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Desalination of brackish groundwater in Zahedan city in Iran

G.R. Lashkaripour[a]*, M. Zivdar[b]

[a]*Department of Geology, University of Sistan and Baluchestan, Zahedan, 98135, Iran*
Tel. ??; Fax ?? email: Lashkarg@hamoon.usb.ac.ir
[b]*Department of Chemical Engineering, University of Sistan and Baluchestan, Zahedan, 98164, Iran*

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Abstract

Zahedan city lies in one of the most arid areas in southeastern Iran. As the capital of Sistan and Baluchestan province it has grown and urbanized rapidly with a population of over 600,000. All water consumption needs are met by groundwater. In recent years, groundwater has been abstracted from the aquifer at a faster rate than the recharge because of extremely low rainfall, rapid development of the city and high population growth rate, resulting in gradual depletion of storage. The result is a continuous decline in the groundwater levels and deterioration in quality. Consequently, Zahedan is the only city in Iran with two separate pipeline systems for drinking and household requirements due to the increasing salinity of the groundwater aquifer. About 50% of fresh water is imported by tanker from Ladiz village about 100 km southeast of the city and then pumped into the pipeline system that provides drinking water at 13 public stations. Shortage of drinking water has caused interest in developing non-conventional options, including desalination of brackish groundwater and a water import project. From the beginning of 2003, three small reverse osmosis desalination units have gone into operation for desalination of brackish groundwater to provide a part of the drinking water requirements.

Keywords: Reverse osmosis; Zahedan; Electrodialysis

1. Introduction

A major reason for the growth of desalination is the water scarcity faced in many countries. Desalination of brackish and seawater is expanding rapidly to support urban and industrial development in arid, semi-arid and coastal areas, and in some situations it is very cost effective. In 2000 more than 120 countries in all regions of the world were using 16,000 desalination units with an installed capacity of more than 26 MCM/d [1]. The number of desalination plants in 1960 was five units with a total production rate of 5,000 m^3/d [2].

The desalination industry is a lifeline for several countries and regions around the world with limited supplies of fresh water. The Middle East countries, mainly the six Gulf Cooperation

*Corresponding author.

Council (GCC) members, are the biggest users of desalination technology with more than 50% of the world's capacity. In these countries, arid climate combined with high population growth caused water scarcity at levels much below 1500 m/cap set by the United Nations as the minimum for sustainability [1].

Groundwater aquifers are major sources of water in most of the Middle East countries such as Iran, Saudi Arabia, Bahrain, Qatar, Kuwait and UAE [3]. However, water is the most important and binding constraint for any future development in this region [4]. These countries that have exploited their limited natural water resources and have no more sources to develop, have turned to desalination.

2. Zahedan groundwater conditions

Zahedan is located in one of the most arid areas of Iran, close to the border with Pakistan. The city has expanded rapidly on the unconfined Zahedan aquifer. This aquifer, with limited quantities of fresh groundwater, is the sole source of water supply for agricultural, domestic, industrial and part of the drinking water. The aquifer, with an area of about 120 km^2, occupies the northern portion of Zahedan watershed. The salinity of the groundwater has increased in recent decades due to low rate of recharge, rapid development of the city and very high population growth rate.

The area under study has an arid climate with extremely low rainfall, averaging 94 mm/y. Potential evaporation averages approximately 2,800 mm/y [5]. The scanty rainfall is confined to the winter season and rain usually occurs as thunderstorms and showers. The Zahedan aquifer is the major exploited aquifer in this region; it is an alluvial deposit aquifer. The groundwater of the Zahedan aquifer is brackish, with an average total dissolved solids of 2,930 mg/l.

The aquifer is mainly recharged from the annual rainfall, and is discharged artificially through a number of dug wells. It is also discharged naturally by underflow to the Lar River. The renewable resources are very limited due to the limited recharge, and water is being abstracted from the aquifer at a faster rate than the recharge, resulting in gradual depletion of the groundwater storage. The monitoring of groundwater level shows decreasing water levels. The main cause of dropping of the groundwater table is attributed to water wells that are pumping out water from groundwater resources at a rate exceeding the natural recharge in recent years.

Growing populations, combined with a rising standard of living have increased the demand for water in this area, where water is scarce. The scarcity of conventional fresh water supplies implies a serious threat to sustainable and balanced socio-economic growth and development.

3. Desalination of brackish groundwater

Brackish groundwater is considered to be the sole natural water resource in the study area. Desalination of brackish groundwater in this region has a great potential with respect to the availability of the resource. Suitability of brackish groundwater quality for reverse osmosis (RO) desalination is reported by different researchers [6–9]. Due to the current low price of brackish water desalination, there is a growing interest in arid countries [8,10,11].

The limited natural groundwater resources in the study area have been exploited and therefore with no more sources to develop, it is logical to turn to desalination. It is also important to note that desalination offers a solution to the problem of providing drinking water that is now transported from long distance with high costs. At present, in order to produce fresh water for drinking purposes, three small reverse osmosis (RO) units using brackish groundwater are in operation.

4. Reverse osmosis system

Reverse osmosis was initially looked upon as a process for the demineralization of seawater and brackish water to produce fresh water for municipal and industrial purposes. High costs associated with demineralization of seawater have so far prevented large-scale application. Distillation still has the competitive edge for large plants. However, the lower Total Dissolved Solids (TDS) of brackish water has permitted broad use of RO particularly for small plants. The two leading membrane processes used for desalination of brackish water are RO and electrodialysis (ED). The salt passage from ED plants is much higher than that from RO. It is apparent that RO treated waters can meet drinking-water standards of less 500 ppm TDS even with a feed-water TDS of 7000 ppm. The ED plants were not normally successful in producing water of less than 500 ppm TDS [9].

The encouraging results of RO desalination and great improvements in membrane materials and equipment, have led to wide use of this method to desalinate brackish water in arid areas of the world. RO desalination is also a suitable method for small mobile plants and it is a cheaper method for desalination of brackish water. Unit product cost has been reduced dramatically over the past two decades. During the 1980's unit cost varied between \$3–5/m^3. Currently, the unit product cost is reported between \$0.5–1.3/m^3 [2]. However, RO is not generally favored, especially in locations which have high temperatures of up to 40°C, high salinity levels, high silt density, high bacteria activity and high pollution, since these require complex pretreatment [3].

5. Discussion

Rapid growth in both population and water demand with little recharge have strained Zahedan groundwater resources, resulting in serious decline in water level. Consequently, the quality of the Zahedan groundwater resource deteriorated sharply in recent years. The quality has shown a downward movement during this period. For example, the average value of total dissolved solids (TDS) rose to 36,35 ppm from 2,299 ppm, and electrical conductivity (EC) rose to 5,370 μmhos/cm from 3,537 μmhos/cm[5].

Zahedan is the only city in Iran having two separate pipeline systems for drinking and household requirements due to increasing salinity of the groundwater aquifer in the last decade.

Zahedan has experienced considerable population growth. The population increased greatly, from 38,976 in 1966 to 419,518 in 1996 [12] and over 600,000 in the year 2003, which makes it the fastest growing city in Iran.

This city has been facing a serious shortage for several years and supplies water by exploiting poor renewable resources. The gap between supply and demand causes planners to follow two major strategic directions: (1) importing fresh water from external sources, (2) developing unconventional water resources such as desalination of brackish groundwater.

At present, about 50% of drinking water is imported by tanker from Ladiz village about 100 km east of the city. Moreover, a great federal project by the Ministry of Power is under construction for importing drinking water. This project will transfer fresh water from Chah-Nemah reservoir to Zahedan city by a 193 km pipeline. This reservoir is fed by the Hirmand river which originates from the Hendokosh mountains in the east of Afghanistan. Therefore, it is important to take into account risks due to instability in the neighboring country. Upon completion of this project in the near future in the end of the year 2003, the majority of Zahedan Water's customers will begin receiving fresh water.

Shortage of drinking water in the city also caused planners to turn to desalination of brackish groundwater, which suffered serious depletion and deterioration, to cover some of its needs. It is important to note that desalination offers a solution

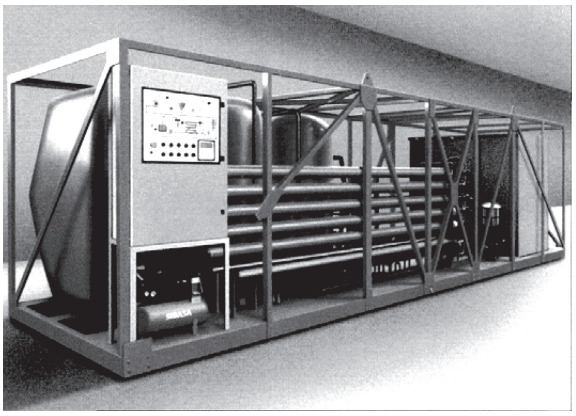

Fig. 1. One of the RO units manufactured by Avab Sanat Co.

to the problem of providing drinking water without necessitating transport from long distances at high costs. At present, in order to produce fresh water for drinking purposes in the city, three small RO units manufactured in Iran, are in operation for desalinating brackish groundwater. Fig. 1 shows one of the RO units with a capacity of up to 1,920 m^3/d.

Produced water is within the limits specified by the World Health Organization (WHO). The average chemical analysis of the brackish groundwater which feeds the units and the quality of the desalinated water produced is shown in Table 1.

Many experts believe that in the short term the drinking water problem in the city can be resolved by desalination of brackish groundwater, and the long term water crisis can be resolved by transporting water from external sources.

6. Conclusions

Water plays a vital role in the development of any activity in the region. Today Zahedan city as an arid area suffers from a water shortage due to rapid population growth, improvement of life-style, increasing economic activities, increasing human intervention in the environment and poor water management. City population expansion has tremendously increased the pressure on the Zahedan aquifer which suffered serious depletion and deterioration. However, the renewable resources are very limited due to the limited recharge. Water is being abstracted from groundwater resource at a faster rate than the recharge, resulting in a continuous decline in the groundwater levels and quality deterioration. This situation has prompted a search for new and unconventional sources including large-scale water transfer from Chah-Nemah reservoir and water desalination.

Table 1
Chemical analysis of brackish and desalinated waters

Test	Brackish water	Desalinated water
EC, μmhos/cm	5400	270
pH	6.8	6.3
TDS, mg/l	2930	140
TH as $CaCO_3$, mg/l	740	25
Ca, mg/l	128	4
Mg, mg/l	100.8	3.4
Na, mg/l	883.2	48.3
K, mg/l	25.35	1.17
Cl, mg/l	781	31.95
SO_4, mg/l	1080	52.8
NH_3, mg/l	1.22	0.2562
NO_3, mg/l	63.8	8.36
NO_2, mg/l	0.0132	0.0099
PO_4, mg/l	0.08	0
Fe, mg/l	0.02	0.02
Mn, mg/l	0.064	0.027
F, mg/l	0.58	0.13

This paper has presented an overview of groundwater conditions and desalination of brackish groundwater in this city. Many studies have shown that fresh water shortages in the region are increasing rapidly. The scarcity of conventional fresh water supplies is a serious threat to sustainable growth and development in the region. Desalination of brackish groundwater may become a competitive potential water resource to meet potable water demand.

The water quality of the Zahedan aquifer is considered chemically suitable for RO treatment technique. In conclusion, it can be stated that RO

desalination method due to the technological advances in membrane manufacture and high efficiency energy recovery equipment is one of the alternatives and must be considered the short term solution of drinking water in this city due to cost reduction.

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