Integrated resistivity and water chemistry for evaluation of groundwater quality of the Gulf of Aqaba coastal area in Saudi Arabia

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ABSTRACT: The most productive lands in the coastal area of Saudi Gulf of Aqaba lie in Wadi Humeidah, where irrigation relies predominantly on groundwater. Crop yields have been lately reduced due to increased salinity of groundwater and have led to abandonment of some wells adjacent to the Gulf area. Geophysical and geochemical investigations were combined to assess seawater-contaminated zones in the shallow coastal groundwater aquifer and to identify subsurface geologic formation. The prevalence of Ca²⁺, Na⁺, Cl⁻ and SO₄²⁻ suggests that weathering of surrounding rocks is potentially the major source of ions. Characterization of aquifer conditions up to a depth of 60 m showed that the groundwater aquifer is composed of three zones with vertically different resistivity values. The surface layer with resistivity of 30–1000 ohm-m, represents the alluvial sand and gravel. The second layer with lower resistivity values ranging from 0.6 to 70 ohm-m, indicates saline-to-brackish-to-slightly fresh water saturated rocks. The third layer extending up to a depth of 60 m is dominated by resistivity values of several hundred to several thousand ohm-meters, reflecting the basement rocks. While the groundwater is generally brackish, the salinity content varied spatially with TDS values that decreased in the northeast direction. The variations in TDS are related to multiple sources and primarily dependent on dissolution of salt-bearing sediments, exploitation rate, over-irrigation with salty water, aquifer-bearing strata and the location of wells. Groundwater aquifers in the vicinity of the coastline were found to have been impacted by saline water. The central east area has a type of groundwater that is relatively less brackish.

Key words: electrical conductivity, salinity, Wenner-Schlumberger electrical array, Gulf of Aqaba coast, Saudi Arabia

1. INTRODUCTION

The coastal groundwater aquifers are inevitably vulnerable to saltwater intrusion, which is the major cause of groundwater pollution in these regions (Al-Agha and El-Nakhal, 2004; Batayneh, 2006; Batayneh, 2007; Silva-Filho et al., 2009; Batayneh et al., 2010; Mondal et al., 2010; Nwankwoala and Udom, 2011; Batayneh, 2013). The extent of saline water intrusion is influenced by the nature of geological settings, hydraulic gradient, rate of groundwater withdrawal and its recharge, and the local hydrologic conditions (Choudhury et al., 2001; Melloul and Collin, 2006; Lee and Song, 2007; Mondal et al., 2008; Kim et al., 2009; Batayneh et al., 2013).

Groundwater accounts for a significant portion of water supply in Saudi Arabia and groundwater development has drastically increased in recent years (Batayneh et al., 2012a). According to Saudi Ministry of Water and Electricity, the annual water consumption in 2012 was 17,000 million m³, of which 50% came from water desalination, 45% from groundwater wells and 5% from dams. Agriculture is the primary consumer of water resources with 82% of the total groundwater use. The industrial and domestic uses account for 5% and 13% of the groundwater resources, respectively. The increased reliance on groundwater resources triggered by rapid economic growth, particularly oil industry, has further lowered water table and deteriorated water quality throughout the country.

The study area, Wadi Humeidah, located along the eastern coast of Saudi Gulf of Aqaba, has experienced growing demands for water in response to the rapid population growth and the increasing number of tourists, mainly during summer season. In addition to reduction in quantity of groundwater, the major groundwater resources issue in the Saudi Gulf of Aqaba is changes in groundwater quality, particularly due to salinization, where the content of dissolved minerals restricts the usability of groundwater. Agriculture is the main land-use activity in the vicinity of the shoreline and is largely dependent on groundwater for irrigation (~98%). Vegetables, fruits and crop yields have been lately reduced due to increased salinity of groundwater. This has also led to abandonment of some wells adjacent to the Gulf area (Batayneh et al., 2012a; Batayneh et al., 2012b). Preventive management tools for protecting groundwater resources is of vital importance in this region, and the knowledge of groundwater improves the effective utilization and sustainable management of these resources, particularly as the groundwater is the principal source of drinking and irrigation water.

Despite the importance of groundwater in the Gulf of Aqaba coast, nothing is known about the natural processes that govern the chemical composition of the groundwater. This study attempts to characterize the source of groundwater chemistry and relate chemical profile to geology. The main processes governing the quality and composition of groundwater aquifer system are also assessed. In addition,
two-dimensional resistivity surveys were conducted and combined with hydrogeological data for better understanding of the groundwater conditions, subsurface lithology and the distribution of groundwater salinity in the coastal aquifers of the Gulf of Aqaba.

2. GENERAL BACKGROUND

The NNW-SSE oriented Red Sea zone is about 1930 km long and 270 km wide. In the north, the Red Sea splits into the western shallow Gulf of Suez and the eastern deep Gulf of Aqaba. The Gulf of Aqaba (Fig. 1) is located between 27°30′–29°N and 34°30′–35°E and is characterized by subtropical arid conditions. It is about 180 km long and 25 km wide with a maximum depth of about 1830 m (Morcos, 1970; Hall, 1975; Maillard and Soliman, 1986; Fahmy, 2003). The marine environment in the Gulf area is surrounded by the African-Arabian deserts with extremely high temperature and low precipitation. These conditions have led to the evolution of unique, and internationally important, coral reef and marine ecosystems, which are particularly susceptible to damage from pollution and other forms of environmental degradation (Assaf and Kessler, 1976). The Gulf of Aqaba also provides an important source of economic activities in terms of sea transportation, tourism development and other industrial activities along the coastal areas.

A regional scale geological map (1:250,000 scale) for the northwestern Saudi Arabia has initially been prepared by Clark (1986). Later, other geological studies have been reported (Hughes et al., 1999; Hughes and Johnson, 2005). According to these studies the Oligocene conglomerates and sandstones of the Sharik Formation (Ts) (which is the main aquifer of groundwater and an abundant source of iron oxides) are the oldest sedimentary rocks in the area and unconformably overlie the Proterozoic basement (Fig. 1). The Sharik Formation is unconformably overlain by deep marine Musayr Formation (Trm) (Early Miocene age), which is composed of sandstone, conglomerate, limestone, shale, and gypsum (undifferentiated). The Musayr Formation is then overlain by Middle Miocene marine mudstones, carbonates and evaporates (undifferen-

![Geological map of the study area (after Clark, 1986). The locations of groundwater boreholes (W1-W10) and resistivity profiles (L1-L8) are also shown.](image-url)