Arab Remote Sensing and Geographic Information System Organisation

The use of Remote Sensing and GIS Techniques as a Guide to Other Geological Methods for Groundwater Investigations in Hamisana Basement Terrains, Red Sea Hills, NE Sudan

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ABSTRACT

The study area lies in in the Hamisana area at the - western flank of the Red Sea Hills in northeastern Sudan, where acute water shortage is experienced. This area is characterized by a desert climate, in which the annual average rainfall is less than 50 mm. The objective of the present study is to investigate the groundwater potentiality via the search of water occurrence indicators through remote sensing and GIS techniques integrated with other geological and structural methods in addition to ground geophysical survey. The investigated area is located within the basement terrain of the Nubian Arabian shield that involves ophiolitic decorated - arc assemblages of the Pan-African Era (950 - 550 MY). The Alluvial sediments in addition to the weathered and fractured basement rocks represent the only water bearing units in the area. Remote sensing investigations aim to reveal the geological, topographical - structural aspects of the area, as well as to delineate and decode the main lineaments (features) and paleo-drainage pattern as important guides for groundwater occurrence. According to the structural analysis, the potential fractures in the study area are the extensional fractures trending NW-SE, and the release fractures in NE-SW direction. The Geo-electrical profiling and Vertical Electrical Sounding techniques provide more reliable results when combined together and integrated with geo-information technologies. These techniques gave comprehensive information on the vertical and lateral lithological variations that govern the water saturated zones. The ultimate distribution of geophysical measurements can be achieved when based on satellite image interpretation and structural analysis disclosing the promising sites for groundwater occurrence. The outcome of the present investigations revealed that the area consists of two types of aquifers: the alluvial aquifers at depths range from 10 to 15 meters below the ground surface; and the weathered/fractured basement rocks aquifers that range in depth between 25-60 meters below the ground surface.

1. INTRODUCTION

Water in the study area is scarce resource, since the area is a part of the Red Sea Hills Region which is suffering from acute water shortage due to geologic as well as climatic factors. The Hamisana area is mostly covered by Precambrian basement rocks, where water supply is very limited and affected by the climatic degradation. As a result, the area is sparsely populated by the Beja nomadic tribes. However, the currently working mining companies are strongly affected by shortages in water supply.

The study area lies in the Red Sea Hills Region of northeast Sudan. It is bounded by latitudes 20° 00′00′′ – 21°00′00′′ N and longitudes 34°30′00′′ – 35°30′00′′ E, within Gebeit El Maadin Locality of the Red Sea State (Fig. 1).



FIGURE (1). Location map of the study area.

Topographically, the study area represents part of the high rugged Red Sea Hills terrain (Fig. 2), which is sloping

rapidly to the east towards the Red Sea and gently to the west towards the River Nile. Generally, the drainage pattern of the Red Sea Hills is structurally controlled by faults and folds that produce rectangular drainage patterns, however, local radial patterns are found around large batholiths. An intricate system of drainage displayed by the numerous intermittent seasonal streams (Wades) dissects the Red Sea Hills (Fig. 2).

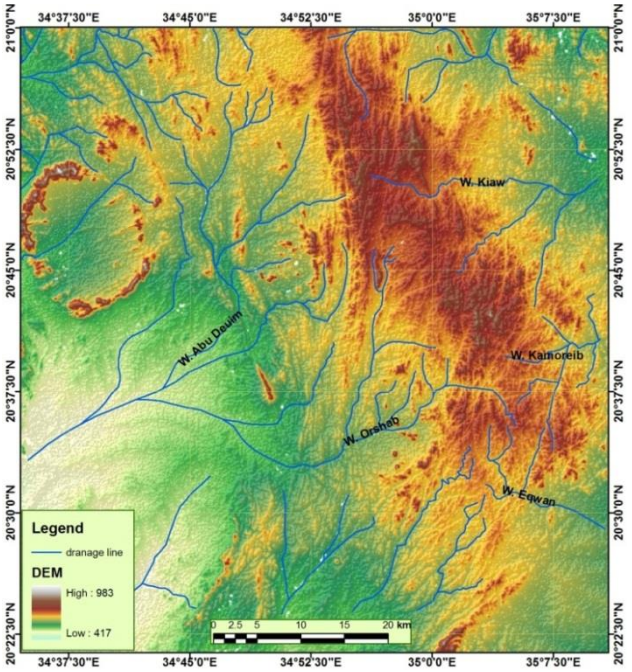


FIGURE (2). Drainage system of the investigated area based on the Digital Elevation Model (DEM).

The study area is located within arid zone that is characterized by desert climate with little annual rainfalls that reach about 25 mm in average. It is characterized by very hot summer, in which the temperature during the day is more than 40°C and a dry cold winter with temperature reaches less than 20°C. Vegetation cover is poor and sparse, where bushes and small trees are confined mainly to the seasonal water courses and some of the sandy plains.

The basement rocks in northeast Africa and western Arabia is referred to as the Arabian Nubian Shield (ANS; 950-550 Ma). It represents, predominantly, juvenile continental crust that was formed by differentiation of mantle melt largely without reworking of pre-existing continental crust (Stern, 1994). The Hamisana Shear Zone (HSZ) is a broad N – S deformational zone, making it one of the largest basement structures in NE Africa (Stern et al., 1989). The study area is dominated by meta-sedimentary, meta-volcanic and ophiolitic rocks marking an old suture between Gabeit and Gabgaba terrains (Almond et al., 1984; Abdel Rahman, 1993). These sequences are intruded by the syn to late- orogenic and post- organic igneous intrusions.

The main objective of the study is to investigate the surface and subsurface geology and related structures that govern the groundwater occurrences within the basement terrains of the southern Hamisana area using combined methods including remote sensing, structural analysis and field geophysical survey.

2. DATA TYPES

The following materials have been utilized during the course of the present study:

- Satellite imageries including four Landsat 7 ETM+ scenes, which were mosaicked and subset to obtain full image coverage of the study area.
- Field survey and measurements for the geological and structural elements.
- Geophysical resistivity geo-electrical profiles and Vertical Electrical Sounding measurements.

3. METHODOLOGY

The methodology employed in the present study was planned in a way to achievement the above-mentioned objectives. It integrates the geological data, and geophysical data guided by the interpretation of the remotely sensed data to assess the groundwater occurrences in the study area. This includes office work, field work and data analysis. Office work was conducted in two stages, pre-field and post-field.

In the pre-field stage, Landsat 7 ETM+ images were digitally processed in order to obtain a full coverage of the area and produce more appealing images suitable for geological interpretation. This was conducted utilizing image mosaicking, sub-setting, false color compositing, spatial filtering, image transformations and fusion. The post- field stage includes the different types of analyses and interpretations of data measured during the field in connection with the interpreted satellite images.

The field work was designed to cover the major aspects of geological, hydrogeological and geophysical investigations. This entailed the collection of field observations and measurements of the geological and structural elements, guided by the remotely sensed data and confirmed by geo-electrical geophysical survey.

Resistivity methods are considered to be one of the most powerful geo-electrical techniques used in groundwater exploration. In this method, an electric current is introduced into the ground by means of the current electrodes referred to by the latters (A) and (B); and the potential difference between two potential electrodes (M) and (N) is measured. This technique was applied adopting Winner arrangement for profiling techniques and Schlumbergeir configuration in the vertical electrical sounding (VES). Both arrangements use four electrodes arranged in one straight line (AB) and (MN).

Measurements were taken using SAS 1000 Terrameter of the ABEM, Sweden. The data analysis phase involves the analyses and interpretations of data of different types and sources, applying many analytical and interpretation procedures.

4. RESULTS AND DISCUSSIONS

In this study, remote sensing techniques were used to guide the field geological and geophysical survey for groundwater exploration in the basement terrain of the southern Hamisana area, Red Sea region. Detailed accounts on the obtained results are provided in the following sections:

4.1 Remote sensing investigations

The occurrence of groundwater is controlled by the surface features (indicators) which are grouped in two categories, direct indicators and indirect indicators (Singhal and Gupta, 1999). The first indicators are directly related to the groundwater regime such as recharge and discharge zones, soil moisture and vegetation. The second indicators are this geological and morphological feature that controls the occurrence and distribution of groundwater, such as the rock types, geological structures and landforms. The structures include rock fractures, lineaments, faults, shear zones and drainage characteristics. Therefore, some of the remote sensing techniques represent the best tool for water exploration that include color composite images, contrast enhancement, band ratio and image filtering (Singhal and Gupta, 1999).

Different lithological units and rock types can be inferred indirectly based on the rock structures and landforms. On photographs and images, the hard rock areas are characterized by the presence of a number of features such as compositional bandings, bedding, foliation, fractures, folds etc. Further, they have characteristic erosional landforms. Accordingly, remote sensing images have found extensive applications for structural studies to decipher planar discontinuities in the terrain and understand their disposition and mutual-relations (Singhal and Gupta, 1999).

For hydrogeological investigations, drainage is a vital parameter for the study. Drainage channels may appear differently on different spectral bands depending upon depth of water, turbidity, vegetation cover …etc. Moreover, drainage pattern and density may give a good idea of the hydrogeological characteristics of the terrain (Singhal and Gupta, 1999).

The study area is covered by parts of the Landsat 7 ETM p172-r45, p172-r46, p173-r45 and p173-r46 scenes. Therefore, these scenes have been mosaicked to produce an image covering the whole area. This large image was then cropped to the coordinates bounding the study area, described above.

For the purpose of lithological discrimination, two different colour composites were prepared: decorrelation stretched bands 7, 4 and 2 and 7, 5 and 4 in RGB, respectively (Fig. 3 and Fig. 4). It is clear that the different rock groups can be distinguished on these images. For instance, the metasediments appear in brown colour, the metavolcanics in light brown to pale olive green and ophiolitic rock are displayed in turquoise in the 7,4,2 in RGB colour composite. On the other image, these rocks appear totally in different colours, the meta-sediments are displayed in dark brown, the metavolcanics in light olive green and ophiolitic rocks are portrayed in deep blue.



FIGURE (3). Colour composite of decorrelation-stretched bands 7,4,2 in RGB, respectively

Different spatial filtering techniques have been applied within the framework of the present study. Directional convolution filtering was utilized to enhance the lineament features in certain directions deduced from previous understanding of the tectonic history of the study area. The Landsat ETM+ band 7 was used for this purpose. The N-S, NE, NW and E-W directions were selected for the directional filtering processes. The result of this process is presented in Figure (5), which was used in the GIS environment for the delineation of lineaments and hence the productions of lineament map, which forms the base for the structural analysis.

Lineaments are defined as the linear alignments of features in satellite images, which could be a geological structure such as a shear zones/faults, joints and fracture traces, rift valleys, truncation of outcrops, alignment of

fissure, pipe and dykes alignment of streams and valleys. The manifestation of the lineaments is depending on the scale of the observation and dimensions involved (Gupta, 2003). Lineament studies are most important for groundwater investigation in hard rock terrains.

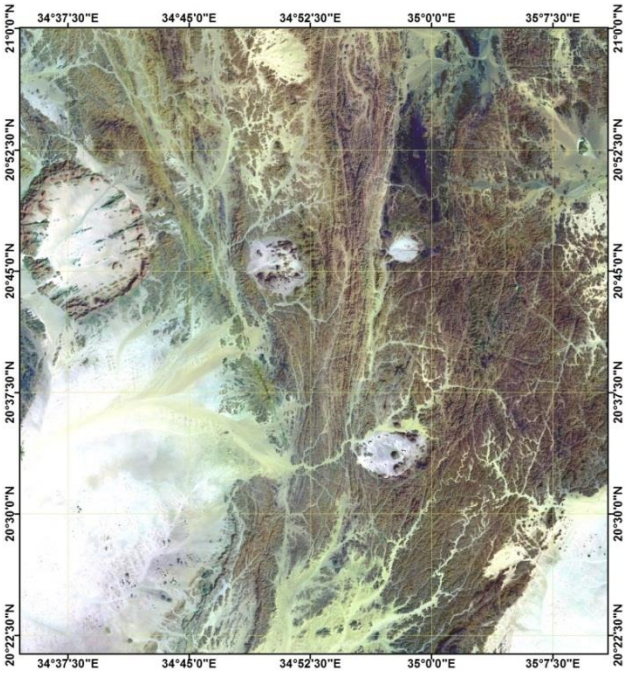


FIGURE (4). Colour composite of decorrelation-stretched bands 754 in RGB, respectively

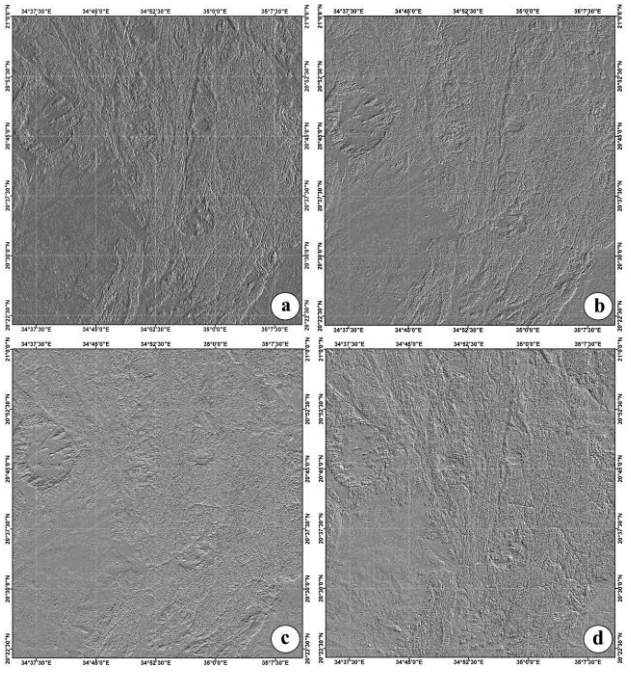


FIGURE (5). Directional filtering of band 7 in (a) 0°, (b) 45° (c) 90° and (d) 315° directions.

The technique of mapping fracture traces and local lineaments from aerial photographs for locating zones of higher permeability in hard rock terrain was developed by Parizek (1976), and the same has now been extended to satellite imagery. It has been shown that wells located on or close to fracture traces yield many times more water than the wells situated away from the fracture traces, and they are more consistent in their yield when located on lineaments than under other conditions. Lineament mapping in the present study was carried out to facilitated two different aspects of geological studies: hydrogeological investigations and structural mapping (Fig. 6).

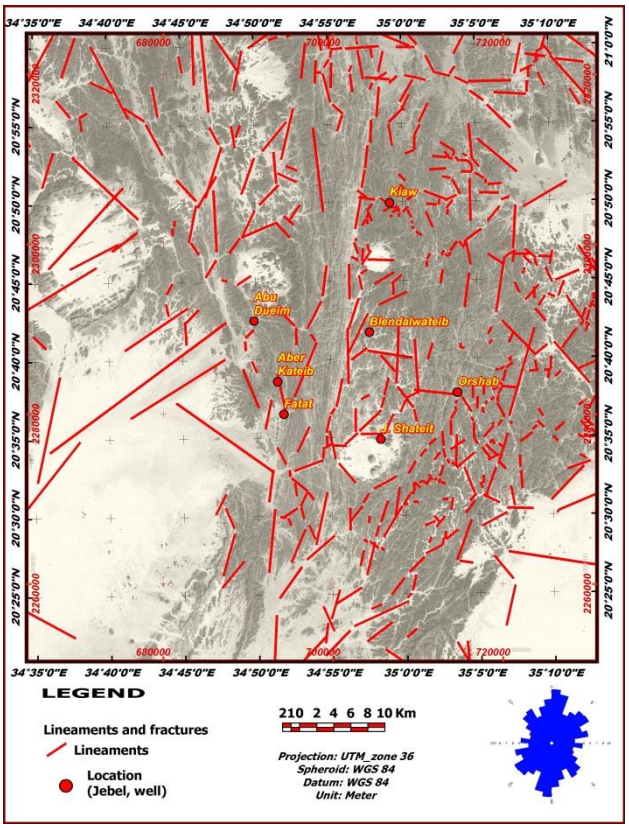


FIGURE (6). Lineament map of the study area obtained through the interpretation of the spatially enhanced satellite image and on-screen digitization in the GIS environment.

4.2 Structural analysis

Remote sensing techniques coupled with the structural analysis proved to be a powerful tool for groundwater exploration in basement terrains (Elsheikh et al., 2013). The structural analysis within the frame of the present study was based mainly on the produced lineament map. The structural analysis was carried out to facilitate the selection of the open fractures, which are favorable for groundwater accumulations. Most structural data describe the final product of some deformation history. The ductile deformation occurs when rocks flow under the influence of stress. The opposite, discontinuous deformation or brittle deformation, occurs when rocks break or fractured. Field observations of deformed rocks and their structures represent the most direct and important source to understand the natural deformation. Brittle deformation occurs under conditions where plastic

deformation mechanisms are negligible and the rupture strength of the rock is exceeded the plastic limit. Brittle structures dominate shallow crustal levels; it can also form in strong and dry zones in the lower crust and mantle, (Cruikshank et l., 1991). The general classification of the fractures is into: open fractures that involves extensional, tensional and release fractures; and closed fractures, which are represented mainly by the two shear fractures (positive and negative shearing).

The collision between Heya, Gebiet and Gabgaba terrains by SE-NW directional force is the common tectonic event in the Nubian Shield during the Pan African era (Abdelsalam and Stern, 1993), that produced the N-S shear zones and the manifestation of the NE sutures. Applying the stress/strain ellipsoids on the extracted lineaments (Park, 1997; Twiss and Mores, 1992), the fractures in the study area were classified into extensional, release and shear fractures (Fig. 7).

The structural analysis of the lineaments defined the trends of the shear and tensional fractures (Elsheikh et al, 2014). The favorable fractures for groundwater occurrences are the extensional and release fractures, while the shear fractures are closed and therefore are not of great importance to groundwater occurrences. The results obtained from the structural analysis were used as a major guide to the geophysical work, which was oriented to investigate the existence of groundwater in the open fracture.

4.3 Geophysical investigations

The resistivity method represents one of the most renowned geo-electrical techniques used in groundwater exploration. The electrical methods have a variety of techniques that employ both natural and artificial sources of energy; the latter has a wider application. The relationship between the apparent resistivity and the true resistivity is a complex relationship. Accordingly, an inversion of the measured apparent resistivity value must be carried out for the determination of true subsurface resistivity.

Geo-electrical survey was conducted in this study using profiling technique with Wenner array and Vertical Electrical Sounding (VES) with Schlumberger configuration. Profiling technique is used for delineating geological structures or reflects lateral changes in electrical resistivity corresponding to variations in lithology at a certain depth, while the vertical electrical sounding was used to determine the variations in electrical resistivity with depth.

8 profiles were conducted with electrodes separation distance (a) = 25m to measure the resistivity at this depth approximately. The open fractures detected as low resistivity values, while the hard basements are appear as relatively higher resistivity values (e.g. Figs. 8 and 9).

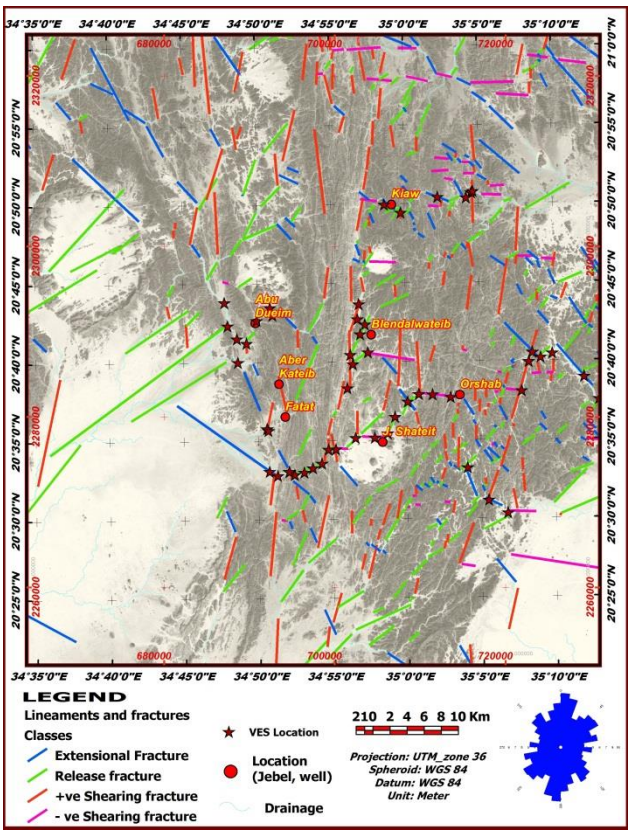


FIGURE (7). Classified lineament map of the study area, classified according to the structural analysis.

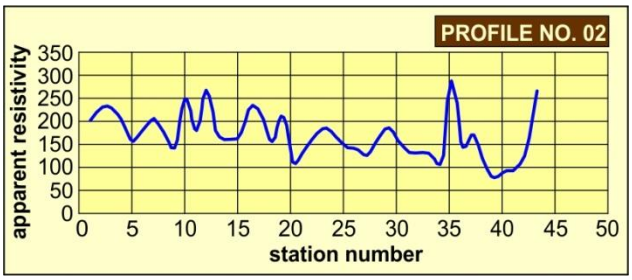


FIGURE (8). Geo-electrical profile No. 2, measured in the study area, guided by the interpretation of the satellite images and the structural analysis.

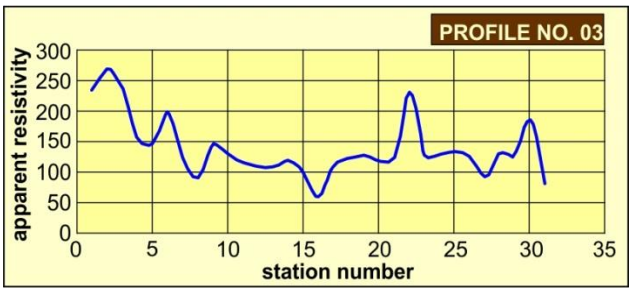


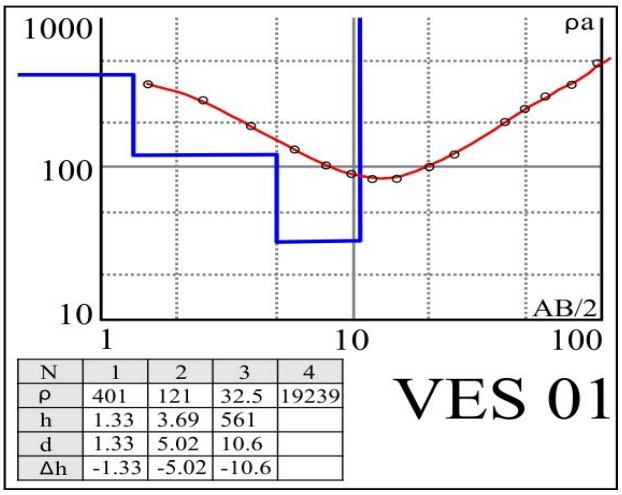
FIGURE (9). Geo-electrical profile No. 3, measured in the study area, guided by the interpretation of the satellite images and the structural analysis.

Measurements of 46 vertical electrical sounding points (VES) were carried out during this work using

Schlumberger configuration. The selection of the measurement points was based on Landsat image interpretation and the subsequent structural analysis.

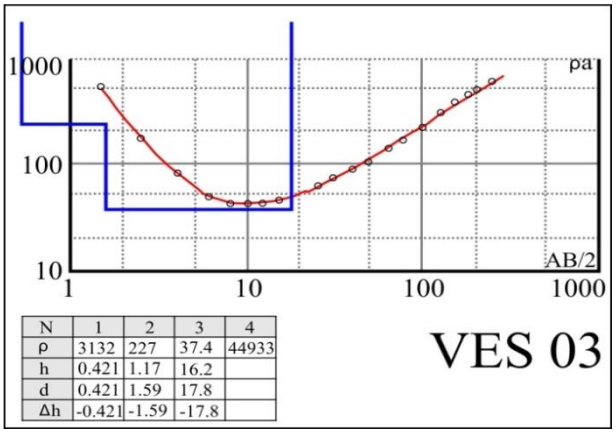
The VESs were carried out in the main micro-watersheds such as Wadi Orshab, wadi Komeraib, Wadi Eqwan and wadi Abu Deuim to recognize the vertical lithological variations. The locations of all the measured VES points are illustrated in Figure (7).

The obtained resistivity data, in the form of apparent resistivity, were analyzed using IPI2win computer software, to obtain the thickness, depth and resistivity of different lithological units. In the Basement Complex rocks, the resistivity change from high values (> 500 Ohm.m) to infinity characterizes the hard basement rock, while the lower values designate the weathered and fractured basement (e.g. Figs. 10 and 11). The lowest resistivity values are conditioned by high conductive zones, most probably influenced by high mineralized water in fractures.



N	1	2	3	4
ρ	401	121	32.5	19239
h	1.33	3.69	561	
d	1.33	5.02	10.6	
Δh	-1.33	-5.02	-10.6	

FIGURE (10). VES 1, measured for the recognition of the lithological variations with depth.



N	1	2	3	4
ρ	3132	227	37.4	44933
h	0.421	1.17	16.2	
d	0.421	1.59	17.8	
Δh	-0.421	-1.59	-17.8	

FIGURE (11). VES 3, measured for the recognition of the lithological variations with depth.

The outcome of the present investigations revealed that the area consists of two types of aquifers: the alluvial aquifers at depths range from 10 to 15 meters below the ground surface; and the weathered/fractured basement rocks aquifers that range in depth between 25-60 meters below the ground surface.

5. CONCLUSIONS

The study area is located in the Hamisana area in the northwestern part of the Red Sea Hills, which is characterized by arid climatic conditions. This study represents comprehensive investigations in different aspects of the application of geological methods in groundwater exploration guided by the remote sensing investigations.

The use of remote sensing and GIS techniques was found to be a powerful tool utilized in the geological investigations, structural elements delineation and groundwater prospecting in the basement terrains. Different geological and structural elements controlling the occurrences of groundwater were obtained through the application of different digital image processing techniques. The study revealed that the potential groundwater accumulation zones are controlled spatially by certain structures and the optimum rechargeable drainage zone in respect to appropriate lithologies. The favorable fractures for groundwater occurrences are the extensional and release fractures trending in NW-SE and NE-SW, respectively, while the closed shear fractures that are not of great importance to groundwater occurrences are trending in N-S.

The Geo-electrical profiling and Vertical Electrical Sounding techniques provide more reliable results when combined together and integrated with geo-information technologies. These techniques gave comprehensive information on the vertical and lateral lithological variations in addition to the water saturated zones. The ultimate distribution of geophysical measurements can be achieved when based on satellite image interpretation and structural analysis disclosing the selection of promising sites for groundwater occurrence.

The outcome of the present investigations revealed that the area consists of two types of aquifers: the alluvial aquifers at depths range from 10 to 15 meters below the ground surface; and the weathered/fractured basement rocks aquifers that range in depth between 25-60 meters below the ground surface.

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