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Recharge sources and geochemical evolution of groundwater in the Quaternary aquifer at Atfih area, the northeastern Nile Valley, Egypt

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ABSTRACT

This study addresses the topic of recharge sources and evolution of groundwater in the Atfih area situated in the northeastern part of the Nile Valley, Egypt. Inventory of water wells and collection of groundwater and surface water samples have been achieved. Water samples are analyzed for major ions according to the American Society for Testing and Materials and for the environmental isotopes analysis (oxygen-18 and deuterium) by using a Triple Liquid Isotopic Water Analyzer (Los Gatos). The groundwater is available from the Quaternary aquifer formed mainly of graded sand and gravel interbedded with clay lenses. The hydrogeologic, hydrogeochemical and isotopic investigations indicate the hydrodynamic nature of the aquifer, where different flow paths, recharge sources and evolution mechanisms are distinguished. The directions of groundwater flow are from E, W and S directions suggesting the contribution from Nile River, the Eocene aquifer and the Nile basin, respectively. The groundwater altitudes range from 13 m (MSL) to 44 m (MSL). The hydraulic gradient varies between 0.025 and 0.0015. The groundwater is alkaline (pH > 7) and has salinity ranging from fresh to brackish water (TDS between 528 mg/l and 6070 mg/l). The observed wide range in the ionic composition and water types reflects the effect of different environmental and geological conditions through which the water has flowed. The isotopic compositions of groundwater samples vary between −14.13‰ and +23.56 for δD and between -2.91‰ and +3.10 for $\delta^{18}O$. The isotopic data indicates that the Quaternary aquifer receive recharge from different sources including the Recent Nile water, surplus irrigation water, old Nile water before the construction of Aswan High Dam, surface runoff of local rains and Eocene aquifer. Evaporation, water rock interaction and mixing between different types of waters are the main processes in the groundwater evolution. Major suggestions are presented to develop the aquifer productivity and to mitigate the deterioration of groundwater quality.

1. Introduction

Egypt, a country lying in North Africa, within the Sahara-Arabia-Iran-Thar desert belt is dominated by arid to hyperarid climatic conditions, with scanty rainfall and high evaporations rates (DRC, 2005). Despite the existence of ample water from the Nile River, Egypt suffers from problems of water deficiency. According to the Nile Water International agreement ratified in 1959, the amount of Nile water assigned to Egypt is about 55.5 billion m^3/year (Elnashar, 2014). Till to the present day this amount of water is as is, although there has been a steady increase in population over the years. Therefore, the need to augment the water resources with groundwater becomes necessary to face the growing population demand for water such as in agricultural production for food security, industrial and economic development.

Great efforts have been directed towards the development of new groundwater resources in many parts in Egypt in the last four decades. One of those parts is the Atfih study area situated in the northeastern Nile Valley in Upper Egypt. The groundwater in this area, beside that from the Nile water, is for domestic, agriculture and industrial purposes. The groundwater is available from the Quaternary aquifer, which is part of the great Nile Basin. Today, the demand for groundwater has increased due to the expansion in land reclamation projects for agriculture in the fringes of the desert in that area.

To rely on the groundwater resources, a rational approach including periodic hydrogeological, hydrogeochemical and isotopic

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investigations should be used to understand the groundwater system complexity including groundwater recharge sources and modification. Data and information on groundwater recharge, evolution and quality are necessary for the optimal utilization and sustainable management of groundwater resources (Liu et al., 2016; Besser et al., 2017). The recharge is one of the major components of the groundwater system and has a strong relationship with quality and quantity of available water. The groundwater recharge is affected by the climatic conditions (such as precipitation and air temperature), mean annual runoff, soil characteristics, infiltration rates and the grain size of aquifer materials (Nolan et al., 2007; El Gayar and Hamed, 2018). In addition, the surface and subsurface structural setting influence greatly the recharge process. Fault planes represent favorable routes for groundwater movement, either upward or downward in an aquifer system. Natural and anthropogenic activities causing the groundwater evolution and deterioration are other important considerations that should be known and understood when studying an aquifer (Edmunds et al., 2006).

Determining the groundwater recharge sources and identification of its evolution using the traditional hydrogeological and hydrochemical tools is affected by the methodological difficulties associated with explanation and evaluation processes (Hough and Jones, 1998; Yeh et al., 2004). Therefore, the use of environmental isotopes comes as an additional tool to confirm results from traditional tools and leads to a better understanding of groundwater system (IAEA, 1980; Craig et al., 2002; Kendall et al., 1995c; Chen et al., 2011; Ayadi et al., 2017). Of these isotopes, oxygen-18 and deuterium are used widely as groundwater tracers because of their high conservative nature. The oxygen-18 and deuterium isotopes are important tools in solving many hydrogeologic issues related to origin of water, recharge ability of aquifers, the hydraulic connection between different aquifers and interconnection between aquifers and surface water bodies (Clark and Fritz, 1997; Awad et al., 1997; Hamed et al., 2010, 2014; Liu et al., 2016; Mokadem et al., 2016).

In the Atfih area, the hydrogeological investigations carried out previously were limited, and there is little up to date information regarding recharge and evolution of groundwater in this region in literature. Fiad (1996) and Korany et al. (1997a) suggested that the Quaternary aquifer in the Atfih area was partially recharged from surface runoff during occasional rainstorms in winter. Korany et al. (1997b) referred to two main problems facing the groundwater development in the area, the decline in piezometric heads and the increase in salinity of the groundwater. Helaly (1996) pointed out that the movement of groundwater in the Quaternary aquifer in the Atfih area is from west to east, the groundwater was more in the western parts compared to the eastern areas. Ahmed (1999) evaluated the groundwater for different uses in the northern part of the Nile Valley and presented an overview of groundwater recharge and evolution. Abdel Moneam (2016) pointed out to the possibility of groundwater recharge from the high accumulation of surface water in the Wadi El Atfihy basin.

This paper presents a recent hydrogeologic, hydrogeochemical and isotopic assessment of the Quaternary aquifer in the Atfih area, Northeastern Nile Valley, Egypt. The main aim is to identify the groundwater flow patterns, recharge sources and groundwater evolution using the piezometric surface contour maps for the aquifer, major element groundwater geochemistry and stable isotope (^{18}O and ^{2}H) analysis. The findings of this study are useful for the sustainable groundwater exploitation and management of the Atfih aquifer.

2. Geological and hydrogeologic setting

The Atfih area belongs to the Giza Governorate in Egypt located to the east of the Nile River between latitudes 29° 21′ 00″ and 29° 31′ 00″ N and longitudes 31° 13′ 00″ and 31° 20′ 00″ E, occupying an area of about 300 km^2 (Fig. 1). The area lies within the arid zone of Egypt, characterized by dry hot summers and relatively warm winters. The annual means of daily air temperature, relative humidity and amount of precipitation are 20 °C, 55% and 15 mm, respectively (EMA, 1996). The evaporation rates are high attaining 11.65 mm/day (Korany et al., 1997a).

The landscape in the study area forms two main geomorphologic units (Fig. 1), the fluviatile plain and the structural plateau (Said, 1962, 1981). The fluviatile plain comprises young and old alluvial plains. The young alluvial plain dominating the western part of the study area is flat with an average elevation of about 25 m (above mean sea level) covered by a thin silty clay layer cut by a number of irrigation canals (such as Brumbulia) and some drains parallel to the Nile River. The old alluvial plain is located to the east of the young plain and forms several terraces. The surface is underlain by a mixture of sand and gravel and rises to about 60 m (on average). The accumulation of these deposits is controlled by NW oriented fault systems (Said, 1981). Recently, this plain has been reclaimed for agriculture and is characterized by a topography of gentle rolling sand plains with a general slope eastwards towards the young alluvial plain cut by the El-Saff canal that is almost runs parallel to the Nile River.

The structural plateau (Gebel El-Galaa El Baharia) located to the east of the old alluvial plain is overlain by Tertiary carbonaceous rocks and rises to about 130 m (on average) above mean sea level. The plateau is cut by a complex network of drainage basins (such as Wadi Rishrash and Wadi El Atfihy) that end westwards in the fluviatile plain. In winter, these drainage basins receive water from occasional heavy showers resulting in short term flash floods. The surface runoff represents a source of recharge of the groundwater aquifers in the area (Korany et al., 1997a).

The regional geology of the northern Nile Valley, in which the study area lies, was the subject of several researches among them Attia (1954); Said (1962, 1981); Soliman and Korany (1980); Strougo (1985); Saleh (1990); Fiad (1996). On a local scale, the surface and subsurface geologic features of the Atfih area are described in Said (1981, 1990); CONOCO (1987); El-Sayed (1993); Korany et al. (1997a,b). Briefly, Quaternary and Tertiary sedimentary rocks undelie the area. The Quaternary sediments cover much of the study area and comprise of the Nile silt, Wadi deposits and fanglomerates. The Tertiary deposits are the Pliocene and Eocene rock units exposed in the eastern and southern parts of the study area. The Pliocene rocks comprise undifferentiated sedimentary deposits including units of Kom El Shelul Formation (Fig. 2). The Eocene rocks, underlying the Pliocene Units, comprise the following lithostratigraphic units: the Maadi Formation, the Mokattam Group and the Beni Suef Formation. Details on the lithologic types in these formations are shown in Fig. 2.

The Eocene rocks unconformably overlie the Upper Cretaceous rocks represented from top to bottom as follows: Chalky limestones of the Khoman Formation layers of shale, siltstone, limestone with sandstone beds of the Abu Roash Formation, and sandstone with minor shale and siltstone beds of the Baharia Formation. These deposits overlie the Kharita Formation of Albian age comprising sandstone with siltstone interbeds, which is in turn overlies the Cambrian basement (Schlumberger, 1984; Abd El-Aal et al., 2015).

As regards the structural makeup of Egypt, six major plate tectonic movements created six regional tectonic deformational systems (Abu El-Ata, 1988). These tectonics movements developed the present day structural features of Egypt. These tectonic movements are:

1) The Pre-Cambrian-Early Paleozoic movement, which created the Meridian Folding System,