both soundings are less than 250Ωm (fig.6).

The shapes of both curves are nearly similar manifesting the similarity of underlying geo-media (fig.6). For electrode spacing (AB/2) less than 100 the resistivity values are less than 125 Ωm(fig.9) manifesting dry top soil and weathered overburden. The values significantly increase for AB/2 greater than 100m (fig.6). This segment manifests ascending pattern indicating the presence of resistive geo-media which is interpreted to be variably fractured sandstone bedrock. This is also likely as it is observed in outcrops of Anger River and a stream along which soundings have been taken.

Location of the Vertical Electrical Soundings (VES) with respect to geology, topography and drainage system The soundings are taken on sandstone bedrock which is covered by variably thick soil overburden. Specifically they are taken at geographic locations: UTM zone 37P 230714mE, 1042560mN (VES_1) and 230935mE and 1042776mN (VES_2). Topographically the soundings are taken at elevation of 1309 and 1299m a.s.l respectively along a straight reach of stream; that is interpreted to be fractures (joints) manifesting weak zone. The significance of weak zone is that brittle deformation that had resulted in fracturing (jointing) significantly increases the secondary porosities of the sandstone which are commonly venues of groundwater storage and flow. It is with these premises that the sites for the Electrical Soundings are selected along this area.

GEOLOGY

Overview of regional geology

In Western Ethiopia, four main types of rocks are known to occur: the Precambrian basement rock, the Paleozoic sedimentary rocks, the Mesozoic sedimentary rocks and Cenozoic volcanic rocks. In the Anger graben, the Precambrian basement rocks are widely distributed. These rocks are commonly overlain by Phanerozoic cover of Paleozoic sandstone and Mesozoic sandstone (Kazmin, V.C. 1979) Elsewhere however, they are covered by volcanic rocks(mainly basalt) which was resulted from Miocene volcanic episodes. The top part of these terrains is covered by relatively thick residual and alluvial soils in interfluves and in topographic lows respectively. At stream cuts however, the superficial covers are eroded away and bedrocks are commonly exposed. The intrusive rocks dominantly granite (locally termed *Gutin* granite) forms magnificent dismembered ridges that generally extend in N-S direction (Kazmin, V.C. 1979, 1973).

Geology of the study catchment

Field survey revealed the occurrence of Paleozoic sedimentary rock (Ayalew et.al and Berhe, 1990) in the study area. This includes fine grained sandstone which is variably exposed in stream cut and at the bank of Anger River (fig.3). Bedding structures that reaches as thick as 25cm are observed on the sandstone; however, thinly bedded with evident lamellae are abundantly exposed at the bank of Anger River. Ripples which had preserved on the surface of a bed of sandstone, forming ripple marks, are magnificently crop out at the bank of Anger River. Variable sized solution holes are clearly observed on the surface of the bedding planes. The regional stratigraphic sequence suggests that the Paleozoic sandstone overlays the eroded surface of Precambrian basement rocks.

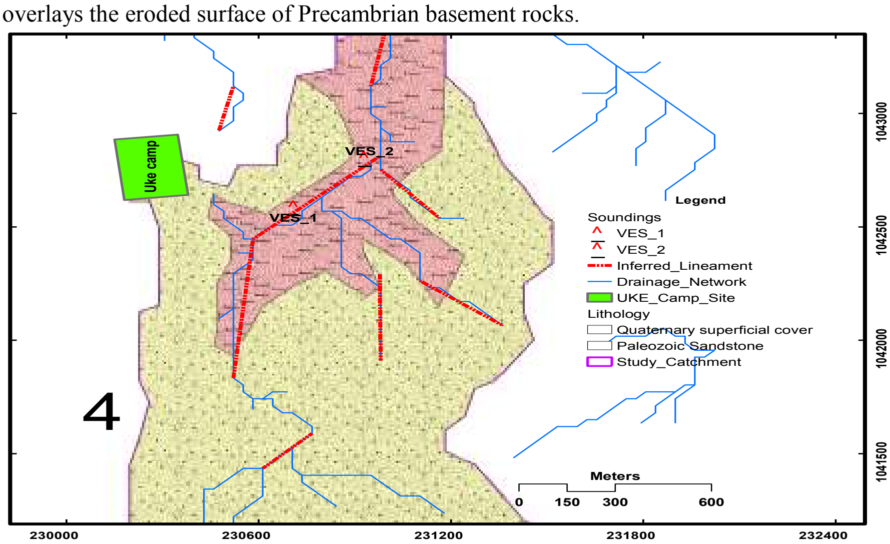


Figure-3: Geologic map of the study catchment

This is termed as lower sandstone as they stratigraphically positioned at the base of other volcanic rocks unconformable overlaying Precambrian basement rocks. The exposures of this unit are ubiquitously found in stream cuts and rarely on slope sides (fig.3). On interfluves, bedrocks are frequently covered by variably thick lateritic soil developed by intensive weathering (fig.3). In water logged areas thick black stiff clay is observed (e.g. around the camp site). Elsewhere, reddish to brownish silty-clay soil and sandy-soil are found ubiquitously distributed over the study area. On the other hand, stream banks and topographic low areas are covered by quaternary alluvial deposits that range from clay to boulders (Mengesha Tefera,et al, 1996). The size of the deposits is dominantly silt to clay size. Boulders and coarse gravels are also common along stream channels. The colour of soil is reddish except in few topographic lows where water accumulates where it gets darker (black).

Geologic structures: The most magnificent structures in the area are lineaments that are shown up as linear features on digital elevation models (fig.4).

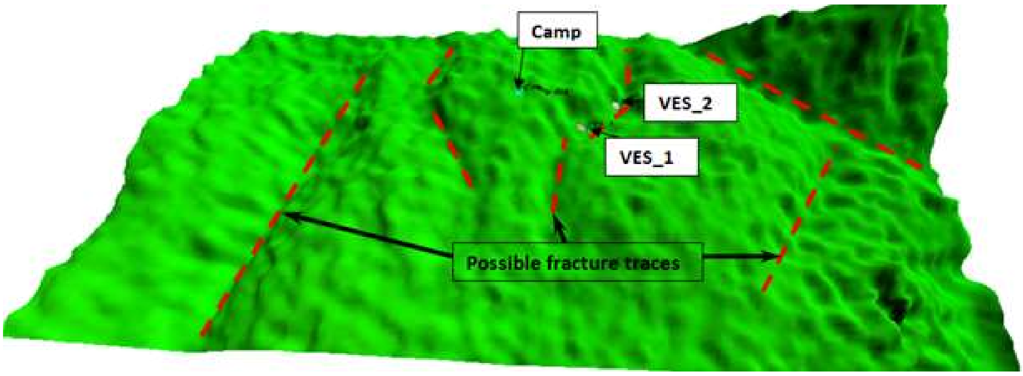


Figure- 4: Linear features as Digital Elevation Model of the area.

These are linear features that are manifested by linear arrangement of stream reach These are manifestations of fractures which possibly interpreted to be elongated fractures, creeks or sags which are manifestations of weak zones. These linear fractures are interpreted to be fractures (joints). Figure 4 Linear features as they inferred from topographic variation (from Digital Elevation Model) of the area and sharp turn of drainage network (fig.4). VES are taken along the fractures. The orientation of these lineaments is commonly in N-S direction with slight shift towards NNE-SSW while few are in NW_SE direction.

Hydrogeology Of The Study Catchment

The nature and distribution of aquifers and aquitard in geologic systems are controlled by the litho logy, structure and stratigraphic of the geologic formations. Litho logy is the physical make up of rocks, including the mineral composition, grain size, and grain packing of the sediments and rocks that make up the geologic systems. In hydro geologic view, litho logy controls the amount and distribution of primary porosity (Tamiru A 2006). The stratigraphic describes the geometrical and age relationship between the formations in geologic system of an area. Structural features such as fractures, folds, and faults are the geometrical properties of the geologic systems produced by deformation after deposition or crystallization. Structural activities are responsible for the formation and distribution of secondary porosities which are modified from primary porosities. In view of this, the sandstone rock, the porosity of which is highly enhanced by fractures and joints systems is water bearing geo-media.

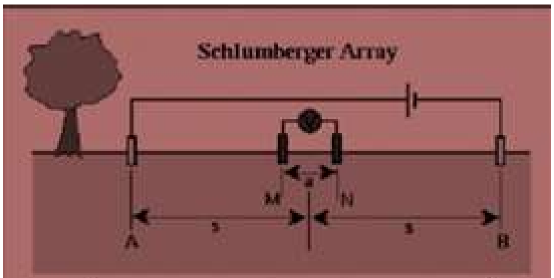
The Hydro geological Unit (The major Aquifer)

The major hydro geologic unit in the study area is the sandstone rock which covers the major portion of the study area. The sandstone is subjected to fracturing, jointing and local faulting processes (Singhal B.B.S Gupta, R.P, 1999). All the discontinuities significantly control groundwater flow system. Relatively thicker soil and weathered overburden receives the high volume of influx from rainfall; stores and release it slowly to the underlying fractured bedrock. The implication is that, vertical leakages from the weathered/soil overburden over wide area extent; can contribute considerable volume of groundwater recharge. Thus, groundwater occurrence exhibit greater variation in hard rock's because their water bearing properties are mostly modified by weathering and structural deformations. This indicates that hard rocks aquifers are highly heterogeneous and are an isotropic with significant spatial variation in groundwater occurrence. As an example, a well drilled about 2km NW of the study site found dry manifesting the spatial heterogeneity of this aquifer. The collective insinuation is that the fractured and jointed sandstone is interpreted to be potential aquifer in the area though it is localized and discontinuous.

III. GEOPHYSICAL INVESTIGATION

Data Acquisition: Electrode Configuration & Instrumentation

Vertical Electrical Soundings (VES) survey was carried out by using the symmetrical Schlumberger expanding spread (fig.5). In the method, the resistivity measurements were taken by progressively increasing the Potential Electrode (MN) along with a relatively large increment of the Current Electrode (AB/2). The Potential Electrode (MN) separation ranges from 1m to 90m whereas; the Current Electrode Separation (AB/2) of 500m was stretched to achieve maximum depth of penetration. Signal Average System Terra meter300C was used for the Resistivity measurement of Resistivity survey.



$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a}\frac{\Delta V}{i}$$

Figure-5: Schlumberger array configuration

Two soundings are taken and the raw data show in the table:

Table-1: Raw data of VES surveyed in study area

No.	Electro de array		Resistance(Ω)		K(m)	Resistivity(Ω-m)	
	AB/2	MN	R1(Ω)	R2(Ω)		P1 (Ω-m)	P2 (Ω-m)
1	1.5	1	2.61	4.03	6.28	16.4	25.3
2	2.1	1	0.973	1.93	13.1	12.7	25.3
3	3	1	0.428	0.847	27.5	11.8	23.3
4	4.2	1	0.273	0.386	54.6	14.9	21.1
5	6	1	0.174	0.174	112.3	19.5	19.5
6	9	1	0.119	0.076	254	30.2	19.3
7	13.5	1	0.0738	0.0376	572	42.2	21.5
8	20	1	0.0452	0.0223	1256	56.8	28
10	30	1	0.833	0.408	95.3	79.4	38.9
11	45	12	0.184	0.102	521	95.9	52.9
12	66	12	0.102	0.0575	1131	115.4	65
13	100	12	0.0494	0.035	2600	128.4	91.1
14	150	12	0.0213	0.0177	5880	125.2	104
15	220	12	0.00952	0.0103	12600	120.0	130
16	330	90	0.0342	0.0469	3730	127.6	175
17	500	90	0.0171	0.0274	8650	147.9	237

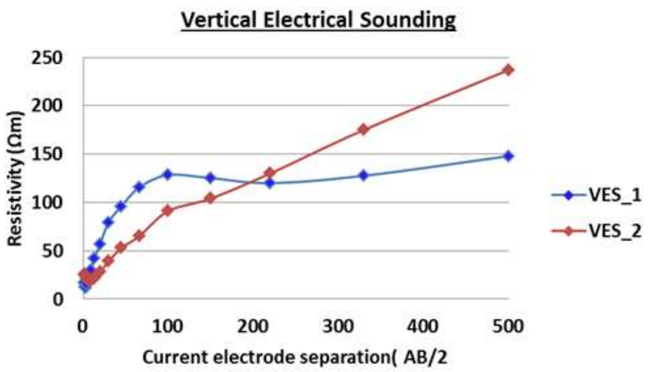


Figure-6: Relation between resistivity data and current electrode separation (AB/2)

Model for Vertical Electrode Sounding (VES1)

The model for VES1 represented 5 geo electric layers (fig.7). The first layer has resistivity value of about 30Ωm. This represents dry soil overburden with thickness of less than a meter. The second layer with significantly reduced resistivity value to about 6Ωm can possibly be interpreted to be a succession of moist clayey soil underlain by weathered mantle. The thickness of this succession reaches up to 2m.This succession gradually grades to

Figure- 7: Model layer and interpreted result for VES1

Fractured sandstone bedrock as it is manifested by relative increment of resistivity value to about 255Ωm of thickness nearly 37m. The 4th layer with significantly reduced resistivity value of 48 Ωm, is interpreted to be variably fractured and loosely bedded sandstone saturated with water. The last layer with resistivity value of ρ=221Ωm (fig.7) can possibly interpreted to be relatively fresh sandstone bedrock. Thickness of this layer is not mapped by this sounding. The sounding has mapped to a depth of bout 97m. The decrement of resistivity value generally indicates the existence of low resistive geo-media which is interpreted to be potential aquifer in the area. This is variably fractured and saturated sandstone.

Model for Vertical Electrode Sounding (VES2)

Like the model for VES1 the model for VES2 also represented 5 geo electric layers (fig.8). The first layer has resistivity value of about 27Ωm. This represents dry silty alluvial soil with thickness nearly 2meter. The second layer with significantly reduced resistivity value of about 16Ωm can possibly be interpreted to be sandy to silty soil of thickness nearly 10m. This succession gradually grades to fractured sandstone bedrock as it is manifested by relative increment of resistivity value to about 640Ωm.

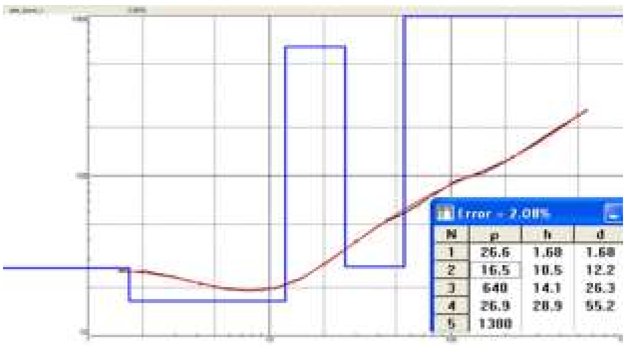


Figure- 8: Model layer and interpreted result for VES2

The thickness this geo-media is as high as 14m. The 4th layer with significantly reduced resistivity value of about 27Ωm is interpreted to be variably fractured and loosely bedded sandstone saturated with water. The last geo-media, with resistivity value as high as 1380Ωm (fig.8) manifests relatively fresh sandstone bedrock with reduced frequency of fractures and tightly bedded. The thickness of this layer is not mapped by this sounding as it is considered to be infinity. The sounding has mapped to a depth of bout 55m. The decrement of resistivity value of the 4th layer indicates the existence of low resistive geo-media from a depth of 30m to about 55m. This is interpreted to be potential aquifer in the area which is variably fractured and saturated sandstone.

IV. DISCUSSION

Converging geomorphological, geological and geophysical evidences imply that fractures and bedding planes are venues for groundwater localization and movement. The zone of concentrated fractures is inferred from the straight reach of the stream; and is interpreted to be local fracture system where groundwater storage and movement is facilitated (fig.4). From hydro geological point of view, the Anger graben can be considered to be groundwater discharge region. Topographic highs surrounding the Southern, Eastern and Northern peripheries of the Anger depression are regions of recharge zones. These areas are covered dominantly by basalt and trachyte. Well-developed columnar joints and fractures on exposed volcanic rocks mainly (basalt and trachyte) facilitate vertical flow to recharge groundwater. Horizontal sets of joints affecting columnar joints enhance horizontal flow of groundwater.

Thus, these discontinuities (sets of fractures and joints) play important role in controlling the groundwater storage and movement in the study area. This signifies that permeability increases where fractures are concentrated. This causes the variation of hydraulic parameters (especially permeability) in space and introduced heterogeneity and anisotropy to these aquifers. Secondary porosities and permeability are expected to increase in the proximities of these fractures and they are the localized venues of groundwater storage and movement. In line of this, the proposed wells are positioned on fracture terraces outlined as stream course (fig.4). Wells are also sited along the sags topographically manifested as elongated depression Therefore, the composite sequence of fractured sandstone bedrock constitutes potential aquifer of the area.

V. CONCLUSION

The following valuable conclusions can be made from the integrated geological, hydro geological, topographical and geophysical (VES) evidences:

The major identified potential aquifers are the fractured bedrock; it comprises fractured, jointed and bedded sandstone. Groundwater Potential sites (proposed well sites) are selected based on converging evidences of litho logy and structures (fig.4).

Well sitting and target depth

The potential well sites are in the proximities of fracture trace (joint) which are outlined by elongated depressions or stream (fig.4).These are venues where discontinuities concentrate, and secondary porosities and permeability of the sandstone bedrock significantly increases. Therefore, two wells are proposed based on the investigation. Table 2 gives the summary of potential proposed well sites and the corresponding target depth and anticipated position of pumps.
*Coordinate system= UTM-Adindan-zone 37P

Table- 2: Locations of proposed well sites and their corresponding target

No.	Proposed well	*Easting (m)	Northing (m)	Elevation (m) a.s.l	Target depth(m)
1	PW1	230714	1042560	1309	150
2	PW2	230935	1042776	1299	150

Therefore, it is advisable to site the wells at a feasible radius centre on the indicated sites. Though the actual depth of a well is determined based on the actual situation during the commencement of the drilling, the target depth for the proposed wells are indicated in table 2.This is actually subjected to the actual field condition that will be encountered during commencement of drilling.

Estimated yields

From the converging evidences obtained from geological, topograhical, geophysiccal and hydrogeological investigation, it can be concluded that the ground water is the only feasible source that can be developed for water supply source for the camp. Data indicate that the yield from the aquifers in the area is well less than2l/sec. Therefore, the average yield expected from one well may be about 1-2l/sec. It is therefore, suggested that the discharge from two wells is expected to be about 2-4l/sec.

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