ABSTRACT

Groundwater is a very important resource, particularly in arid regions. In Makkah, which is the religious capital of the kingdom, water supply is provided from the aquifers of many valleys inside and around it and from the desalination plant in Jeddah. In this paper, the chemical and bacteriological water qualities of different resources of groundwater in Makkah were evaluated. The results of the chemical and bacteriological parameters were compared with the Saudi Arabian Specifications and Measurements Agency and with the United State Environmental Protection Agency (USEPA) standard in order to determine the suitability of these water resources for drinking. The paper depicted the contamination sources of each location and studied the quality of each well by periodic examinations and described the deviation in the quality of groundwater with time.

Keywords: Groundwater, Makkah, Water quality, Contamination, periodic examination, Wells, chemical analysis, bacteriological examination; Water samples.

1. INTRODUCTION

Makkah is the Holiest City of the Islamic world. It has the Grand Mosque of Harm. Makkah is located in the western region of Kingdom of Saudi Arabia (K.S.A.). It is the intersection of latitude 21° 25’ north and Longitude 39° 49’ east. The two main sources of water in Makkah City are desalination water and groundwater. Desalination water comes through a pipeline from a desalination plant in Jeddah City 85 kilometers from Makkah City. Groundwater is obtained by digging and pumping from wells in different valleys around and inside Makkah City. Zamazam is the name of the historical well that provides billions of people with water throughout history, especially during the Hajj pilgrimage. The well is still the main source of drinking water for people in Makkah City.
Due to the increase of human water requirements for drinking, irrigation, and industry, and the physical limitation of fresh water resources, the use of other water resources are very important. Groundwater is a very important resource, particularly in arid regions like Makkah City.

There are many valleys that supply Makkah city with groundwater. Ibrahim valley Basin extends from the northeast of Makkah city and there is water recharges divide at the pilgrimage parking in Al-Shrayia area. This divide separates Ibrahim valley and Urnah Valley. Urnah Valley Basin abuts Ibrahim Valley on the northeast, east, and southeast boundaries. In the north and east directions, these two valleys meet each other at the water divide. Noman Valley and Fatimah Valley are the major valleys in western Saudi Arabia. Both of these valleys are located near the pilgrims' areas, and the Holy City of Makkah.

The main objective of this paper is to evaluate the chemical, and bacteriological water quality for the 58 wells in three locations inside Makkah City (Al-Shraiya, Al-Omrah, and Al-Kakiah) and another three locations around Makkah (Al-Qushashiyah, Noman Valley and Bany Omair). Also, this study aims to compare the results of the chemical and bacteriological parameters with the Saudi Arabian Specification and Measurements Agency and with the United States Environmental Protection Agency Standard to ascertain the suitability of the water for drinking. Also, it aims to depict the contamination sources of each location and study the water quality of each well by periodic examinations and describe the deviation in the water quality with time.

2. METHODOLOGY

Five areas were selected for water sampling, two areas inside Makkah and another around it. The two areas inside Makkah are Al-Shraiya and Al-Omrah. The three areas around Makkah are Al-Qushashiyah, Noman valley and Bany Omair. Bany Omair is situated on the way between Al-Jamom and Al-Zimah, about 60 km from Makkah. Al-Qushashiyah is located beside Al-Jamom, about 45 km from Makkah. A list of wells number in each location is shown in Table 1. Figure 1 represents the wells locations.

<table>
<thead>
<tr>
<th>Well Location</th>
<th>Al-Shraiya</th>
<th>Al-Omrah</th>
<th>Al-Qushashiyah</th>
<th>Noman Valley</th>
<th>Bany Omair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>

At each well location, four tasks were performed. First, samples for field water quality determination were carefully obtained. Second, the field tests for water quality were performed on the sample. Third, the groundwater samples for laboratory analyses were obtained. Finally, the laboratory water quality assessments were performed on each sample. The water samples were collected every three months from July 2002 to July 2004.
3. RESULTS AND ANALYSIS

3.1 Existing Case

Water samples were collected from existing water wells following strict standard procedures. The chemical analysis and bacteriological examination were carried out for all collected water samples. Samples were analyzed for major anions and major cations and heavy metals. They were used to determine the water quality and identify suitable uses for these water resources. As the chemical characteristics tend to be more specific in nature than the physical characteristics, so they are the most useful in the evaluation of the water quality. After the chemical and bacteriological examination, the water was observed to have the following characteristics.

3.1.1 pH

The pH ranged from 7.1 to 8.3, which shows that it is to slightly the alkaline side. The pH of raw water used for public water supplies is important because such water can be corrosive and adversely affect treatment processes. The pH of water applied for irrigation purpose is not so critical because the pH of applied water is rapidly changing to approximately that of the soil. All the pH values were within the Saudi Arabian specification standards (SAS) that require the pH range to be 7.0 – 8.5. Also, all the pH values were within the United States Environmental Protection Agency (USEPA) standard that requires the pH to be in the range of 6.5 – 8.5 for drinking water.

The pH values of the water samples did not exceed 8.3, so it was expected that the water may contain calcium bicarbonate and magnesium bicarbonate. Also, there was a possibility that the water in these wells contains a slight amount of carbonate.
3.1.2 Total Dissolved Solids

Figure 2 represents minimum and maximum concentration of total dissolved solids in each location. The Saudi Arabian Specification and Measurements Agency states that the optimum value for the total dissolved solids (T.D.S.) is 500 mg/l, and the maximum allowable value is 1500 mg/l. Using this standard, all the samples of the locations around Makkah were within the maximum allowable value of the total dissolved solids. The percentages of water samples for Al-Omrah and Al-Shraiya, within the maximum allowable value were 75% and 66.67%, respectively. This would indicate that many of these wells are not suitable to be used as drinking water.

The USEPA maximum allowable value is 500 mg/l. Using this standard, all the water samples of Al-Shraiya exceeded the maximum allowable value. The percentages of water samples that below the maximum allowable value were 60%, 25%, 25%, and 16.67% of the water samples for Al-Qushashiyah, Noman valley, Bany Omair and Al-Omrah locations, respectively.

From the total dissolved solids examination, it was obvious that the total dissolved solids differ from one location to another and from well to well. This is an indication of the difference of the types of soil and rock that the ground water passes through. The total dissolved solids in some wells especially in Al-Shraiya exceeded the maximum allowable value in the Saudi Arabian Specification and Measurements Agency and USEPA limits, which make their use for drinking impossible before removing the exceeding total dissolved solids or dilution with water of low total dissolved solids concentration.

![Figure 2: Minimum and maximum concentration of dissolved solids in each location](image-url)
3.1.3 Electric Conductivity

Saudi Arabian Specifications and Measurements Agency states that the optimum value for the electric conductivity is 800 micro-mohs, and the maximum allowable value is 2300 micro-mohs. Using this standard, all of the wells were above the optimum value except 14.28 and 16.67% of the wells for Al-Omrah and Al-Qushashiyah, respectively. All the samples of locations around Makkah were below the maximum allowable value for electric conductivity. The percentages of wells below the maximum allowable value inside Makkah were 66.67 and 66.67 of the wells for Al-Shraiya and Al-Omrah, respectively. Figure 3 represents the minimum and maximum electric conductivity in each location.

3.1.4 Total Hardness

The SAS states that the maximum allowable value of total hardness concentration for drinking water is 500 mg/l. The percentages of water samples for Noman Valley, Al-Qushashiyah, and Bany Omair, within the maximum allowable value, were 92.86, 90, and 70%, respectively. Figure 4 represents minimum and maximum concentration of total hardness in each location.

![Figure 3: Minimum and maximum Electric conductivity in each location](image.png)
3.1.5 Chloride

The chloride (Cl$^-$) concentration values ranged from 68 mg/l to 630 mg/l. The SAS states that the optimum value of the concentration of chloride for drinking water is 200 mg/l and the maximum allowable value is 600 mg/l. Using this standard, the water samples of all locations were within the maximum allowable value of the chloride except 16.67% of samples of Al-Shraiya. The USEPA states that the maximum allowable value of chloride is 250 mg/l. Using the American standard, all wells of locations around Makkah were below the acceptable value for chloride. The percentages of water samples of Al-Omrah and Al-Shraiya within the American standard were 83.33% and 75%, respectively.

3.1.6 Sulfate

The sulfate concentration (SO$_4^{2-}$) of water samples ranged from 64 mg/l to 302 mg/l. The SAS states that the maximum allowable value of the sulfate concentration for drinking water is 400 mg/l. Using this standard, all samples were below the maximum allowable value. The USEPA states that the maximum allowable value for sulfate is 250 mg/l. Using the American standards, all the samples of Al-Qushashiyah and Noman valley were below the maximum allowable value of sulfate concentration.

3.1.7 Nitrates and Ammonia

The SAS and the USEPA state that the maximum allowable value for drinking water in term of nitrates is (NO$_3$-N) is 10 mg/l. All of the water samples significantly
exceeded the maximum allowable value of the total nitrate (NO$_3$-N) using either standards except 30% of water samples of Al-Qushashiyah. This means that this water should not be used for drinking purposes before treatment or dilution with water of low nitrate concentration. For long term, drinking with high concentration of nitrate may cause illness in humans, including blue baby syndrome, which affects an infant’s ability to carry oxygen in his blood. Figure 5 represents minimum and maximum concentration of nitrates in each location.

Ammonia (NH$_3$-N) was detected in 33.33, 16.67, and 10% of water samples of Al-Shraiya, Al-Omrah, and Bany Omair locations, respectively at maximum concentration of 0.3 mg/l.

### 3.1.8 Total Alkalinity

The total alkalinity as Hco$_3$ ranged from 72 mg/l to 290 mg/l. The SAS states that the maximum allowable value of the total alkalinity for drinking water is 400 mg/l. All the values of the water samples for total alkalinity of all locations were within the limit.

Results from alkalinity and hardness analysis showed that the hardness high values of some wells were due to the presence of high value of calcium, magnesium, and sodium. These solids were in the form of bicarbonate, chloride and nitrite forms. The calcium hardness represents the highest percentage. Because the total hardness was greater than the total alkalinity the hardness of the water is considered of the permanent type.

![Figure 5: Minimum and maximum concentration of Nitrates in each location](image-url)
3.1.9 Sodium and Potassium

The SAS and USEPA state that the maximum allowable value of sodium ($\text{Na}^+$) is 200 mg/l. Therefore, all the samples of the locations around Makkah were below the maximum allowable value of sodium for drinking water. The percentages of water samples for Al-Omrah, Al-Shraiya within the maximum allowable value were 66.67 and 75 %, respectively.

The SAS states that the optimum allowable value of the potassium ($\text{K}^+$) for drinking water is 30 mg/l and the maximum allowable value is 100 mg/l. All the water samples of all locations were below the optimum allowable value. The USEPA has no recommendation for potassium.

3.1.10 Calcium and Magnesium

The calcium concentration ($\text{Ca}^{2+}$) ranged from 48 mg/l to 725 mg/l. The SAS states that the optimum value for calcium ($\text{Ca}^{2+}$) concentration is 75 mg/l and the maximum allowable value is 200 mg/l. All of the water samples significantly exceeded the maximum allowable value of the calcium concentration except 60% of the water samples of Al-Qushashiyah.

All the water samples of Al-Qushashiyah and Noman valley were below the maximum allowable value. The percentages of the water samples for Bany Omair, Al-Omrah, and Al-Shraiya within the maximum allowable value were 90, 91.67, and 83.33, respectively.

The SAS states that the optimum value for magnesium ($\text{Mg}^{2+}$) is 30 mg/l and the maximum allowable value is 150 mg/l. All the water samples of locations around Makkah were within the optimum allowable value except 20% of the water samples of Bany Omair. While all of the water samples of Bany Omair, and Al-Shraiya were below the maximum allowable value. The percentages of the water samples for Al-Omrah within the maximum allowable value were 83.33%.

3.1.11 Heavy Metals

The SAS and USEPA state that the maximum allowable value of the lead (Pb) for drinking water is 0.01 mg/l. The lead concentration values ranged from 0.002 to 0.009 mg/l. Using either standard all of the water samples of all locations were within the maximum allowable value.

The SAS states that the maximum allowable value of the iron (Fe) concentration for drinking water is 0.1 mg/l. The iron concentration values ranged from 0.01 to 0.08 mg/l. This means that all of the water samples of all locations were below the maximum allowable value.

Cadmium (Cd) was not detected in any of water samples of all locations of the study area.
3.1.12 Dissolved Oxygen

The dissolved oxygen of the water samples ranged from 3.1 mg/l to 5.4 mg/l for all locations. The dissolved oxygen values were not high, which would not cause any problem in terms of metal corrosion. Excess of oxygen increases the rate of metal corrosion that can increase the concentration of iron and other metals in drinking water.

3.1.13 Total Coliform Bacteria

The total coliform bacteria in the water samples ranged from 0/100 ml to 560/100 ml. The preferred value for the total coliform bacteria is 0 – 1 units/100 ml of the water sample as stated in the Saudi Arabian Specification and Measurements. All wells exceeded the maximum allowable value of the total coliform bacteria. The total coliform bacteria were detected in all locations as follows in Table 2:

<table>
<thead>
<tr>
<th>Well Location</th>
<th>Al-Shraiya</th>
<th>Al-Omrah</th>
<th>Al-Qushashiyah</th>
<th>Noman valley</th>
<th>Bany Omair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage (%)</td>
<td>58.33</td>
<td>50</td>
<td>20</td>
<td>14.29</td>
<td>20</td>
</tr>
</tbody>
</table>

From the chemical and bacteriological analysis, it was obvious that the water quality of the locations around Makkah is better than of those locations inside Makkah. The water quality of Al-Qushashiyah and Noman valley is the best one and the water quality of Bany Omair follows it. Then the water quality of Al-Omrah and Al-Shraiya comes in the second category. Chlorination facilities must be used on the wells that exceeded the maximum allowable value of fecal coliform. The chemical and bacteriological results indicate that the present state of the most wells around Makkah is suitable for human consumption after dilution with water or using simple treatment.

3.2 Contaminations Sources

The quality of groundwater of each location was studied according to the periodic follow up to depict the main sources of contamination. The periodic examination of water quality was done every three months from July 2002 to July 2004.

For Al-Shraiya, the percentages of increase of total dissolved solids, electric conductivity (EC), and nitrates concentrations were found 11.5, 8.9, and 14.5% per year, respectively. From Periodic examinations, it was obvious that there is an external source of contamination. Al-Shraiya district has no sewer systems so the wastewater passes directly into the subsurface. Figure 6 shows the changes in ground water quality with time in Al-Shraiya.
For Al-Omrah, the percentages of increase of total dissolved solids, electric conductivity, and nitrates were found 9.1, 7.45, and 12.3% per year, respectively. From Periodic examinations, it is obvious that there was an external source of contamination. Al-Omrah district has no sewer systems so the wastewater passes directly into the subsurface. Figure 7 shows the changes in quality of groundwater with time in Al-Omrah.

For Noman Valley, the percentages of increase of total dissolved solids, electric conductivity, and nitrates concentrations were found 9.7, 8.18, and 5.82% per year,
respectively. From Figure 8, it is clear that there is deterioration in the groundwater quality of Noman valley. This is due to a drop in groundwater table level. The drop of groundwater table level can be attributed to the heavy pumping and low level of annual precipitation in this area.

![Figure 8: Groundwater changes quality with time at Noman Valley](image)

For Al-Qushashiyah, the percentages of increase of total dissolved solids, electric conductivity, and nitrates concentrations were found 5.5, 7.4, and 3.2% per year, respectively. Figure 9 shows there is deterioration in the groundwater quality of Al-Qushashiyah. This is due to the continuous withdrawal of water and the low level of annual precipitation.

![Figure 9: Groundwater quality changes with time at Al-Qushashiyah](image)
For Bany Omair, the percentages of increase of total dissolved solids, electric conductivity, and nitrates concentrations were found 3.9, 3.4, and 2.8% per year, respectively. From Figure 10, it is obvious that there is deterioration in the groundwater quality of Bany Omair. This is due to the continuous withdrawal of water and the low level of annual precipitation.

![Figure 10: Groundwater quality changes with time at Bany Omair](image)

### 4. CONCLUSIONS

The following major conclusions can be drawn from this investigation:

i. The chemical and bacteriological results of quality for the 58 wells indicate that the water quality of Al-Qushashiyah and Noman valley is the best one and the water quality of Bany Omair follows it. Then the water quality of Al-Omrah and Al-Shraiya comes in the second category.

ii. The chemical and bacteriological results indicated that the present state of the most wells locations around Makkah is suitable for human consumption after dilution with water or using simple treatment, while the most wells of Al-Shraiya and Al-Omrah, in its natural state can be utilized for agricultural development and industrial fields.

iii. From periodic examination of water, it was obvious that the quality of ground water of all locations outside Makkah were getting worse from time to time. This is due to the continuous withdrawal of water and the low level of annual precipitation. While, groundwater inside Makkah is vulnerable to contamination due to nitrites from a variety of sources. These sources are the buried livestock and no sewer system for Makkah for a long time.
REFERENCES


