SUMMARY AND CONCLUSIONS

The area under investigation covers about 12000 Km^2 in the southeastern part of Eastern Desert of Egypt, It is located between latitudes 22° 10′ and 23° 50′ N and logititudes 34° 30′ and 35° 30′ E. It is characterized by arid to semi arid climatic conditions.

Geomorphologically: Five geomorphic units are recognized.

1- Red Sea mountains

This unit is mainly composed of crystalline basement rocks, running parallel to the Red Sea coast and forming the main water divide between Red Sea and Nile valley drainage systems.

2- Sandstone Plateau

Such unit is located in the northwestern part of Wadi Hodein, including Gebel Abraq, Gebel Hodein, Gabal Kalat and Gebel Sa'alik.

3- Tectonic depressions:

These depressions are oriented in NW-SE and formed along the grabbens structure.

4- Tertiary volcanic ridges

Tertiary volcanic ridges occur between Red Sea Mountains and piedmont plains.

5- Piedmont and coastal plains

They extend from Red Sea coast to the inland mountainous area representing moderate sloping and covered by poorly sorted alluvial deposits.

Geologically, The area under investigation comprises a wide diversity of igneous, metamorphic and sedimentary rocks, ranging in age from Precambrian to Quaternary. The rocks units in the area are chronologically grouped into the following main sequences from oldest to younger :

1-Precambrian Basement rocks.

-Gneisses and metasediments.

-Ophilitic serpentinites and related rocks.

-Metagabbros.

-Metavolcanics.

-Old granitoides

-Younger granitoides.

-Ring related rocks.

2-Cretaceous Sediment.

-Abu-Aggag Formation.

-Timsah Formation.

-Um Baramil Formation.

3-Quaternary sediments.

Hydrogeologically, the study area comprises three water- bearing formations :-

- Quaternary alluvial aquifer
- Upper Cretaceous Nubian Sandstones aquifer
- Precambrian Basement rocks

Such aquifers were investigated through 39 water points. Also, 61 water samples were collected and chemically analyzed during two field trips.

Quaternary Groundwater exists in the main delta of Wadi Hodein and in the main channel of the delta of subsidiaries wadies draining to Wadi Hodein mega basin. Seven water wells are tapping the Quaternary aquifer. Four of them in the Delta of Wadi Hodein. Two at Wadi Eigad (tributary of Wadi Beitan) and only one at Wadi Urga El-Rayani. The groundwater exists as free water table. The depth to water ranges from 6.23 m. to 23.86 m. The general direction of groundwater flow is in the

same direction of surface runoff. The Quaternary aquifer in the area under investigation is mainly composed of wadi fill deposits including silt, sand and gravel. It is distributed along the main wadi channels and in the deltas.

The **Upper Cretaceous aquifer** is represented at northwestern part of the area (Wadi Abraq, Wadi El-Dif and Abu-Sàafa area). Three water-bearing formations namely Um-Barmil, Abu-Agag and Timsah are recognized and mainly composed of sandstone intercalated with shale and iron ore deposits and underlain by basement aquifer. The aquifer is composed of block-faulted sandstone, slightly folded and mainly affected by the Red Sea rift; Such blocks are acting as independent isolated aquifers. Twenty groundwater samples are tapping the aquifer, eight of them as springs, five hand-dug wells and seven as drilled wells. Groundwater exists as a free water table, however gravity springs are recognized at Abu-Sàafa, Abraq and El-Goderate springs. The investigated aquifer is mainly recharged from surface runoff as well as direct precipitation during tolerant floods. Concerning drilled and hand-dug wells, the depth to water ranges between 2.5 m. to 23.5 m. at El-Sunta and Wadi El-Dif areas, respectively.

Groundwater trapped in the **Pre-Cambrian aquifer** includes variable bearing rocks, scattered in different wadis as granite rocks at Wadi Madi, syenitic rocks at Wadi Amrite, metagabbroic and gneissic at Wadi Beitan, metavolcanic at Wadi El-Beida and the upstream of Wadi Rahaba, and metasedimentary at Wadi El-Beida. The depth to water ranges from 2 m. to 10.7 m.

A detailed geochemical rock analyses were performed for 18 fresh and their altered equivalents from different basement water bearings. These samples were analyzed for major and some trace elements to show the distribution of the mobile elements and their relation to the

redistribution of these elements and their effect on the groundwater quality. The significant features of these studies show a strong depletion of MgO, CaO, Na_2O, K_2O and some times of Fe_2O_3.

Moreover a petrographical and X-ray diffractions studies were carried out to investigate the mineralogical content of different water-bearing rocks.

Groundwater chemistry of the **Quaternary aquifer** depends mainly on its location to sea, where the groundwater located at the downstream portion of Wadi Hodein is characterized by high salinity while groundwater at the upstream portion of Wadi Hodein is characterized by low. The groundwater salinity in this aquifer varies from brackish to highly saline, it ranges between 1363.76 mg/l at Wadi Eigad to 19353.19 mg/l in Delta Wadi Hodein.

The distribution of major and trace ions in the groundwater located at the upstream portion of Wadi Hodein depends mainly on the types of different rocks, located closed to the shed area of each wadies, where the groundwater in Wadi El-Urga is directly affected by the granitic rocks characterized carbonate veinlets (sodium is the dominance cations (95.31%)) and bicarbonate is the dominance anion (40.75%), while groundwater at Wadi Eigad is directly affected by the presence of serpentinite rocks, located at the shed area, where records magnesium (40.69%).

The groundwater chemical types varies from chloride-calcium in the groundwater of Delta Wadi Hodein, reflecting the impact of marine deposits on the groundwater chemistry to chloride-sodium in groundwater of Wadi Eigad, showing final stage of groundwater evolution and bicarbonate-sodium in groundwater of Wadi El-Urga. Groundwater within the coastal area is characterized by the presence of $MgCl_2$ and

Distribution of major ions in the groundwater of Nubian Sandstone aquifer is directly affected by the presence of near shore to deltaic deposits, where sodium appears as the major cations, while chloride appears as the major anion. Ca^{+2} ions increased in groundwater at Abu-dobisat area, where carbonate between sandstone grains, as cement material (field observation), SO_4^{-2} ions increased in groundwater at the down stream of Wadi Amrite due to the presence of gypsum encountered in clay sheets, while HCO_3 increases in shallow groundwater, where appreciable amount of recent recharge is available.

The concentration of iron in the groundwater is directly affected by the presence of oolitic iron ore deposits encountered in Timsah Formation.

Groundwater chemical types varies from Bicarbonate-Sodium in most of shallow groundwater (Abraq, Gumbite, Abu-Sàafa and Wadi El-Dif areas), Bicarbonate-Calcium (Abraq and E-Sunta areas). Chloride-Sodium characterizes most of drilled wells (Wadi El-Dif, Abu-Sàafa areas) and chloride calcium characterizes shallow groundwater at Abu-Dobisat area.

The majority of Groundwater in the concerned aquifer is characterized by the prevalence of NaCl, Na_2SO_4, $NaHCO_3$ or $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ salts, while groundwater at El-Sunta, Abu-Dobisate and Abu-Sàafa localities is characterized by NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$, and $Ca(HCO_3)_2$ salts.

The groundwater salinity of the **Pre-Cambrian aquifer** in the area under investigation varies from fresh to moderately saline. Values of salinity in the concerned aquifers range from 382.72 mg/l at El-Gahlia area to 8860.53 mg/l at Wadi El-Beida. Lower salinities are recorded where a limited chance for leaching and dissolution, (water wells are

located at the upstream portion of Wadi Rahaba). In addition, the presence of dissected dykes, acts as a groundwater entrapment, giving more chance for recharge and replenishment of groundwater. The higher salinity (8860 mg/l) in metasedimentary rocks is mainly due to the reusability of metasediments for leaching. The groundwater chemical types varies from, Also the higher salinity of groundwater trapped in gneissic rocks is mainly attributed to the foliation and lineation, which characterizes these rocks.

Groundwater trapped in metavolcanic rocks at El-Gahlia area granitic rocks at Wadi Madi and syenitic rocks at Wadi Amrite is characterized by the prevalence of NaCl, Na_2SO_4, $NaHCO_3$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$, salts (58% of total samples) while the groundwater trapped in metagabbroic and gneissic rocks is characterized by the presence of NaCl, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ salts(25% of total samples). Groundwater in metagabbroic rocks at Wadi Beitan, differs slightly, as appearance of $CaSO_4$ while $Mg(HCO_3)_2$ disappears. The presence of magnesium salts in groundwater is mainly attributed to the presence of serpntinite rocks at the shed area of Wadi Beitan. In Wadi El-Beida NaCl, $MgCl_2$, $CaCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$ appear (16%). This assemblage characterizes saline groundwater in metavolcanic bearing formation at Wadi El-Beida and saline groundwater in metasedimentary rocks. Presence of $MgCl_2$ and $CaCl_2$ salts reflects final stage of groundwater evolution. In metavolcanic rocks, $CaCl_2$ salt disappears.

The groundwater chemical types varies from Chloride-Sodium, characterizing groundwater in Wadi El-Beida and groundwater in metagabbroic and Bicarbonate-Sodium characterizing groundwater in metavolcanic rocks at El-Gahlia area, granitic rocks and Syenitic rocks.

Bicarbonate-Magnesium characterizes groundwater trapped in metagabbroic and metavolcanic rocks. Chloride-Magnesium, this type is detected in groundwater trapped in gneissic rocks at Wadi Beitan .

The petrographical and geochemical studies revealed that, the basement rocks in the investigated area comprise different rock units, each of them has its own mineralogical and geochemical characteristics. Some effective secondary minerals were formed due to water-rock interactions phenomena (e.g. Kaolin, sericite, chlorite, saussurite and carbonate veins). Such minerals play the most important role in the mobility of major component (e. g. Na, K, Ca, Mg, Fe, and SiO_2) and in turn affects groundwater composition.

The study of groundwater composition of the Basement aquifer reveals the following:

1. Seven groundwater samples have $NaHCO_3$ water type of shallow meteoric genesis, while four groundwater samples have $MgCl_2$ water type of marine origin. The presence of $MgCl_2$ water type indicates intensive evaporation process, which elevate Cl^- concentrations relative to K^+, Na^+ and Mg^{+2}.
2. High bicarbonate concentrations in the majority of groundwater samples reflects leaching of talc carbonate rocks at the upstream portion.
3. Groundwater composition in metavolcanic rocks at El-Gahlia area reflects high concentrations of Na^+ and Mg^{+2} compared to Ca^{+2} content. High Na^+ content is attributed to the dissolution of Na-plagioclase (andesine) and sodalite minerals (X-ray investigation). High Mg^{+2} contents are referred to the dissolution of biotite minerals.
4. Groundwater composition in metavolcanic rocks at El-Beida area reflects high concentrations of Na^+, Ca^{+2} and Mg^{+2}. Very high Na^+ content is attributed to the dissolution of Na-plagioclase minerals and

high evaporation rate. Weathering and alteration of amphiboles and pyroxenes may contribute to Ca^{+2} and Mg^{+2} concentrations. This is confirmed by the sausritization of plagioclase and alteration of ferromagnesian minerals.

5. Groundwater composition in metagabbro at Wadi Beitan has high concentrations of Ca^{+2}, Na^{+} and Mg^{+2}. High Ca^{+2} contents are attributed to the dissolution of Ca-plagioclase (anorthite) and alteration of this mineral to sauserite. Alteration of hornblende to chlorite and actinolite may contribute to Ca^{+2}, Mg^{+2} and Na^{+} concentrations.

6. Groundwater composition in gneissic rocks at Wadi Beitan area has high concentrations of Mg^{+2}, Ca^{+2}, Na^{+} and K^{+}. High concentration of Mg^{+2} is referred to the alteration of biotite, while high content of Ca^{+2} is attributed to the dissolution of Ca-plagioclase. High concentrations of Na^{+} is referred to the alteration of Na-plagioclase, while high content of K^{+} is attributed to the dissolution of K-feldspar, muscovite and biotite.

7. Groundwater composition in granitic and syenite rocks at Wadi Madi and Wadi Amrite area, have very high concentrations of K^{+} + Na^{+} compared to Mg^{+2} and Ca^{+2}. A high concentration of Na+ is referred to the presence of sodalite and meionite (X-ray investigation) and alteration of Na-plagioclase, while high content of K^{+} is attributed to the dissolution of K-feldspar. This is confirmed by the intensive feldspar alteration and kaolinization, which give a strong chance for K^{+} and Na^{+} liberation. The alteration of biotite mineral may contribute in Mg^{+2} concentrations in groundwater in granitic rocks, while the alteration of arfvedsonite mineral may contribute in Na^{+} and Mg^{+2} concentrations in syenite rocks.

Main conclusions and recommendations:

1- Studying the mobility of elements during alteration processes, which leads to the concentration increase of some elements in groundwater.

2- Groundwater chemistry of the Quaternary aquifer is directly affected by rock types forming shedarea and wadi channel.

3- Groundwater quality in Nubian Sandstone aquifer depends mainly on the depositional environment, which varies from continental to near shore deltaic.

4- Groundwater chemistry in Basement aquifer is directly affected by the petrography of water – bearings.

5- From salinity point of view, groundwater in Delta Wadi Hodein can't be used under any conditions for human uses, while natural springs at Abu-Saafa area, El-Gahlia area, Abu-Beit area and Wadi Madi area can be used safely.

6- Most groundwater in the area under investigation can be used for agriculture purposes, by using a developed irrigation systems.

7- Detection of some hydrolysis phenomena (reactions), as a result of silicate rocks –water interactions and their role in the formation of some secondary minerals and leaching of some major elements in rocks (e.g. Na, K, Ca, Mg and Fe).

8- Identification of some secondary minerals that formed due to the different alteration processes (e g. Kaolinite, Sercite, Chlorite, Sausserite and Carbonate) and in turn their effects on groundwater quality.

9- Identification of the different rock units nearby water wells through petrographic investigations as well as field observations.