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Hydrochemical processes regulating groundwater quality in the coastal plain of Al Musanaah, Sultanate of Oman

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ABSTRACT

The Al Batinah coastal aquifer is the principal source of water in northwestern Oman. The rainfall in the Jabal Al Akhdar mountain region recharges the plain with freshwater that allowed agricultural and industrial activities to develop. The over-exploitation of this aquifer since the 1970s for municipal, agricultural and industrial purposes, excessive use of fertilizers in agriculture and leakage from septic tanks led to the deterioration of groundwater quality. The objective of this study was to investigate the hydrochemical processes regulating the groundwater quality in the southwestern section of Al Batinah. From available data collected during the spring of 2010 from 58 wells located in Al Musanaah wilayat, it was determined that the groundwater salinity increased in the direction from the south to the north following the regional flow direction. In addition to salinisation, the groundwater in the upstream and intermediate regions was contaminated with nitrate, while groundwater in the downstream region was affected by fluoride. Calculations of ionic ratios and seawater fraction indicated that seawater intrusion was not dominant in the study area. The primary factors controlling the groundwater chemistry in Al Musanaah appear to be halite dissolution, reverse ion exchange with clay material and anthropogenic pollutants.

1. Introduction

Groundwater is often the only source of freshwater in many coastal towns and cities located in arid and semi-arid regions. The rapid growth of population in these areas enhanced groundwater salinity through over-exploitation of this resource for domestic, municipal, agricultural and industrial purposes (Nowroozi et al., 1999; Cheng and Ouazar, 2004; Mhamdi et al., 2006; Mondal et al., 2011). Additionally, the expansion of agricultural areas and the excessive use of nitrogen-based fertilizers induced an increase in the nitrate content of the aquifers (Kim et al., 2003). Leakage from septic tanks and sewage systems can also be major sources of nitrate pollution (Robertson et al., 1991; Kaçarogolu and Günay, 1997).

The origin of groundwater salinisation in coastal regions has been investigated using a variety of approaches. For example, Kouzana et al. (2009) studied the salinisation expansion in the aquifer of Korba in Tunisia using measurements of major ions and a statistical approach. In that country, Charfi et al. (2013) used isotopic characterisation and multivariate statistical methods to identify geochemical processes that control water chemistry in the Grombalia aquifer system. Circulation of groundwater was studied in the marine Jeffara aquifer using specific electrical conductance (Agoubi et al., 2013). Jamrah et al. (2008) used the DRASTIC index method in a GIS environment to assess groundwater vulnerability in the Barka area, Oman. In this area, the chemical constituents originating from saline water sources, reverse ion exchange and mineral dissolution were successfully differentiated using ionic delta (Rajmohan et al., 2009). A similar approach was used to analyse the dynamics of the freshwater/seawater interface in the Sadras coastal aquifer, India (Mondal et al., 2010). Osman et al. (2010) applied geophysical methods to estimate the rate of seawater intrusion in the Al Khabourah region, Oman. Recently, modelling approaches were used to investigate the dynamic of the freshwater/seawater interface under different boundary conditions. Kacimov et al. (2009) used the SUTRA model to analyse freshwater/seawater interaction in the Al Batinah region, Oman. In that country, Shammas (2007) used MODFLOW to investigate seawater intrusion in the Salalah coastal aquifer.

Recently, groundwater contamination by nitrate has been reported in many coastal aquifers all over the world (Eichler and Schulz, 1998; Laegreid et al., 1999; Thorburn et al., 2003). This problem was studied using different methods. Hajhamad and Almasri (2009) developed a lamped-parameter model to simulate nitrate concentration in the groundwater of Gaza City and Jabalia

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Camp. To confirm the influence of anthropogenic activities on the Sines coastal aquifer in southwestern Portugal, Fernandes et al. (2008) used chemical measurements and principal component analysis. Katz et al. (2011) used Cl/Br ratios and other indicators to assess the potential impact on groundwater quality from septic systems in the United States of America. Zghibi et al. (2013) assessed the effects of seawater intrusion and nitrate contamination on groundwater quality in the Korba coastal plain using hydrogeochemical measurements, seawater fraction and NO_3/Cl ratios.

Groundwater contamination by seawater intrusion and nitrate is a major problem in the coastal aquifers of Oman, especially due to over-pumping and excessive use of fertilizers for agriculture (Zekri, 2009; MAF and ICBA, 2012). Consequently, several farms near the coast were abandoned due to high groundwater salinity (Rajmohan et al., 2009). The Al Batinah coastal region provides a good example of these problems. It has been used for agriculture since the 1970s, and thus groundwater was considered as the main agricultural water resource. In this region, agriculture is based on intensive irrigation and fertilization to improve crop production. Thus, the objective of this study was to investigate the hydrochemical processes regulating groundwater quality in the southeastern section of Al Batinah using conventional multivariate statistical methods, molar ratios and ionic deltas.

2. Methods

2.1. Study area

The study area, encompassing an area of 200 km^2, lies between 57°11′36″ and 57°14′12″E Longitude and 23°35′30″ and 23°37′24″N Latitude (Fig. 1). It is situated in northern part of the Al Musanaah wilayat at approximately 80 km northwest of Muscat City, Oman. The Gulf of Oman constitutes a natural border in the north, while the piedmont of the Jabal Al Akhdar mountain lies to the south, which serves as a recharge zone for the study area. The elevation in the study area ranges from 24 m above sea level to zero at the sea, and higher elevations are observed in the south. Three ephemeral wadis exist in this area, and flow towards the coast.

Generally, Al Musanaah has a dry climate with high rates of evapotranspiration and low rainfall (approximately 65 mm/year). However, high rainfall was recorded at the Jabal Al Akhdar mountain (>300 mm/year in the elevation higher than 2000 m a.m.s.l) (Weyhenmeyer et al., 2002). Rainfall takes place mostly during the cool winter months from December to February. During the summer months from May to July, the weather is hot, with temperatures up to 48 °C.

Geologically, the study area lies in the southern part of the Al Batinah coastal plain. The catchment can be subdivided into upper mountains and lower alluvium plains, and this area is located in the lower catchment. The Quaternary-aged alluvium and Neogene-aged Upper Fars Group, with a total thickness of approximately 650 m, are the main geological units in the study area (Ashworth, 2006) (Fig. 2). These two geological units are significant for groundwater availability because all of the wells in the coastal plain obtain water mostly from the alluvium aquifer. The Quaternary alluvium is formed by the weathered products of limestone and ophiolite and is composed of loose gravels interbedded with clay. The thickness of this layer reaches a maximum of 300 m. The alluvium aquifer has horizontal transmissivity values within the range of 0.9–16,900 m^2/day. The lowest horizontal transmissivity was associated with cemented, clayey sands, while the highest values were associated with uncemented sands and gravels. The Fars Group, underlying the alluvium formation, can be divided into three main formations, viz., the Upper Fars Formation, Middle Fars Formation, and Lower Fars Formation. The Upper Fars is composed of cemented gravels/conglomerates interbedded with brown and pink dolomitic and chalky limestone, clay, and silt, and the thickness of this layer varies between 565 and 582 m. For the Upper Fars, the horizontal transmissivity varies from 17 to 468 m^2/day. The Middle Fars Formation is composed of clay–stone interbedded with thin cemented gravels, and the thickness of this formation reaches up to 146 m. The Lower Fars Formation is composed of calcareous shale interbedded with silty limestone, and the thickness of this formation ranges between 8 and 133 m.

The alluvium and Upper Fars aquifers are considered as a single hydrogeological unit under water table conditions with two layers: the alluvium layer (Layer 1) and the Upper Fars layer (Layer 2). The

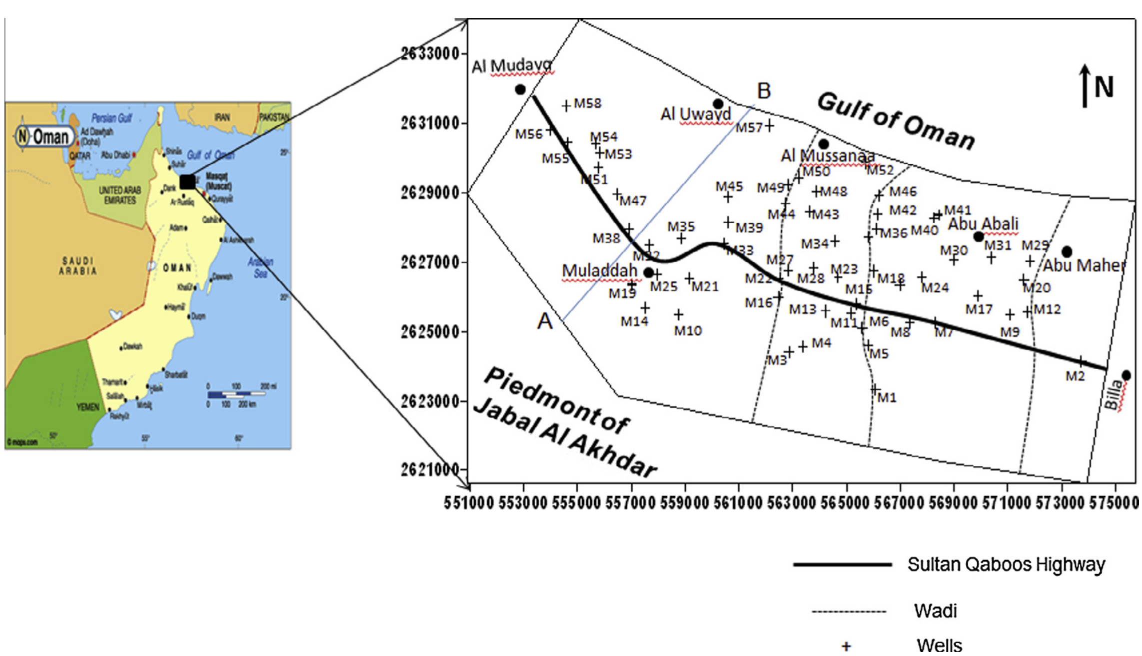

Fig. 1. Map shows the location of monitoring wells. Line A–B is cross section explained in Fig. 2.