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Geophysical and geochemical studies to delineate seawater intrusion in Bagoush area, Northwestern coast, Egypt

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ABSTRACT

Coastal aquifers are the main source for sustainable freshwater in many arid and semi-arid regions around the earth. In such regions, groundwater extraction far exceeds the natural replenishment rates due to additional demands on groundwater resources especially in the last few decades. The characterization of the seawater intrusion in the Baghoush area along the northwestern coast of Egypt assesses the risk of seawater intrusion for the purpose of managing the groundwater resources in coastal areas. The (SI) in the oolitic Pleistocene aquifer is affected by several natural factors, including the drainage patterns, geological structures, distance from the sea and the manipulation of groundwater. Electrical Resistivity Tomography (ERT) has been implemented to identify the geometry of the brackish/saline water interface and to map the distribution of brackish water zone floating over the denser saline water. Seven 2-D resistivity imaging profiles were conducted using a Wenner array with different electrode distance spacings. The inverse resistivity models of these profiles indicate that these profiles are composed of three zones: the upper dry zone, the middle brackish water zone, and the lower saline water zone. The thickness of the brackish groundwater zone decreases toward the sea and the resistivity decreases with depth due to increase in water salinity. Water table along these profiles decreases from south to north, which indicates that groundwater flow is from south (inland) to north (sea). Groundwater chemistry and stable isotopes were used to determine the fresh groundwater recharge source(s), to identify mixing of different groundwaters, to evaluate seawater intrusion zone along the coast, and to investigate the upwelling of deep saline groundwater underneath the brackish zone. The recharge of fresh groundwater originates from the mountain watershed located upstream as well as the annual rainfall; however, seawater is the main source of groundwater salinization. The estimated mixing ratios between the fresh groundwater recharge to seawater ranges between 32% and 75% groundwater to 68% and 25% seawater. The outcomes of this study emphasize the importance of closely monitoring groundwater management to limit upwelling of the underlying salt-water into the overlying groundwater along the coast to limit further seawater intrusion.

1. Introduction

Contamination of freshwater bodies caused by saltwater intrusion is a global issue affecting water quality near the coast. The coastal areas along the Northwestern coast of Egypt are of great environmental, economic, social and cultural relevance. Therefore, the implementation of sustainable monitoring and protection actions is fundamental for their preservation and for assuring the future use of these resources. Such actions have to be based on preserving coastal environmental integrity and planning sustainable water resources. In arid regions, the deterioration of freshwater resources in coastal aquifers threatens the sustainability of the fresh water supply in coastal societies and their economic

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development (Eissa et al., 2013a, b). Freshwater resources in such arid coastal aquifers are vulnerable to degradation due to: (i) its close proximity to seawater, (ii) scarce subsurface recharge and annual precipitation and, (iii) the sensitivity of fresh groundwater floating over deep saline water, due to pumping induces.

In recent years, many research studies have been carried out across the globe to better understand the mechanisms of groundwater recharge sources, thickness and spatial distributions of fresh or brackish water as well as developing strategies to control groundwater salinization processes (Eissa et al., 2016 and Isawi et al., 2016). Groundwater in the oolitic limestone aquifer occurs in porous media under uncoffining conditions (Hammad, 1972). In the northwestern coast, the freshwater zone in the oolitic aquifer overlies the saline water bodies into the fractured Miocene aquifer (Massoud et al., 2015). The groundwater close to the coast in the oolitic aquifer shows a relatively high salinity due to seawater intrusion (Atwia and Masoud, 2013) as a result of groundwater over exploitation in the northwestern coast (Eissa et al., 2015a; Embaby and Shanab, 2012). In order to manage groundwater pumping withdrawal in a sustainable way, the thickness of the fresh/brackish groundwater lens should be evaluated and the recharge sources should be determined. Hydrogeochemistry, Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT) have been widely applied in the coastal area to map the seawater/freshwater interface (Kouzana et al., 2010; Zarroca et al., 2011; Perttu et al., 2011; Atwia and Massoud, 2013; Eissa et al., 2015b). In this study, ERT, hydrogeochemistry and multi isotopes have been implemented to identify the geometry of the brackish/saline water interface and to map the distribution of the brackish water zone floating over the denser saline water. ERT was employed in this study because it represents an optimal tool for better reconstructing the geometry of the seawater intrusion and mapping the areas characterized by a high level of groundwater salinization (Barker, 1980; McNew and Arav, 1995; Satriani et al., 2011) where the presence of seawater strongly reduces the resistivity values. Groundwater chemistry and both stable and radioactive isotopes were used to determine the main sources for groundwater recharge in the oolitic Pleistocene and Miocene aquifers.

2. Geology, geomorphology and hydrogeology

The investigated area falls within the northwestern coastal plain of the Mediterranean Region of Northern Egypt, which is bounded by latitudes 31.10° and 31.20° and longitudes 27.58° and 27.70° (Fig. 1). The study area is underlain by rocks ranging in age from Tertiary to Quaternary (CONOCO, 1987). The study is characterized by four geomorphic units (Fig. 2): coastal plain, pediment plain, structural plain and hydrographic basins (Hammad, 1972; Misak, 1974; Raslan, 1995). The coastal plain stretches adjacent to the present Mediterranean shoreline and comprises three coastal ridges enclosing three depressions including the coastal plain (El Shamy, 1968). The structural plateau is located in the southern portion and acts as the major catchment area feeding the drainage basins during winter (Shata, 1957). The area is characterized by an arid climate, with hot and dry summer, moderate temperature and considerably short rainfall storms during winter season. The rainy season is from October until January (Atwa, 1979; Raslan, 1995), where the average annual rainfall (1958–1993) is about 155 mm/year for the northwestern coast (Ali et al., 2007). Runoff occasionally occurs in the lower part of the main watershed and on their benches which consist of low permeable massive calcareous crust. The area of study is comprised of two main aquifer systems that belong to the Quaternary (Pleistocene) and the Tertiary (Miocene). The Pleistocene aquifer (oolitic limestone aquifer) is composed of oolitic limestone interbedded with sandstone and clay in the lower part. The aquifer has a wide distribution in the region, and is considered to be the most important aquifer dominating the whole coastal strip (Hammad, 1972). The oolitic limestone extends southward from the coastal line for about 4 km inland in the Baghoush area. Groundwater generally flows from South to North with the general slope of the ground surface (Morad et al., 2014). The groundwater salinity in the oolitic aquifer ranges widely from fresh to brackish due to the low recharge, over-pumping and sea water intrusion (Shaaban, 2001; Yousif and Bubenzer, 2013). The Pliocene rocks in the study area occur as a thin layer of clay, limestone and marl of low permeability and act as confining bed (Soliman, 2005; Hammad, 1966). The Tertiary aquifer (fissured limestone aquifer) is composed of limestone of Miocene age with few clay intercalations (Said, 1962). Groundwater occurs in two forms: shallow groundwater (perched groundwater) and deep groundwater (Rizk, 1982). Rainwater that percolates through joints and fractures as well as primary porosity is the main source of recharge of this aquifer. Perched aquifer exists in the form of water accumulated above the clay layers or lenses formed in the area. On the other hand, deep groundwater is formed when the rainwater is accumulated in the fractures and fissures of the limestone rock. The limestone aquifer is generally a low potential aquifer and salinity ranges from fairly fresh to hyper saline water.

3. Materials and methods

3.1. Two-dimensional resistivity imaging technique (2-D)

Geophysical techniques are considered rapid, less expensive and less time-consuming in the field of groundwater exploration and in investigating environmental and engineering problems. To achieve the main target of this work, Electrical Resistivity Tomography (ERT), including two-dimensional resistivity imaging technique (2-D), was used to accurately determine depth to water (water table), thickness of the brackish water zone and the depth of brackish/saline water interface which will be used as input data in the modeling process. This technique was widely used to study groundwater occurrences in karstified/fractured limestone aquifers and shallow limestone coastal aquifers because of the huge contrast in resistivities between the saturated zone and the dry zone (Ioannis et al., 2002; Koukadaki et al., 2007; Cimino et al., 2008; Kouzana et al., 2010; Satriani et al., 2011; Tanguy et al., 2011; Van Dam et al., 2014; Tassy et al., 2014; Mahmoud et al., 2015).

The acquired data includes seven 2-D resistivity imaging profiles. These profiles extend from north to south and are perpendicular to the Mediterranean Sea, except for profile G-G′ which run in the east-west direction (Fig. 3a,b). The field measurements of these 2-D resistivity profiles were made by applying Wenner alpha configuration using Resistivity-meter SYSCAL JUNIOR Switch-72 with multi-Electrodes system. Wenner array is an attractive choice due to its high signal strength and better signal to noise ratio and is also useful if a good vertical resolution is required. The field survey technique was carried out by a system where 72 steel electrodes are arranged along a line with constant electrode spacing (a-spacing) at the same data points while increasing this space by a multiplying factor (2, 3, 4, etc …) to increase depth of investigation along the profile (Fig. 3a,b). In this work, a-spacing was selected to reach the required depth of investigation as it is based on all available information about depth to water and ground elevation. These a-spacings were 1 m and 2 m in the northern part of the study area where groundwater exists at shallow depths from the ground surface (profiles B-B′, A-A′ and E-E′ respectively). Whereas, it was 5 m and 7 m in the southern part of the study area where the depth to water and ground elevation are increased towards this direction (Profiles C-C′, D-D′, F-F′ and G-G′ respectively).