Status of Quaternary aquifer sustainability at Umm Ghafa area, eastern part of Al-Ain area, UAE

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Abstract The Quaternary aquifer of the Umm Ghafa area, located in the eastern part of the Al-Ain area of southeast UAE, is facing a serious threat that might harm the sustainability of the aquifer. Groundwater sustainability in the region has been reduced and deteriorated. There are many natural and human factors affecting the quality and quantity of the groundwater. These factors include agriculture practices, weathering of the Oman Mountains, dissolution of carbonate rocks that exist in the study area, and atmospheric precipitation stored on the surface. Groundwater salinity is observed and high salinity in groundwater may be attributed to the evaporation of return flow and heavy groundwater abstraction for agricultural activities. In addition, high groundwater salinity may result from upward discharge of underlying brine as groundwater moves downgradient. The feasibility of agricultural activities is observed from high concentrations of nitrates in groundwater. Contamination chromium in the study area was noticed and exceeded the limit of WHO. The main reason for high chromium concentration in groundwater is weathering of pyroxenes and olivines of the Oman Mountains.

Key words aquifer; sustainability; groundwater; UAE; evaporation; weathering

INTRODUCTION

Freshwater and its availability have become one of the important issues in arid countries, and in particular in the United Arab Emirates (UAE), due to the sharp increase of water for different uses. Freshwater resources have been severely affected by many sources of pollution, including sewage system, industries waste, deforestation, and poor agricultural practices. Management and preventive schemes for contaminated water are important to overcome the deterioration of water resources. Alternative sources of freshwater such as desalination, harvesting rainwater, re-using and recycling water are developed. Water resources constitute important elements for the sustainable development in UAE. The conventional water resources in the study area can be grouped into two major sources: groundwater and surface water. The groundwater is mainly encountered in Quaternary aquifers, while surface water is encountered in the falajes such as falaj Saau. Most of the water demand for agriculture in the Al-Ain area is met by groundwater from the aquifer, which is considered the main source groundwater in this area.

Umm Ghafa area lies in the eastern part of Al-Ain city and represents one of the rapidly urbanizing areas. Since the 1980s this area has been considered as the main resource of freshwater for the centre of Al-Ain city, but at present the Al-Ain Distribution Company is responsible for supplying water to the area. Due to the expansion in development activities, groundwater is severely over-pumped in the Umm Ghafa area. Signs of groundwater depletion and salinity increase were noticed in the last few years. Moreover, agricultural activities on the land are enhancing contamination of this shallow aquifer via infiltration through the sandy soil. The main purpose of this study is to assess the quality of groundwater using a chemical analyses approach. The physio-chemical characteristics of the groundwater of the Quaternary aquifer at the study area were studied to determine the groundwater quality.

In general, the agricultural activity is intense in the study area, with heavy groundwater extraction being pumped from numerous wells. The increase of salinity of some wells in the area is probably related to the agricultural activity and intrusion from the bottom aquifer. The historical data obtained from Al-Ain Municipality, Agriculture Department, showed that the quality of groundwater in the study area has deteriorated during the period 2002–2006. The average salinity
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of groundwater in the study has been doubled and changed from 494 mg/L in 2002 to 832 mg/L in 2006. The pH of groundwater has been changed slightly from 8.5 in 2000 to 7.9 in 2006 (Al-Ain Municipality, 2008).

STUDY AREA

Al-Ain area lies east of Abu Dhabi Emirate, near the border with the Sultanate of Oman and on the western margin of the northern Oman Mountains. It is one of the largest and most ancient oases of the Arabian Peninsula due to a plentiful supply of fresh groundwater from the Oman Mountains in the east. Umm Ghafa is located southeast of Al-Ain city (Fig. 1).

The geological elements comprise geomorphology, stratigraphy, geometry and distribution of geologic units, along with the structural deformation affecting the hydrogeology of these geological units. The geomorphology of the Al-Ain area includes mountains, gravel plains, sand dunes, interdune areas, and inland sabkhas (Hunting Geology and Geophysics Ltd, 1979; Abou El-Enin, 1993; Al-Shamsei, 1993; Garmoon, 1996; Baghdady, 1998; El-Saiy, 2002). Jabal Hafit is the most prominent feature of the Al-Ain area and a Tertiary anticlinal structure plunging southeasternly in Oman and northwesterly in the UAE. The rocks forming Jabal Hafit are mainly composed of limestone, marls and dolomite limestone (Hunting Geology and Geophysics Ltd, 1979; Abou El-Enin, 1993; El-Saiy, 2002). Two gravel plains terminate the eastern part of the Al-Ain area; one fringes the Oman Mountains and the second fringes Jabal Hafit (Hunting Geology and Geophysics Ltd, 1979). The main features of these gravel plains are low-relief piedmonts that slope gently westward away from the western margin of the Oman Mountains. The Al-Ain area is exposed by a rock sequence ranging from Cretaceous to Quaternary (Fig. 2). Umm Ghafa is a large (15 km) and prominent piedmont situated east and southeast of the city of Al-Ain in the Al Jaww Plain between the Oman mountains and Jabal Hafit. It consists of gently inclining gravelly materials transported by wadis, dissecting the northern Oman Mountains. This area is transversed by numerous wadis.
such as Wadi Shik, Al-Ain, and Muraykhat. Three alluvial fans within this area; namely: the Zarub fan in the north, the Moundassah fan in the middle, and the Ajran fan in the south (Al-Shamsei, 1993). This area is mostly covered with the Quaternary deposits. The sediments types in the study are broadly contemporaneous and represent different facies of deposits being formed by present-day process (Hunting Geology and Geophysics Ltd, 1979).

RESULTS AND DISCUSSIONS

All chemical analyses were carried out at the Central Laboratories Unit (CLU), UAE University. The sampling of groundwater was started in June 2005. Thirty one samples were collected from active wells in the study area (Fig. 3). Moreover, one sample of the commonly-used fertilizer (manure) was analysed for comparison purposes. Before sampling, stagnant water in the pipes of the wells was emptied. Field and laboratory measurements were carried out for the collected
groundwater samples from the area of study. Field analyses were made for the pH and EC (electrical conductivity). Two bottles from each well were collected for major anions, major cations and trace elements. The other parameters were analysed at the Central Laboratories Unit (CLU), UAE University; they were stored at 4°C and protected against the light. Nitric acid (HNO₃) was added to the collected samples to achieve a pH of <2 for major cation and trace metal analyses.

Field and laboratory measurements were conducted for collected groundwater samples to meet the objectives of this study. The physical properties must suit the groundwater in the study area. Three parameters are generally used in the preliminary assessment of groundwater quality. These parameters include pH, total dissolved solids (TDS) and electrical conductivity (EC). The groundwater samples of the Quaternary aquifer have pH values ranging from 6.5 to 8, with an average value of 7. There is no specific trend for the pH patterns in the study area, and these patterns have irregular distribution but do not completely match with the water salinity. The pH values are inversely proportional to the salinity content. However, relatively low pH values were
observed along the rest of the area. The measurements of EC values of groundwater were generally below 2500 µmhos/cm, except well no. 16, which had 10 230 µmhos/cm. The high EC values of groundwater in the Umm Ghafa area might be attributed to the evaporation of return flow for agriculture activities and to reduction in the head due to heavy groundwater abstraction that causes water from underlying formations to enter the aquifer. However, the range of TDS in groundwater samples is from 284 to 5660 mg/L. It was observed that the highest TDS values are associated with samples located within the cultivated area (Fig. 4). Therefore, high salinity of groundwater might be ascribed to the evaporation of return flow and heavy groundwater abstraction for agricultural activities. In addition to that, mixing with saline water of geothermal wells at Jabal Hafit and Ain Al Fayada to the west of the study area might affect the salinity of groundwater in the area.

![Fig. 4 Distribution of total dissolved solids (mg/L) distribution in the study area.](image)

The chemical concentration of ions is affected by the type and amount of soluble products of rock and decomposition. The parameters that best relate to the major constituents of a water are potassium (K⁺), sodium (Na⁺), magnesium (Mg²⁺), calcium (Ca²⁺), chloride (Cl⁻), sulphate (SO₄⁻²), and nitrate (NO₃⁻) (Davis & DeWeist, 1966). The major cations of groundwater samples have the following order: Na⁺ > Ca²⁺ > Mg²⁺ > K⁺. However, the sequence of the major anions in the groundwater of the Quaternary aquifer at the study area has the order of Cl⁻ > SO₄⁻² > NO₃⁻.

The groundwater samples collected from the study area has sodium concentration in the range of 15 to 381 mg/L. It is observed that the concentration of sodium increases from southeast to northwest and from south to north due to the agriculture activity and weathering of the Oman Mountains in the north. One of the main sources of sodium is weathering of plagioclase feldspars minerals (Davis & DeWeist, 1966) which are more abundant in the Oman Mountains. The calcium
ion concentration in groundwater samples ranges from 8.7 to 732 mg/L. The concentration of Ca\(^{2+}\) increases gradually from the southeast to the northwest. The concentration of calcium in the east and the centre is less than 500 mg/L. High calcium concentration is encountered in the northwest of Jabal Hafit, mainly due to the dissolution of carbonate rocks of the Jabal Hafit and the calcite cement in the alluvial gravels. In addition, as the recharged water moves from Oman Mountains to the discharge area in the Jabal Hafit, the concentration of calcium will increase as the distance from recharge increases. This increase of calcium concentration is observed in the contour maps (Fig. 5).

![Fig. 5 Distribution of the calcium concentration (mg/L) in the study area.](image)

Generally, the concentration of magnesium ion (Mg\(^{2+}\)) in the freshwater is less than calcium due to the low geochemical abundance of magnesium (Mathess, 1982). The concentration of Mg\(^{2+}\) in groundwater ranges from 9.22 to 185 mg/L. The maximum Mg\(^{2+}\) concentration presents on the western side of Jabal Hafit and is related to the weathering of the olivines and pyroxenes of the ophiolite clasts in the alluvial fan. Also, few wells of high Mg\(^{2+}\) concentrations are located in the southern part of the study area and are related to the agriculture activity. However, potassium can be introduced to the groundwater from the igneous rocks as feldspars and sedimentary rocks as silicate and clay minerals (Hem, 1989). The concentration of K\(^+\) in groundwater ranges from 3.37 to 39.6 mg/L. Generally, the availability of potassium is low in the study area, but high
concentrations are recognized in cultivated areas in the south of the study area.

Gypsum (CaSO\textsubscript{4}\cdot2H\textsubscript{2}O) and anhydrite (CaSO\textsubscript{4}) are examples of sedimentary rocks, which are releasing sulphate (SO\textsubscript{4}\textsuperscript{2-}) to the groundwater. Sulphides minerals are in contact with water which is oxidized to yield sulphate. Also, other sources of sulphate (SO\textsubscript{4}\textsuperscript{2-}) comes from breakdown of the soil and fertilizers (Davis & DeWeist, 1966). The concentration of (SO\textsubscript{4}\textsuperscript{2-}) in groundwater ranges from 53.8 to 1715 mg/L (Fig. 6). Most of the study area is characterized by high sulphate concentration of <459 mg/L, while high concentrations are recognized in the south of the area and this might be due to agricultural practices in the area.

![Fig. 6 Distribution of the SO\textsubscript{4}\textsuperscript{2-} concentration (mg/l) in collected groundwater samples from the study area.](image)

The distribution of chloride in natural water is wide. There are many sources of chloride in water. These sources include ancient seawater entrapped in sediment, halite, evaporite deposits and dry fallout from the atmosphere, especially in the arid region (Davis & DeWeist, 1966). The highest concentrations of Cl\textsuperscript{-} in groundwater of the study area are recognized in the south of the study area and this might due to agriculture activities of the region and also might be related to the fertilizers that are used for agricultural practices. Some of the fertilizers used in the region are chlorinated disinfectant such as dursban and traxc. The values of the chloride in the study area range from 0.19 to 2490 mg/L. Also, most of the study area has showed an excess of chloride, which clearly indicates multiple sources of chloride.

The availability of nitrates (NO\textsubscript{3}\textsuperscript{-}) in groundwater originates from several natural and from human activities. The maximum limit of nitrate concentrations in drinking water is not excess of 10 mg/L according to the World Health Organization (WHO) (2004). The effect of agricultural activities is observed in high concentration of NO\textsubscript{3}\textsuperscript{-}, which varies from 2.55 mg/L in the west of the study area, to 108 mg/L in the north (Fig. 7). The increase of nitrate concentrations is to
Fig. 7 Distribution of the nitrate concentration (mg/L) in collected groundwater samples from the study area.

Fig. 8 Distribution of the chromium concentration (mg/L) in collected groundwater samples from the study area.
the north of the study area with the direction of groundwater flow in the region. In addition, nitrate could be released to the environment through atmospheric precipitation stored on the surface waiting for a recharge event.

Serious hazards affect human health if high concentrations of trace metals are present in groundwater. Groundwater samples collected from the study area were analysed for several trace metals (Mn, Cu, Fe, F, Pb, B, Ba, Sr, Al, Cr and Zn), but there were no significant values observed, except chromium, which could affect human health and the groundwater. The availability of chromium in groundwater originates from several natural and from human activities. The WHO maximum limit of chromium concentrations in drinking water is 0.05 mg/L (WHO, 2004). Figure 8 shows the distribution of chromium concentrations in groundwater. The concentration of chromium varies from 0.0004 mg/L in the centre of the study area to 0.148 mg/L in the north. The increase of chromium concentrations to the north of the study area is due to weathering of olivine and pyroxene of Oman Mountain in the north and might be possibly due to using the manure for agriculture activities. One sample of manure was analysed and showed that the chromium concentration is 0.18 mg/kg.

CONCLUSION

The Quaternary aquifer in the Al-Ain region is facing huge stress from urbanization and population growth. Groundwater of this aquifer in the eastern part of Al-Ain area was assessed using a chemical approach. The chemical assessment of groundwater showed that there are many factors affecting groundwater quality in the region that could affect the sustainability of groundwater. These factors include: evaporation of return flow, heavy groundwater abstraction for agriculture activities, and the natural location of the country in the arid zone environment. The upward discharge of underlying brines as groundwater moves downgradient could increase groundwater salinity. Contamination of chromium in the study area is observed due to the weathering of pyroxenes and olivines of the Oman Mountains.

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REFERENCES