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Research Article

Groundwater Occurrence and Aquifer Classification in En Nuhud Basin, Kordofan Region, Sudan

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ABSTRACT

En Nuhud basin is the only source for water supply in a wide, densely populated and economically important area. The study aims to evaluate the hydrogeological environment and to highlight the critical factors that affect groundwater occurrence in En Nuhud basin. Integration of borehole data with geophysical investigations, in addition to pumping tests was used to achieve the mentioned objectives. The main and hydrogeologically important unit in the study area is the Nubian Sandstone Formation; conglomerates and sandstones represent the main distinguishable aquifers. Basement Complex when it is weathered enough to form secondary porosity and when it is close to the upper saturated sediments, serves the purpose of circulating and accumulating groundwater. Generally the depth of productive wells in the area ranges from 90 to 410 m and mostly the drilled wells within the sedimentary sequence less than 100 m are failed. No Perched water is recorded due to the high permeability of the upper formations. Regarding the thickness of the aquiferous zone, it ranges from 10 to 140 m. The aquifers in the study area were classified into two categories; unconfined aquifers that dominate the northern half of the area and they found to be relatively shallow to medium in depth; confined aquifers dominate the southern part and they usually related to the deep sedimentary sequence or found when multi-layered aquifer occurs.

Keywords: Aquifer Classification, Confined, En Nuhud Basin, Groundwater, Nubian Sandstone

Introduction

Earth's water resources include surface water and groundwater. Water is essential for all aspects oflife on earth and is the mainstay to many sectors of the economy. Water as one of the natural resources is irregularly distributed in space and time and it is under pressure due to human activity; human activities and natural forces affect the available water resources in quantity and quality. Although public awareness of the need to better water resources management has evolved in recent decades, economic criteria and political considerations are driving water policies at all levels; science and best practice are rarely given adequate consideration. Pressures on water resources are increasing as a result of urbanization, population growth, increased living standards, growing competition for water and pollution. The effect of these factors isamplified by climate change and variations in natural conditions.

Study Area

The study area is situated within Kordofan Region in Sudan, between longitudes 28° 15′ and 30° 00′E and latitudes 12° 22′ and 13° 28′N (Figure 1).

Physiography of the area is generally as undulated plain; it is dissected by isolated ridges and mounds and stabilized sand dunes. The altitude of the surface over most of the area ranges between (538) and (660) meters above the mean sea level. En Nuhud Basin is more important in that it is the only source for water supply in the area.

Many hydrogeological studies were conducted including the study area, the more prominent of which are:Rodis et al, (1964); Karkanis B.G. (1966); Strojexport, (1971-1976); Ginaya (2001); (Ginaya 2011) and Elmansour (2016). The study represents an assessment for groundwater resources and description of the structural setting and tectonic characteristics in the study area.

Scope and Justifications of Thestudy

All the previous studies in the area either they neglect or slightly touch the question of the aquifer types; the common a statement concerning this issue is that the aquifers in this basin are under slightly confining pressure. This paper aims to fill the gaps in the previous work and to highlight the critical factors that affect groundwater occurrence in En Nuhud basin. It deals with the physical characteristics of the aquiferous horizons and the type of the aquifers to evaluate groundwater environment.

Methodology

Integration of borehole data with geophysical investigations, in addition to pumping tests was used to describe the physical conditions controlling the groundwater occurrence in the study area. Data concerning the study area was collected from the relevant institutionsand agencies and practitioners, in addition to field observations within this study. The obtained data and information were processed and interpreted to construct maps, profiles and sections (Figure 2) and hence to deduce a comprehensive picture for the study area.

Geology

Geologically, En Nuhud Basin is a rift structure, tightly controlled by two sets of faults trending NNW-SSE and E-W (Figure 3).

Four geological units underlie the area, those are: Basement Complex, Nubian Sandstone Formation, Laterites and Superficial Deposits (Strojexport, 1976), (Figure 4).

Basement Complex (Precambrian) includes schists, gneisses, granites, basicand ultrabasic bodies, quartzite and crystalline limestoneVail, 1978; Rodis et al, 1964). The Nubian Sandstone is believed to be laid down in a subaqueous environment during the Early Cretaceous (Whiteman, 1971) or Upper Jurassic/ Cretaceous (Harms et al., 1990).

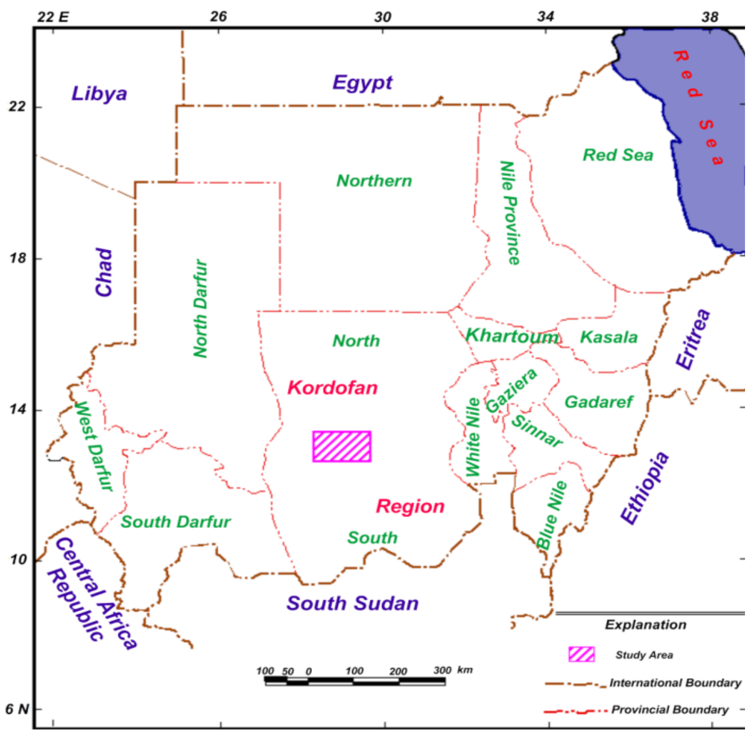

Figure 1.Location Map of the Study Area

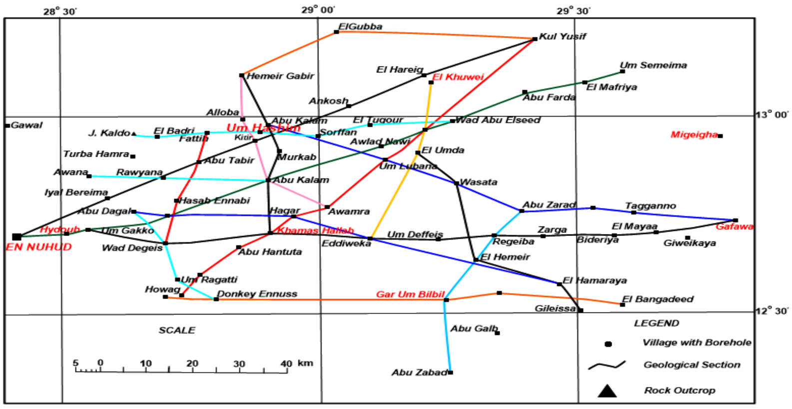

Figure 2.Layout of the Geological Cross Sections in the Study area

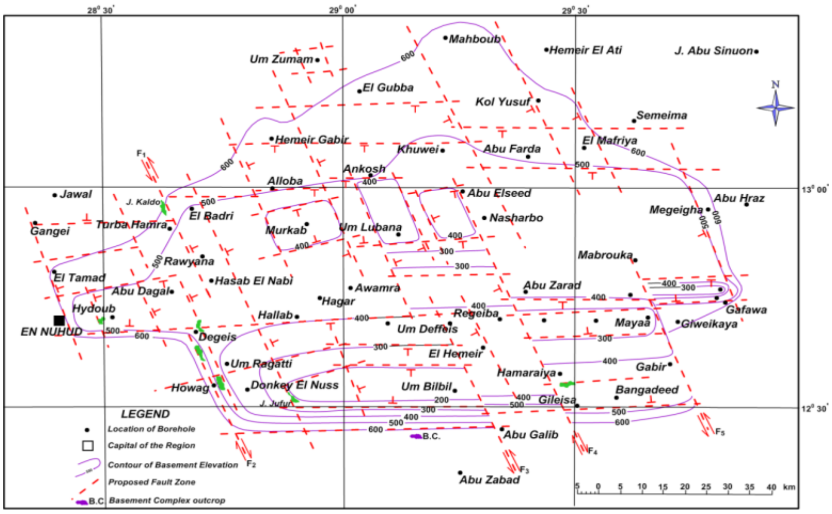

Figure 3.Basement Topography and the Dominant Structures(after Elmansour, 2016)

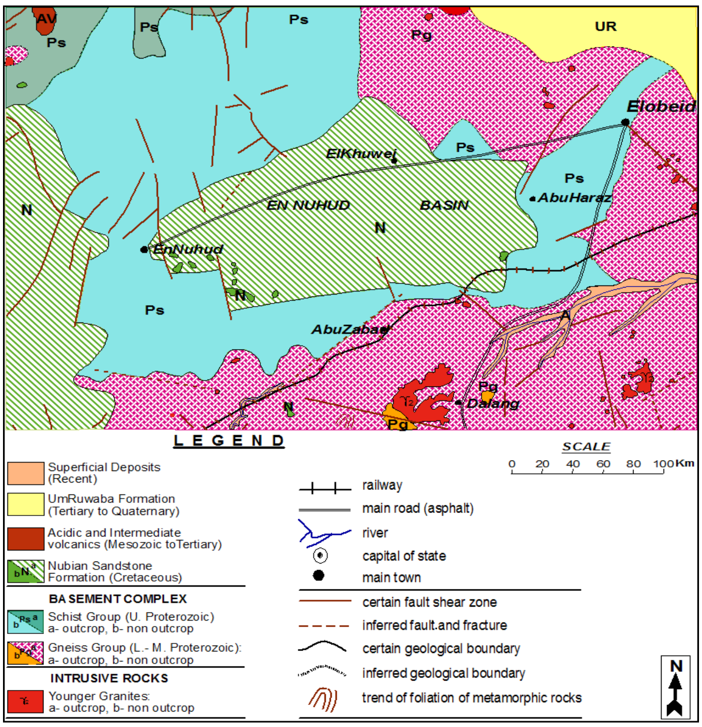

Figure 4.Geology of the area (After G.M.R.D,Khartoum-Sudan, 1981, Modified by the Author)

The common lithology is poorly sorted, coarse to medium sandstones, conglomerates and mudstones (Vail, 1978). Strojexport, 1976classified the Nubian Sandstone in the study area into two divisions: pelite-aleurite facies (grain size < 0.05mm) and psammite-psephite facies (grain size > 0.05mm).Laterites are recorded at the western part of the study area as highly ferruginous layer, usually of few meters thick; geologists proposed ages extended from late cretaceous to Middle Tertiary (Whiteman, 1971 and Rodis et al (1964) for laterites. Superficial Deposits (Pleistocene to recent) includes gently-rolling sheets and fixed sand dunes (Qoz sands), clay plains, hill wash deposits and alluvial deposits. The Qoz sandsare wide spread and veneer the older rocks; they were derived from the weathering of the Basement (Grabham, 1935) and/or the Cretaceous Sandstone (Edmond, 1942).

Result

General

Geological cross sections constructed on the basis of the integration of borehole and geophysical data give detailed dissection for the basin geometry and stratigraphy. It is noticed that the stratigraphic setting is strongly distorted by breaking and ripping of rock structure, due to intensive fracturing and rock displacements. Accordingly, discontinuity and variations in depth of strata by the sides of fractures occur;sometimes displacement manifests as approximately full-scale or a complex contrast in lithology (Figure 5). Thrusting and/or crumpling of the sedimentary strata due to compression stresses may be responsible of this situation. At the surface of the ground, fault zones usually express themselves by some subsidence; many times thickening of the Superficial Deposits occurs above the rift structures (Figure 6); loss of circulation of drilling fluids is customary and can be an evidence for fracturing around the bores sites. This geological setting greatly influences the groundwater occurrence in the study area.

The main and hydrogeologically important geological unit in the study area is the Nubian Sandstone Formation. The lithological classes within this formation vary in their importance as water bearing environment, their importance degree is related to the genetic lithology characteristics, composition, structure and texture.

Groundwater Occurrence

Sandstones and conglomerates represent the main distinguishable aquifers in the study area; they are often silty or muddy. Mudstones and claystones usually act as confining layers (Figure 7), but jointed and fractured mudstones may contain water. Basement sometimes represents a suitable environment for circulation and accumulation of groundwater, where it shares the water saturation with the close upper sediments in some parts of the basin (Figure 8), this happens when the Basement Complex is weathered enough to form secondary porosity.

Generally the depth to water bearing horizons has not regular distribution, but it can be said that the total depth of productive wells in the area ranges from 90 at Um Deffeis to 410 at Gar Um Bilbil. No Perched water is recorded in the study area as it may be expected around the water courses. This is due to the high permeability of the top formation, so any percolation from the surface go directly to the deep aquifers. Regarding the thickness of the aquiferous zones, borehole data shows a thickness ranges from 10 to 65 m. From geophysical work thickness up to 140 m is revealed in Hydoub at the western margin of the basin.

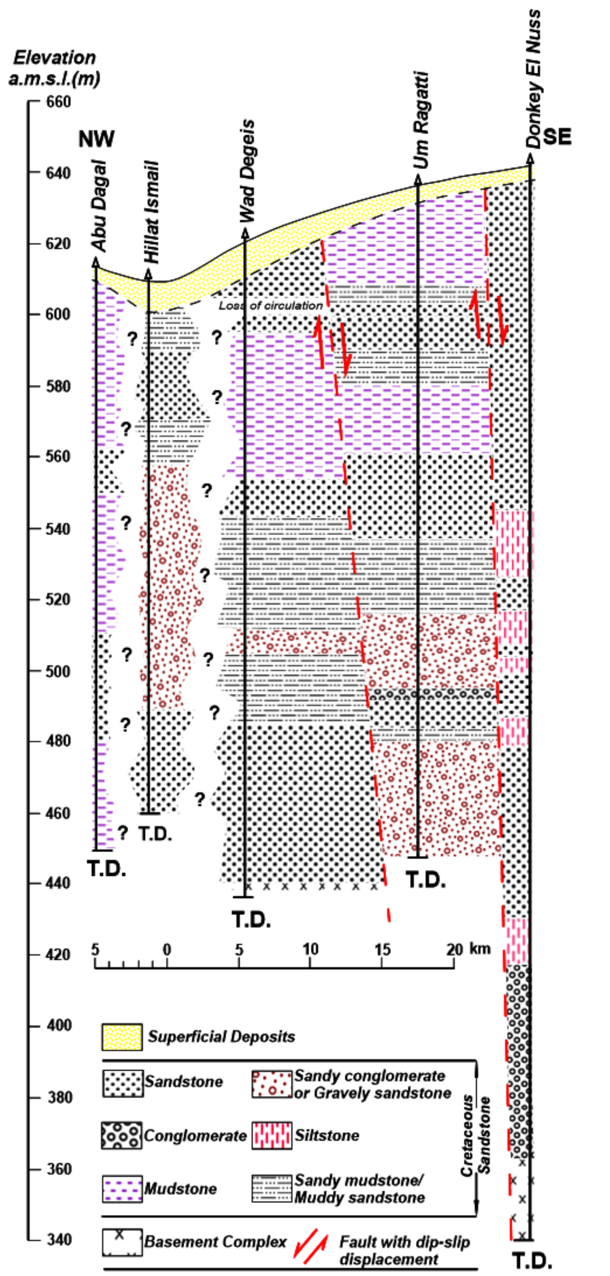

Figure 5.Distortion of the Stratigraphic Setting

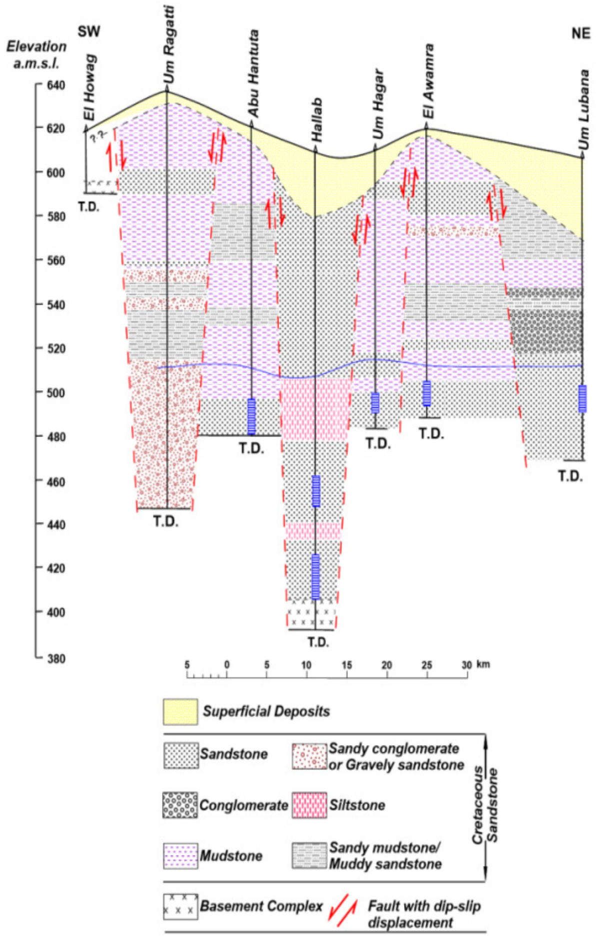

Figure 6.Subsidence and Thickening of strata

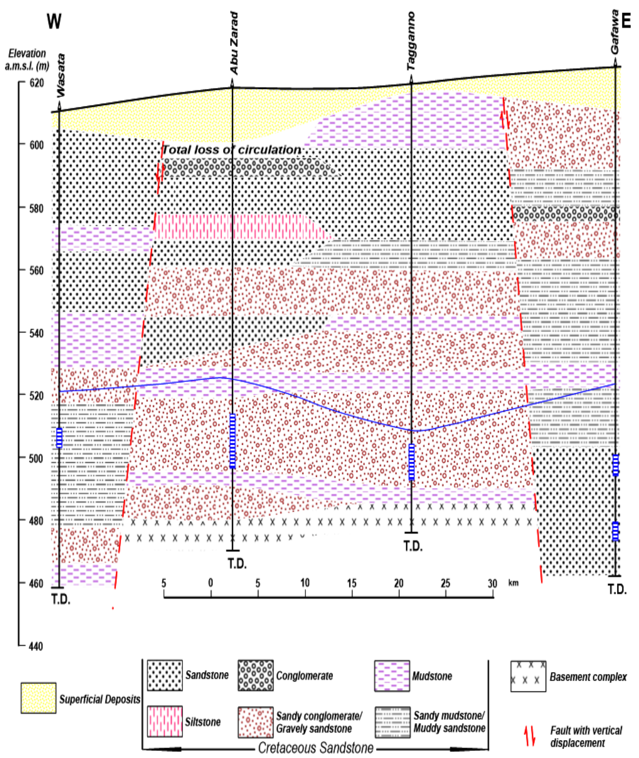

Figure 7.The dominant lithological units in the area

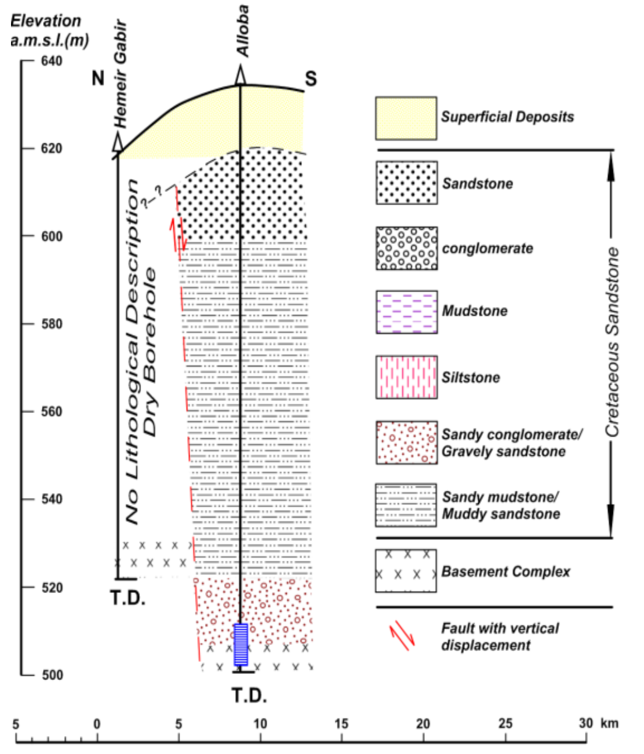

Figure 8.A Case of a Basement saturated zone

Superficial Deposits and Laterites, as they are always above the zone of saturation, they do not serve as sources of groundwater in the study area. Nevertheless the high permeable Qoz sands can serve as a conduit for recharging water to the zone of permanent saturation, from the rainfalls and surface runoff.

According to (Bouwer, 1978) values of hydraulic conductivity from the tested wells are assigned to the grain size of material, Table (1). These values show that the dominant size in the aquifer material is the coarse sand, followed by fine sand size, then medium sand and lastly the gravel size, where only one sample test show a conductivity of gravel size (> 100 m/d).

Table 1.Assigning values of hydraulic conductivity to grain size (Bouwer, 1978)

#	Hydraulic Conductivity (m/d)	Grain Size	%
1.	>100	Gravel	2.60
2.	20-100	Coarse Sand	47.40
3.	5- 20	Medium Sand	21.00
4.	1-5	Fine sand	29.00

Aquifer Classification

The traditional aquifer representation in the study area employed by many authors is that the aquifer conditions are slightly confined. Based on some observations this concept is inspected and re-examined. This is regarded as an important issue to understand the hydrogeological conditions that dominate the aquifer system and consequently to choose the most suitable design of water wells and to accurately organize methods for analyzing and interpreting the pumping test data.

Examination process is performed on the borehole reports where more than 200 borehole reports were studied in addition to other sources of data.

Attention is paid to some hydrogeological relations and observations, these are:

- The characteristics of the vertical limits of the water bearing zones, where log description, screen distribution, geophysical logs and drilling penetration rate are used for this purpose.
- The physical characteristics and location of aquitard or aquiclude above the saturated zone.
- Presence and characteristics of multi-layered aquifers.
- The depth of static water level in wells relative to the upper limit of the saturated zone and to the ground surface.
- Total drawdown and the time elapsed for full recovery of water level in the pumped wells.

When the water level is the same as or deeper than the lower limit of the impermeable bed that located above the saturated zone then the aquifer is considered as unconfined. In some boreholes the aquifer is completely open to the ground surface; impermeable materials are absent above the water table in the water bearing formation which represents an ideal unconfined aquifer (Figure 9).

A simple look on the hydrogeological sections clearly shows that the static groundwater surface follow or near parallel the surface topography in many sections (Figure 10); this situation will disturb sometimes when the section crosses a confining zone or due to influence of some lithological or structural elements.

On the other hand groundwater surface in some confining zones also show some fitness with ground surface; it may be due to a low confining pressure at that part (Figure 11 and 12).

From pumping test data the small drawdown and quick time recovery in many wells point out for high storage coefficient or specific yield, which characterizes un-confining conditions. Hydraulic parameters estimated from previous studies and this study support this assumption, Table (2).Based on (Struckmeyer and Margat, 1995),

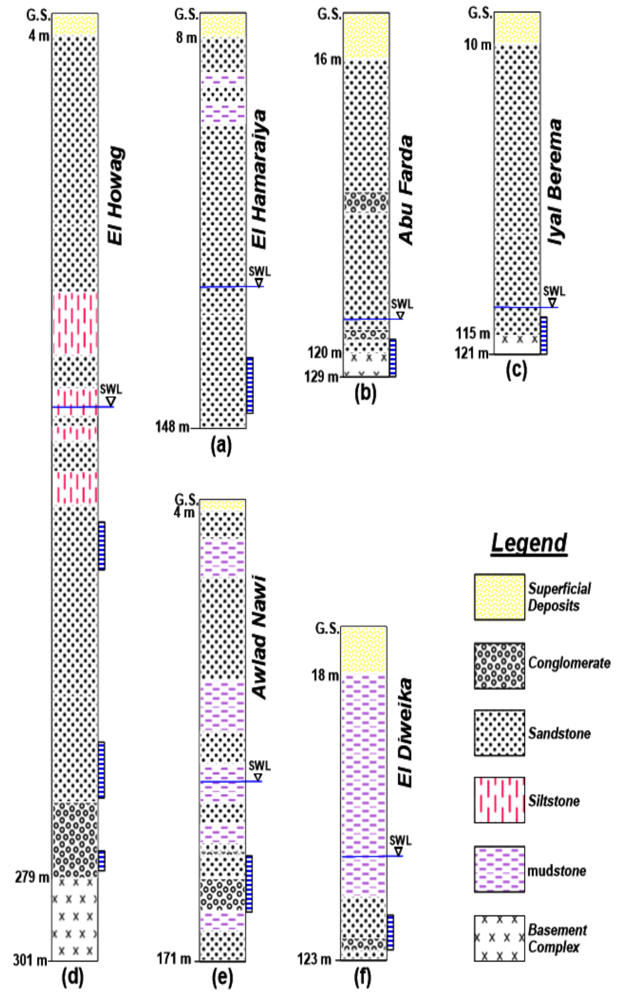

Figure 9.Typical Lithological Logs; unconfinedaquifer zone (a, b, c) and confined aquifer zone (d, e, f)

transmissivity obtained from the pumping test results is scaled as: v. high, high and intermediate, Table (3).

Table 2.Summary of the results of pumping Tests

Property	Confined Aquifer		Unconfined Aquifer	
	min	max	min	max
Drawdown (m)	0.63	5.79	0.026	5.79
K (m/d)	0.405	84.71	1.14	137
T (m^2/d)	13.20	2951	35.66	2844
S	$2.09x10^{-5}$	$1.69x10^{-1}$	$1.38x10^{-2}$	$6.76x10^{-1}$
Sp. Cap (m^3/d/m)	$5.69x10^{-3}$	$9.28x10^{-2}$	$6.33x10^{-3}$	$7.38x10^{-1}$

(Abbreviations: Sp. Cap. = Specific Capacity, m = Meter, max = Maximum, min = Minimum)

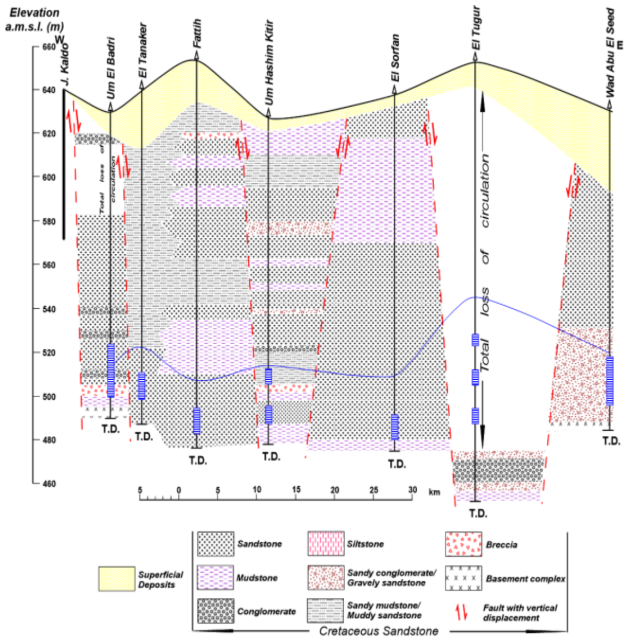

Figure 10.Groundwater Surface Fit to the Ground Topography

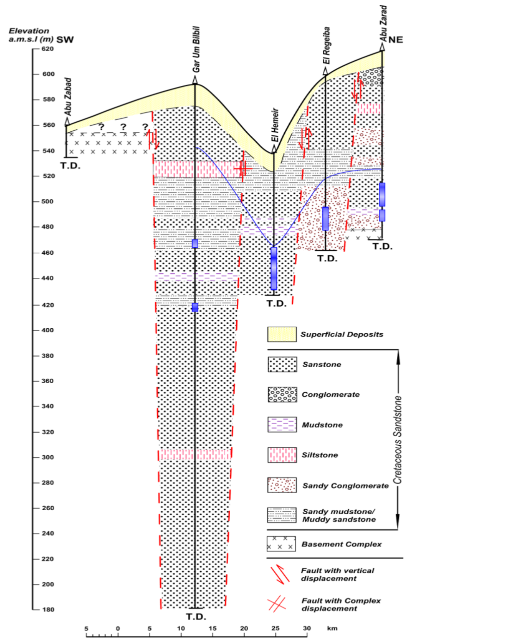

Figure 12.Groundwater Surface with Respect to Aquifer Conditions and Ground Surface Topography

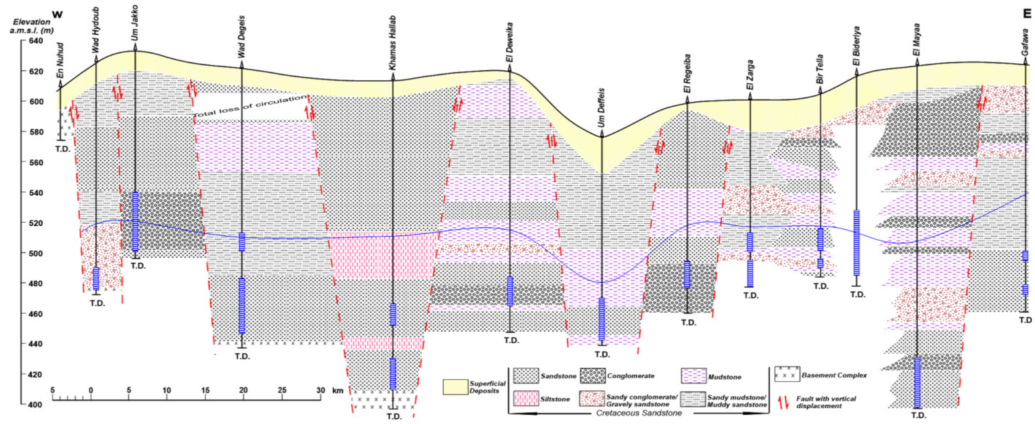

Figure 11.Groundwater Surface with Respect to Aquifer Conditions and Ground Surface Topography

According to the mentioned stipulations the aquifers conditions in the study area are classified into two categories:

- Un-confining aquiferconditions occupy the northern half of the basin, in addition to a polygonal area in the southeastern part.Some small pockets within the northern part show local confining conditions, which located around Awlad Nawi, Murkab, Abu Tabir, Hasabennabi and partly hydoub area (Figure 13). Unconfined aquifers are found to be relatively shallow to medium in depth.
- Confining aquiferconditions (including semi-confined type) which generally occupy the southern part of the study area in addition to the pockets that mentioned in the previous section (Figure 13). Confined aquifers are usually related to the deep sedimentary sequence or found when multi-layered aquifer occurs.

Table 3.Classification of transmissivity values (Struckmeyer and Margat 1995)

#	Trans-missivity (m²/d)	Class	Designation	Groundwater Supply Potential	%
1.	>100	1	Very High	Regional Importance	26.3
2.	20-100	2	High	Lesser Regional Importance	55.3
3.	5-20	3	Intermediate	Local Water Supply	18.4

Some parts within the basin confining or un-confining conditions are not clearly distinguished, this exists when the geology is more complex or the available geological data is not sufficient, so more investigations are needed for these cases.

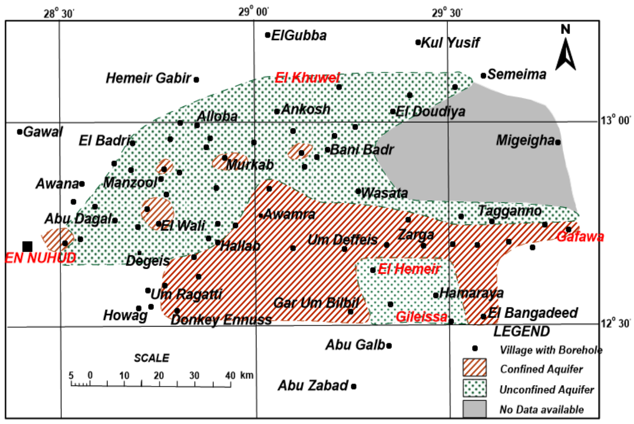

Figure 13.Classification of aquifers conditions

Disscussion

In spite of that many hydrogeological studies were conducted in the area, they have not taken care in demand of some aspects; such as the physical conditions of the aquiferous horizons and the type of aquifers; such knowledgeis important forproper use of the groundwater sources.The degree of hydrogeological importance of the lithological classes within the Nubian Sandstone is related to the genetic lithology characteristics, composition, structure and texture. Consequently variations in depth, saturated thickness and potentiality of the water bearing horizons show a wide range spatially.On the other hand, the distortion of rocks due to intensive fracturing and displacements are responsible of the discontinuity and variations in depth of water bearing formations, in addition to the loss of circulation of drilling fluids.The relatively thick aquifers in the western part of the basin (Hydoub area) is likely due to thickening under the influence of the compression stresses that seemed to affect that part. Restriction of the unconfined aquifers to the northern half (shallow) and the confined ones to the southern (deep) manifests the impact of the depth and structureon the aquifer conditions.Whereas the weathered Basement sometimes represents a suitable environment for circulation and accumulation of groundwater, then accurate geophysical study outside the hydrogeological boundary of the basin (Basement shallower than 100 m) may reveal some saturated zones there, especially within the extensions of fractures that crosses the basin.

Conclosion

The determined thickness of the sedimentary sequence, including the Nubian Sandstone and the Superficial Deposits, varies and generally increases from north to south. Nubian Sandstone is the main water bearing formation in the study area, but weathered Basement sometimes represents a suitable environment for groundwater storage. The depth, thickness and potentiality of the productive horizons are influenced by the lithological and structural characteristics. Superficial Deposits and Laterites do not contain water and no perched water is recorded. Generally the water bearing formations are assigned into two categories; shallow to medium unconfined aquifers in the northern half of the area and relatively deep confined aquifers in the southern part of the study area. It is necessary to consider the aquifer conditions in designing water wells and so attention must be paid when loss of circulation occur to avoid erratic design of water wells; geophysical well logging may be helpful in such cases.

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