Summery and Conclusion

The present thesis deals with the Hydrochemical and Environmental Isotopes investigations at Wadi Sudr Delta to the southwest of Sinai. This could be considered as a basis for gaining new insights relating to the groundwater management for Ras Sudr delta area.

The thesis comprises the following chapters

Chapter One: Introduction and Literature.

Chapter Two: Geomorphological features and geological aspects.

Chapter Three: Hydrochemistry and water quality

Chapter Four: Environmental Isotopes

Chapter (1)

Introduction and Literature

This chapter contains a general description of the characteristics of the study area (location and climate), an outline of the aims of the study and the general methodology followed for conducting the investigation as well as an overview of the previous studies conducted in this area

Location and Climate conditions of the study area:

The area of study of Wadi Sudr Delta is situated on the eastern side of the Gulf of Suez. It covers an area of about 670 km2 bounded between latitude 29º 30′ and 29º 50′ and longitudes 32º 40′ and 33º 20′.In Sudr area as well as in other localities along the Gulf of Suez, the climate is characterized by extreme aridity with low and erratic rainfall, high evaporation rates and low relative humidity, high summer temperature and generally vigorous winds. Average values of the climatic parameters as recorded at Ras Sudr station are included in the thesis.

Aims of the Present Work:-

a) Defining the recharge sources and its renewability.
b) Investigating the flow regimes and the impact of lithofacies and structural elements on the hydrological system
c) Highlighting the mechanism of Salinization and water quality parameters
d) Evaluating the groundwater quality for different uses (drinking, irrigation, industry…).

Chapter (2)

Geomorphological Features and Geological Setting

Geomorphologic Setting:

Three geomorphological units are described in Wadi Sudr area:-

- The Structural Plateau: It is represented in the western horn of El-Tih plateau which covers a wide area land stretch about 20 km in width. Its surface is barren and underline by compacted Palaeogene and Miocene limestone.

- The Elevated Plain: It represents the most promising unit in the area. It located between the foot of the scarp and the Oolitic sand dunes on the sill line of the Gulf of Suez. It combines the following units:
    1. The pediment like plain.
    2. The playa deposits.
    3. The lagoonal depressions.
- The Oolitic Sand Dunes: They are elongated dunes running almost parallel to the sea shore line of the Gulf of Suez. These dunes are composed essentially of white calcareous oolitic materials varying from loose to slightly cemented limestone.

Geological and hydrogeological Setting:

Stratigraphy: The straitgraphic succession in the study area is mainly composed of the exposed Cretaceous-Eocene limestone, Miocene, evaporities and Quaternary deposits.

A brief description has been given in the thesis for the stratigraphic units which cover the area under consideration.

Water Bearing formation: Within Wadi Sudr, groundwater occurs in the following two main formations:

1. The fractured limestone aquifer.
2. The alluvial deposits aquifer.

The fractured lime stone outcrops occurs at the upper reaches of the wadi and are directly recharged by infiltrating rainfall. The groundwater in the fractured limestone flows naturally through perennial springs.

The alluvial aquifer in Wadi Surd exists in the main Wadi Channel and the Delta. The data obtained from the drilled and borehole wells revealed that, the alluvial deposits constitutes an extremely thick series of fluviatile sand and gravels with clay and sandstone interbeds. The total thickness of these deposits is mainly controlled by the local geological and physiographic conditions. The measured depth to water varies from 4.6 meter to 17.1 meter from the ground surface, while the water level varies from +11.0 meter to +2.0 meter towards the Gulf of Suez.

Chapter (3)

Hydrochemistry and water quality

Hydrochemical Characteristics and salinity processes

The mean values, standard deviations, and ranges of variations of the hydrochemical parameters (TDS and major ions) of the collected water samples

are to great extent matchable in the four sampling campaigns which covers the rainy and dry seasons .This indicates that the recharge from meteoric water that reach the aquifers is somewhat limited due to the aridity and the little annual precipitation which characterizes the study area.

The areal distribution of TDS and the major ions show a central zone of lower solute content compared to the areas to the north and south and in the sea water zone. This can highlight both the rock/water interaction as well as sea water intrusion.

The correlation coefficients between TDS and different ions and between different ion pairs in the four trips shows the highest correlation of TDS with Na^{+}, Cl^{-}, Mg^{+2}, Ca^{+2}, indicating their strong associations in salinity evolution. The following ion pairs are strongly correlated (Na^{+} vs. Cl^{-}), (Mg^{+2} vs. Cl^{-}), (Ca^{+2} vs. Cl^{-}), (Ca^{+2} vs. Mg^{+2}), (Ca^{+2} vs. Na^{+}), (Mg^{+2} vs. Na^{+}) indicating that they are related to the same sources and their salts characterize the composition of the study samples.

The dominant sequence of ionic order and water types shows that the major cation sequence is $Na^{+}>Ca^{+2}>Mg^{+2}$ for all the samples, the anionic order is on the other hand dominated by $Cl^{-} >SO_4^{-2} > HCO_3^{-}$ for about 98% of the total samples while the remaining samples have the anionic order $SO_4^{-2} > Cl^{-} > HCO_3^{-}$. The water type is accordingly Cl^{-}- Na^{+} and to a very little extent SO_4^{-2}- Na^{+}.

Different methods of graphical representation of analysis have been proposed to detect and identify mixing of waters of different composition and to identify some of the chemical processes that may take place as natural water circulates. The distribution of the water points on Piper Diagram indicates that the hydrochemical facies are ($SO_4^{-2} + Cl^{-}$ / $Ca^{+2} + Mg^{+2}$) or ($SO_4^{-2} + Cl^{-}$ / Na^{+}) which indicates that the groundwater samples of alluvial aquifers in the study area have meteoric origin of mineralization, that is possibly infiltration of pure meteoric water affected by salinization processes (leaching, dissolution and cation exchange).

The expression of the ionic relationships in terms of mathematical ratios (hydrochemical coefficients) have been calculated as a quite helpful tool in establishing chemical similarities among waters extracted from a single aquifer and also useful in detecting sources of groundwater salinity or mixing with other water recourses. The following ionic ratios (Na^+/Cl^-, (Cl^- Na^+)/ Cl^-, Ca^+/Mg^+, SO_4^{-2}/ Cl^-, Ca^+/ Cl^-, Ca^+/ SO_4^{-2}, Mg^+/ Cl^-, Cl^-/HCO_3^-, (Na^+-Cl^-)/ SO_4^{-2},) have been calculated for the collected samples in the four sampling campaigns, The mean values and ranges of variations of the indicated ionic ratios are compared with the corresponding values in seawater and rainwater. There is a greet deal of match between the mean ionic ratios in the four sampling campaigns reflecting the homogeneity of recharge source and salinization mechanism.

The Na/Cl ratio reflects the combination of both halite dissolution , ion exchange and inverse ion exchange for salt modification . The Ca/Mg ratio shows the salinity evolution trends in the study area are related to dissolution of carbonate rocks dominated by calcite and dolomite. The Mg/Cl ratio shows that more than 90% of the samples are located above the seawater composition line indicating the presence of another source of Mg^{+2} rather than seawater such as magnesite and hydromagnesite, the hydroxide brucite and dolomite, which exist in sedimentary rocks. The (rCa^{+2}/rCl^-) ratio may indicate some marine development of the original meteoric water .The rSO_4^{-2}/rCl indicates the effects of a local terrestrial source of sulfate such as gypsum, anhydrite and glauberite (NA_2SO_4. $10H_2O$). The $rCl^-/rHCO_3^-$ ratio suggests that the original meteoric water recharging the aquifer is modified through processes increasing the chloride or decreasing the bicarbonate. This could be resulted from seawater intrusion or washout of sea spray or marine salts or precipitation of carbonate minerals, and this will be verified through the next relation.

The distributions of the points compared with the mixing trends (TDS/ major ions) of sea water and rainwater shows generally dismatch indicating that

mixing with seawater, if present, is not effective in the mineralization of the studied groundwater. The dissolution of marine salts is more possible.

The groundwater samples of the alluvial aquifer are under saturated with respect to anhydrite, gypsum, halite, where their saturation indices always show negative values, meaning that this water are still capable of dissolving much more of these minerals. On the other hand, the groundwater samples are supersaturated with respect to calcite and dolomite with saturation indices having positive values reflecting its potential precipitation to these minerals.

Chapter (4)

Environmental Isotopes in Hydrology

The results of isotopic investigation are based on the analyses of oxygen18 and deuterium for three sampling campaigns, the tritium content of selected samples as well as radiocarbon age determination of two samples.

The ranges of variation of O-18 and D are relatively wide and show some differences between different sampling campaigns while the mean values are on the other hand comparable. This indicates that the recharge sources are similar as a whole in the study area while their contribution in the different samples is variant and the mean values dampens all these variations.

The relationship between oxygen-18 and deuterium as well as d-excess values indicates that the major source of groundwater recharge in the study area is the rainfall that has been affected by evaporation prior to recharge. This rainfall is related to different moisture sources and storm trajectories (i.e. east Mediterranean and Indian Ocean) as well as catchment altitudes. Some indications exist that paleowater of different meteoric cycle may reach the aquifer through fractures or joints from deep aquifers or from other aquifers in contact.

The areal distribution of Oxygen-18 and deuterium are to great extent match able. These generally show a central zone of highest depletion surrounded by more enriched values all the way around and toward sea water zones; this may reflect a case of sea water intrusion.

The extreme O-18 depletion of some samples, the low tritium content and the non modern C-14 ages emphasize the presence of paleometeoric component of recharge and/ or rainfall at high altitude catchment with retarded flow system. Sea water contribution to recharge is not excluded and may affect the zones that lie close to the coast; this can be attributed to groundwater over pumping that causes decrease in the water level.

The O-18 vs. TDS relationship does not show a well defined pattern where different processes contribute in salinity evolution of the study groundwater. These are separated into evaporation that tends to increase O-18 with the increase with TDS, leaching and dissolution that increase the salinity with a wide range with no increase in O-18, the mixing of different waters including sea water leads to a wide range of O-18 with TDS in the range of mixing sources.

Chapter (5)

Water Quality Criteria

According to standards for drinking water, it is indicated that all water samples representing the area of study are unsuitable for human drinking because of its high salinity and major ions .All the groundwater in the study area is suitable for consumption by different livestock and poultry. According to the hardness classification, all groundwater are unsuitable for laundry uses because they have very hard class.

The groundwater samples of the area under study for the four sampling campaigns were plotted on Wilcox diagram which represents the relation

between sodium percent and electrical conductivity or the total dissolved salts, it is noticed that all water samples are unsuitable for irrigation because all the points are located out the diagram. The SAR vs Electrical conductivity relationship revealed that about 10% of groundwater samples are considered to be very high salinity water for irrigation purposes (C4 class) while the remaining samples are out of range.