



## ARTICLE

# Investigation of Geology and Hydro-geophysical Features Using Electromagnetic and Vertical Sounding Methods for Abu Zabad Area, Western Kordofan State, Sudan

Elhag A. B<sup>1</sup> Musa M. A.<sup>2\*</sup>

1. Department of Civil Engineering, College of Engineering, King Khalid University, Abha, Saudi Arabia, on leave from Kordofan University, Sudan

2. Department of Geology, College of Science and Information Technology, Nyala University, Nyala, Sudan

### ARTICLE INFO

#### Article history

Received: 8 October 2019

Accepted: 21 October 2019

Published Online: 31 March 2020

#### Keywords:

Electromagnetic and geoelectric survey

Aquifer units and groundwater potential

### ABSTRACT

The geology and hydro-geophysical features can aid in identifying borehole location. The study aims to investigate groundwater aquifers and best location of boreholes in the crystalline basement area of Abu Zabad near El Obeid Southwest, Sudan. The study area is underlain by two aquifers formations from Precambrian age. The oldest units of basement complex of area under investigation consist of metamorphic rocks including gneiss, schist, and quartzite. The geophysical methods electromagnetic (EM) and vertical electrical sounding (VES) surveys showed that best aquifers yield for construction of boreholes are in weathering and fractures formation. The EM results revealed that structural features are significant for groundwater potential and interpretation of the VES data also revealed four geo-electric layers, but generally two distinct lithologic layers, which include Superficial deposit and bedrock-basement respectively. The curves generated from the data revealed H curve and HK curve, and thickness of these layers varies from 15 m to 50 m in the area. The aquifer thickness range from 20 m to 30 m. The study concludes that these techniques are suitable for identifying borehole location in the basement rock in Abu Zabad Area Sudan.

## 1. Introduction

Groundwater investigation of different techniques; geological, hydro-geological, geophysical techniques. The hydrological cycle as results of climatic changes have a significant associated impact on water resources (Stoll et al. 2011). Jyrkama and Sykes (2007)

studied the variation of the groundwater recharge.

Lineaments provide the pathways for groundwater movement in hard rock areas<sup>[3,4]</sup>. Furthermore, in order to locate favorable sites for groundwater exploration a lineament density map was prepared as suggested by<sup>[17]</sup>. The movement and occurrence of groundwater depends mainly on the secondary porosity and permeability resulting

\*Corresponding Author:

Musa M. A.,

Department of Geology, College of Science and Information Technology, Nyala University, Nyala, Sudan;

Email: [ahmedhydro@gmail.com](mailto:ahmedhydro@gmail.com); [abalhaj@kku.edu.sa](mailto:abalhaj@kku.edu.sa)

from faulting and fracturing etc. [7]. In October 1966 and 1973, Kordofan State was shaken by strong earthquakes that have great attention to hydrology due to a few of groundwater wells in the aquifer are dry [8]. In study area geological formation is exposed in the eastern part of Torda (Precambrian age). They are predominantly massive and compact of schist and gneiss metamorphic rocks (Figure 4).

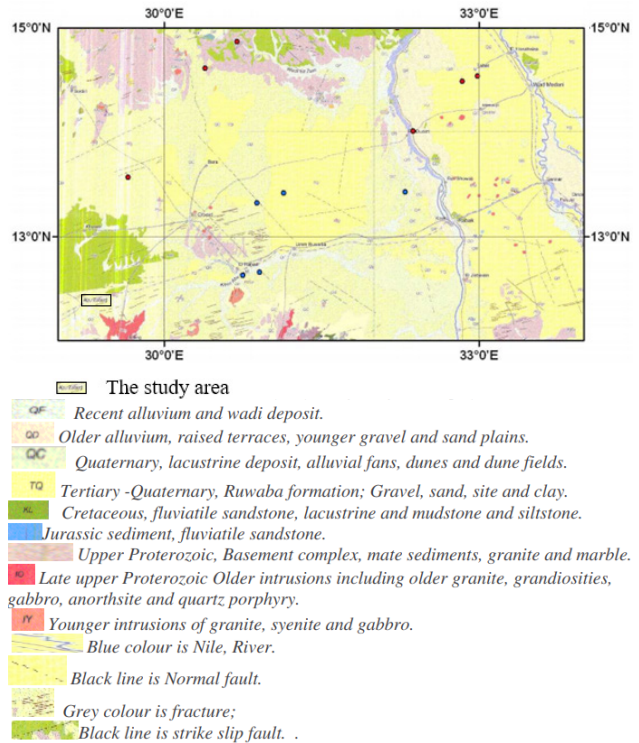
Surface geophysical survey is a veritable tool in groundwater exploration, owing to its economy in borehole construction by identifying borehole location prior to drilling [12]. Hydrogeophysical study is very important in basement rocks areas and considered a priority in many groundwater prospecting. Many geophysical methods used in basement areas, but the electrical resistivity (ER) method is essential tools [10].

The electromagnetic (EM) and vertical electrical sounding (VES) survey used in this work for locating the aquifers extension [16]. The two most common arrays used for VES are Wenner array and Schlumberger array [5]. This method is regularly used to solve a wide variety of groundwater problems such as determination of depth, thickness and boundary of aquifer, determination of zones with high yield potential in an aquifer, determination of the boundary between saline and fresh water zones and estimation of aquifer transmissivity and in environmental problems as well [1,2,11,13,15].

### Study Area

This paper focus on the geology and groundwater resources of western Sudan in terms of aquifers properties, investigated area includes Abu Zabad area which lies within Western Kordofan State. The target area is covers an area of about 25 Km<sup>2</sup> between Latitudes 12° 20'–12° 38' N and Longitudes 29° 28' – 29° 45' E (Figure 1), and characterized by undulating topographical surfaces mostly covered by sand dunes and gentle slopes to the east of Torda (watercourse) (Figure 1). The rainfall generally occurs in summer season, with maximum in the month of August. The prevailing winds blow from the south during summer, and blow north during winter. The average of temperatures ranges between 30°C in January and 48°C in June.

Western Kordofan area is the most important district area in Kordofan States as it is located within the basement complex and Nubian sandstone formation area. An intensive geophysical survey was carried out to locate different types of rocks. The ages of these rocks in most localities are assigned to the Precambrian period.



**Figure 1.** Distribution of pre-Quaternary geological units in the Kordofan Region

Source: [20]

The objective of the study is to recognize water-bearing formations in study area, and to examine suitable and available resources of groundwater. The main rocks characterization and recognition of aquifers, lateral and vertical extensions useful for drilling boreholes, as well as the main objectives of the geophysical survey in the study area are as follows:

- (1) Determine anomalous (conductive) zones.
- (2) Determine fractures, faulting and similar rock deformations which play an important role in sub-surface hydrology of the area (water movement and recharge).

## 2. Materials and Methods

The study employed two direct current (DC) methods: Vertical Electric Sounding (VES) and electromagnetic (EM). In both electric potential produced by (DC) current injected by two electrodes is measured by another pair of electrodes. VES technique employed Schlumberger array, which is particularly efficient when main resistivity gradient is in vertical direction. The electromagnetic (EM) array is more suitable to study grounds with lateral resistivity variation. The weathering and fracturing of analysis were also carried out to determine the optimized location and groundwater well.

The vertical electrical sounding and electrical profiling

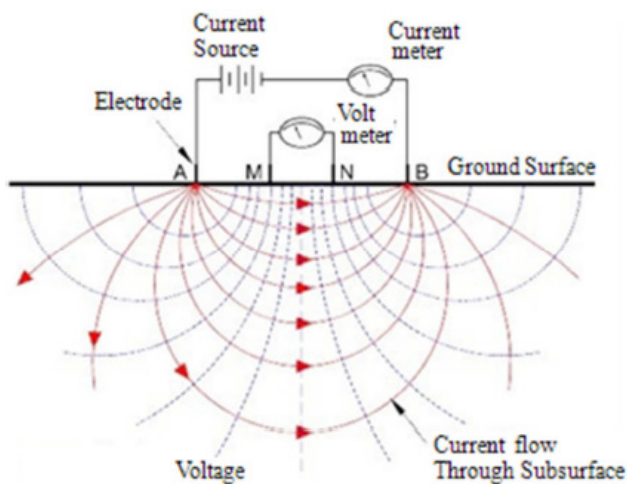
methods are based on four-electrode principle as shown in (Figure 2). The electrical current ( $I$ ) is applied to A and B electrodes and the potential ( $\Delta U$ ) is measured between M and N electrodes. The bulk soil electrical resistivity ( $ER$ ) is calculated with:

$$ER = K \frac{\Delta U}{I} \quad (1)$$

Where:

$K$  = is the geometric factor.

The conductive and EM anomalies delineated by across the entire study area, and carried out to determine depth to fresh rock. Figure 8 reveals the geo-electric sequence along W – E within the study area. Conductive and EM anomalies were delineated at three VES,s and three EM profiling locations within the study area. The Figure 8 was combined the VES and Electromagnetic data and obtained by computing the depths and locations of fractures.



**Figure 2.** Two current and two potential electrodes on the surface of ground of resistivity

Source: [7]

### Geology and Hydrogeological Setting

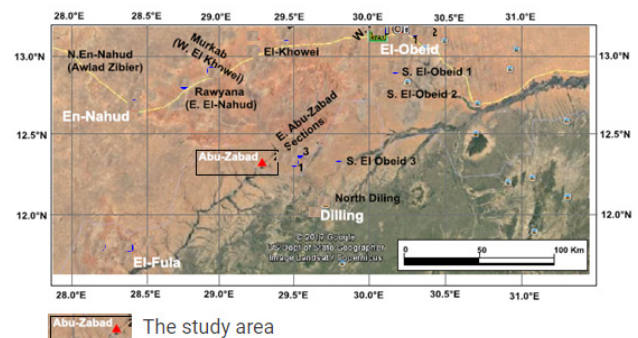
The study area lies South of Central African Shear Zone (CASZ). The Torda basin Complex is main basin in study area and in general trending North to South. The Torda basin, located in Eastern extension of Abu Zabad town (Figure 3). The basement complex is divided into three groups which include weathering, fracture and tide crystalline rocks. Hydrogeological and lithological log have been studied and evaluated to characterize aquifer potentials, and suitable sites for several wells were selected in Torda basin to define aquifers extensions (Figure 3). Geologically, Torda basin Complex is composed of two major basins, named weathering and fractures basement regolith. The groundwater

occurs in drilled wells in weathering and fractures basement regolith.

The target area is generally an undulating plain of low relief with altitude ranging range from 610 to 616 m above mean sea level, and major drainage system in study area Khor El Ganam, Khor Sheween and Wadis and ground surface slopes gently to east towards Torda.

The regional geologic map of the study area is composed of igneous and metamorphic rocks surrounded by Paleozoic and Cretaceous sedimentary rocks. The Precambrian rocks are extending southward from the valley of Abu Zabad through subdued topographic basin drained by Torda.

In Eastern Abu Zabad city (Figure 3), groundwater extraction from hand dug wells (shallow boreholes) and deep boreholes around the water pool (Torda) is used for drinking and irrigation. The geological logs from the surface down to 53 m depth revealed that the structural features consist of Superficial deposits, and bedrock-basement. The individual thickness of these layers varies from 5 m to 10 m in the area (Figure 4). The main aquifer appears at depths below 20 m, composed of fragment of metamorphic and igneous rocks.



**Figure 3.** Geomorphological map of the study area

Source: [9]

### 3. Results and Discussion

The geological setting of the study area consists of superficial deposits and Precambrian basement rocks. The sediments exposed in Northern part are mostly Cretaceous in age belong to the Wadi of Ger Ellassal formation. They are dominated by fine to coarse grained cross-bedded fluvial sandstones forming. The Precambrian basement rocks consist of gneisses, schists and quartzites (Figure 4). The weathered and fractured basement rocks constitute major aquifers or aquitards.

The degree of weathering is one of the most significant factors controlling the type and abundance of clay minerals [6]. In basement rock of study area percentage of clay



minerals is proportional with intensity and time interval of weathering (Figure 4). Whereas, weathered and fractured basement rocks constitute the major aquifers or aquitards.



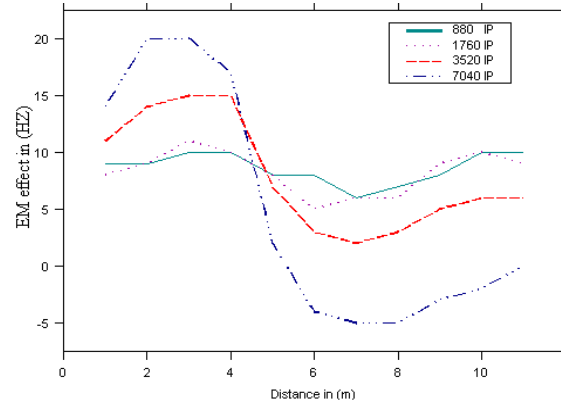
**Figure 4.** Weathering and fractured profile on gneiss of the study area (Abu Zabad - Torda)

*Note:* Photograph with the author (May, 2018).

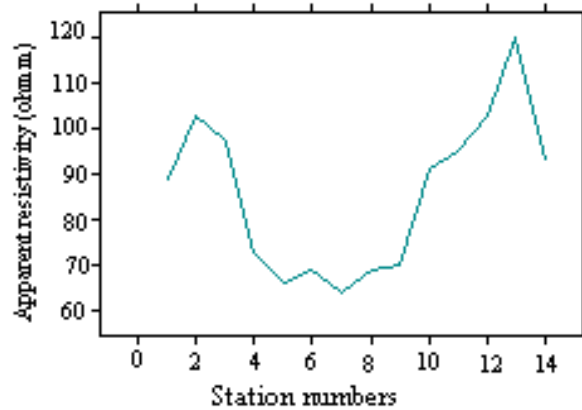
**Interpretation of Resistivity Data**

The resistivity method data indicates variation in groundwater potential because rock formation is not isotropic. The resistivity and thicknesses of geo-electric/lithology layers within the subsurface are presented in figure (7). The profiles and curves generated for apparent resistivity data using surfer-8 and IPI2win softwares are presented in figure (6 and 7), and the geo-electric section for the study area is presented in figure (8). The most of the VES curves coverage to the basement complex represented by the types H and KH, these types are very important from the qualitative interpretation point of view, which increases at right branches of sounding curves often rises at an angle of 45° owing to influence from tight basement rock, that usually indicates igneous or metamorphic rocks (granite, schists and gneisses rocks) of very high resistivity which called typical basement complex, that observed in the geo-electrical curves (Figure 7).

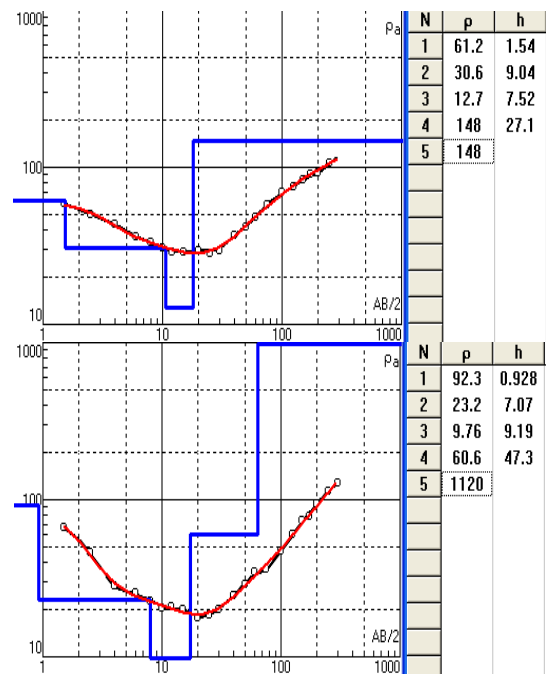
Three subsurface geologic layers were delineated along three VES,s and three EM profiling locations within the study area; the top soil Superficial deposits, weathered basement and fresh bedrock (Fig. 8). The VES curve revealed five resistivity layers for traverse at the crack or point (7) from EM Profile figures (5 and 6). The first layer mixed with superficial deposits composed of sand with clay lenses. The resistivity of this layer range from 50 to 63 ohm.m and the thick reach about 2-10 m. The weathered and fractured basement complex forms the second layer. The resistivity range between 25 to 150 ohm-m and thickness reach about 42 m, ended by hard basement complex which are shows increase in the resistivity value attains 1400 Ωm (Figure 8).



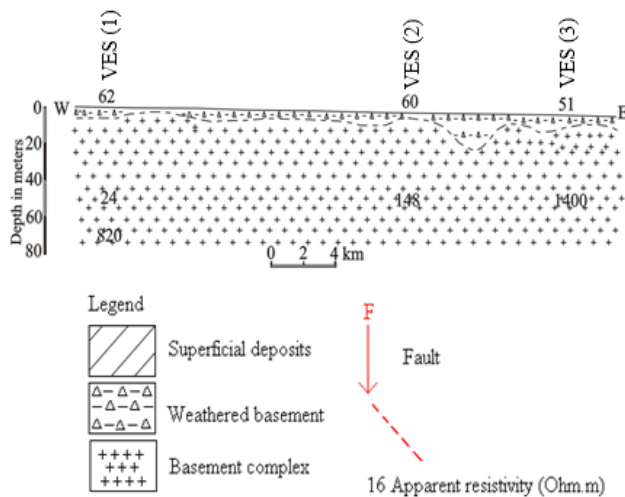
**Figure 5.** EM survey conducted in basement complex in the study area



**Figure 6.** Horizontal electrical profiles showing variation in the basement complex



**Figure 7.** Vertical electrical sounding curves for detection of water-bearing formations



**Figure 8.** Shows that traverse of EM and three points of VES

To recognize the two aquifers at different depths, the lithological analysis of well logs is useful for obtaining variations of weathering and fractured basement rocks (Figure 4). The water table marks of aquifer are underlain by an unsaturated zone which composed of superficial deposits, and thickness of unsaturated zone above aquifer is about 20 m to groundwater table. In Torda towards east, water table is the shallowest (about 15 m) and therefore unsaturated zone is a thin layer. The total thickness of the aquifer varies from 30 m in the eastern part to 10 m in the west with an average thickness of about 20 m.

Annual groundwater level fluctuations related to groundwater recharge and discharge in the aquifer system. Direct reflected in variations of groundwater level when recharge exceeds discharge, water table levels will rise and when discharge exceeds recharge, they will fall. Whereas, two types of fluctuations are recorded, which include either seasonal or diurnal ones. The water level in study area fluctuates in response to variation in recharge periods, rise due to the seasonal rainfalls and decline in the summer and during droughts in response to a decrease in groundwater recharge from precipitation. The influence of the recharge extends to certain distances and then becomes negligible. Groundwater quality is saline in the western area where is low recharge, but in eastern area (Torda basin) is good quality occurs; the total dissolved solids (TDS) range between 300 to 600 mg/l, and groundwater is suitable for drinking and irrigation purposes.

Several pumping tests that were conducted at different wells in the study area to determine the hydraulic properties of the aquifer. The base of the aquifer is at the depth of range from 20 m to 30 m, and the yield about borehole about 2500 g/h.

## 4. Conclusions

The study area composed of two aquifers weathered and fractured basement rocks, both aquifers are found at relatively in the Torda Basin in the East direction. Groundwater recharge by the flood of many Khors; Khor El Ganam, Khor Sheween and Wadis respectively. Groundwater salinity progressively increases with the low recharge.

This study investigated the groundwater potential and aquifer extension, western Kordafan state, Abu Zabad, Sudan. Electromagnetic and vertical electrical sounding using the Schlumberger array configuration were carried out. Analysis and interpretation of EM and VES data obtained from the study area showed profile 1 and 2, and VES 3 and VES 5 to be locating the successful for borehole drilling due to low resistivity of the weathered and fractured aquifer layers coupled with the relatively high thicknesses of the weathered layers. It is therefore recommended that for future groundwater exploration in the study area, geophysical prospection should be taken to locate the best site for groundwater drilling.

## Acknowledgement

The authors would like to express their gratitude to King Khalid University, Saudi Arabia for providing administrative and technical support.

## References

- [1] Acharya, T. Biswas, A. Bhattacharyya, A. Chakraborty, A. Chakraborty, M., Sarkar, M.. Vulnerability mapping of saline water intrusion in coastal aquifers of West-Bengal, India using flow-net approach. *Indian Groundwater*, 2018, 10: 46-56.
- [2] Biswas, A., Sharma, S. P.. Geophysical surveys for identifying source and pathways of subsurface water inflow at the Bangur chromite mine, Odisha, India. *Natural Hazards*, 2017, 88 (2): 947-964.
- [3] Biswas, A. Jana, A., Mandal, A.. Application of Remote Sensing, GIS and MIF technique for Elucidation of Groundwater Potential Zones from a part of Orissa coastal tract, Eastern India. *Research Journal of Recent Sciences*, 2013, 2 (11): P. 42-49.
- [4] Biswas, A. Jana A., Sharma S. P.. Delineation of groundwater potential zones using satellite remote sensing and geographic information system techniques: a case study from Ganjam district, Orissa, India. *Research Journal of Recent Sciences*, 2012, 1 (9): 59-66, Available online at: [www.isca.in](http://www.isca.in).
- [5] Cardimona, S.. *Electrical Resistivity technique for Subsurface Investigation*, 2017.
- [6] Duzgoren-Aydin, N.S., Aydin, A., Malpas, J.. *Distri-*

- bution of clay minerals along a weathered pyroclastic profile, Hong Kong. *Catena*, 2002, 50: 17-41.
- [7] Elhag A. B.. Application of Remote Sensing and Geo-Electrical Method for Groundwater Exploration in Khor Al Alabyad, North Kordofan State, Sudan. *American Journal of Earth Sciences*, 2016. <http://www.openscienceonline.com/journal/archive2?journalId=715&paperId=2914>
- [8] Elhag, A. B., Elzien, S. M.. Structures Controls on Groundwater Occurrence and Flow in Crystalline Bedrocks: a case study of the El Obeid area, Western Sudan. *Global Advanced Research Journal of Environmental Science and Toxicology*, 2013, 2(2): 037-046. ISSN: 2315-5140. Available online: <http://garj.org/garjest/index.htm>.
- [9] Eltahir, A. D. M.. Late Quaternary Sedimentary and Paleoclimatic Evolution of Kordofan, Sudan, Ph.D. Dissertation for the doctorate degree of the Université Grenoble Alpes, France, 2018.
- [10] Gautam, P., Biswas, A.. 2D Geo-electrical imaging for shallow depth investigation in Doon Valley Sub-Himalaya, Uttarakhand, India. *Modeling Earth Systems and Environment*, 2016, 2 (4): 175.
- [11] Nejad, H. T.. Geoelectrical Investigation of the Aquifer Characteristics and Groundwater Potential in Bahbadan Azad University Farm, Khuzestan province, Iran. *Journal of Applied Sciences*, 2009, 9(20): 3691-3698. ISSN: 1812 – 5654
- [12] Obiora, D. N., Ownuka, O. S.. Groundwater Exploration in Ikorodu, Lagos-Nigeria: A Surface Geophysical Survey Contribution, University of Nigeria, Nsukka. *The Pacific Journal of Science and Technology*, 2005, 6(1): 86–93. <http://www.akamaiuniversity.us/PJST.htm>
- [13] Parial, K. Biswas, A. Agrahari, S. Sharma, S. P., Sengupta, D.. Identification of contaminated zones using direct current resistivity surveys in and around ash ponds near Kolaghat Thermal power plant, West Bengal, India. *International Journal of Geology and Earth Sciences*, 2015, 1 (2): 55-64.
- [14] Rodis, H.G., Hassan, A., Wahadan, L.. Groundwater Geology of Kordofan Province-Sudan, Contribution to the hydrology of Africa and Mediterranean Region. United State government printing office. Washington, 1968.
- [15] Sharma, S. P., Biswas, A.. A practical solution in delineating thin conducting structures and suppression problem in direct current resistivity sounding. *Journal of earth system science*, 2013, 122 (4): 1065-1080.
- [16] Sharma, S. P., Baranwal, V. C.. Delineation of groundwater-bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data. *Journal of Applied geophysics*, 2005, 57 (2): 155-166.
- [17] Sree Devi, P. D., Srinivasulu, S., Ragu, K. K.. Hydro-geomorphological and groundwater prospects of the Pageru river basin by using remote sensing data. *Environmental Geology*, 2001, 40: 1088-1094.
- [18] U.N.S Special 92 Fund (DOX - SUD - A 39). United Nations Special Fund, F.A.O Land and Water Use Survey in Kordofan Province, Sudan. Reports of the following notations:- DOX - sun – A 39, 1965.
- [19] Van Daele, K.. Characterization of geological materials, their weathering products and their relationship with soils in the Gilgel Gibe catchment, SW Ethiopia. Ghent University, Belgium. (published M.Sc. in geology), 2011, 14.
- [20] Warage, A.. Seismotectonics in Central Sudan and Local Site Effect in Western Khartoum, Master Thesis in Geodynamics, Department of Earth Science University of Bergen, Norway, 2007.