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# Groundwater Chemistry of Wadi Uoranah-Al Abdiah Area, Western Province, Saudi Arabia

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ABSTRACT. Hydrochemical aspects of the alluvial aquifer in Wadi Uoranah-Al Abdiah area are discussed to show the quality and nature of groundwater. By characterizing groundwater types on the basis of major ions chemistry, a reasonable assessment of groundwater quality in relation to use for irrigation purpose has been made. The concentration of nitrogen compounds in the study of the alluvial aquifer in the area ranges from 0.0 to 303 ppm (part per million). The reason for high concentration of nitrogen in the groundwater has been discussed.

## Introduction

The area under consideration is located in the middle part of the Western Province of Saudi Arabia, within the Arabian Shield, between latitudes 21°17′30″ and 21°27′N and longitudes 39°55′ and 40°03′E (Fig. 1). The total catchment area is about 210 km$^2$, this area is about 20 km east of the holy city of Makkah and 40 km west of At-Taif city. About 200 water wells have been drilled in this area. These wells are tapping the water bearing formation which consists mainly of alluvial deposits. The quality of water is generally good for agricultural purposes, but it has been noticed that the salinity of groundwater increases with time. The static water level in most of the water wells decreases with time due to the continuous abstraction from these wells. This area is considered to be one of the most arid region which means that the discharge from the water wells must be controlled, because the average annual precipitation is 88.02 mm (Sharaf 1984).

## General Geology and Hydrogeology

The investigated area lies within the middle western margin of the Arabian Shield in which older metamorphic units are invaded by different younger intrusive units, most of these rocks being particularly covered by alluvial deposits within the valleys.

The main rock units have been recognized in the area under consideration. These are as follows from youngest to oldest:

| *Rock Unit* | *Average Thickness* | *Age* |
|---|---|---|
| Alluvial | 24 m | Quaternary |
| Precambrian | Unknown | Precambrian |

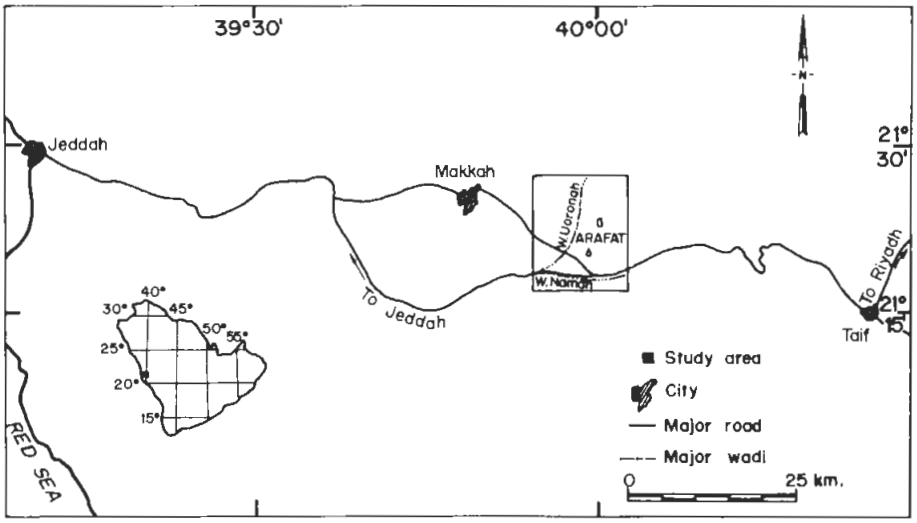


FIG. 1 Location map.

From the hydrogeological view point, the main water bearing formation is the alluvium. In Wadi Uoranah, the direction of groundwater flow takes the same direction of the valley, *i.e.*, from the northeast to the southeast while in Wadi Al Abdiah the groundwater flows from east to west (Fig. 2).

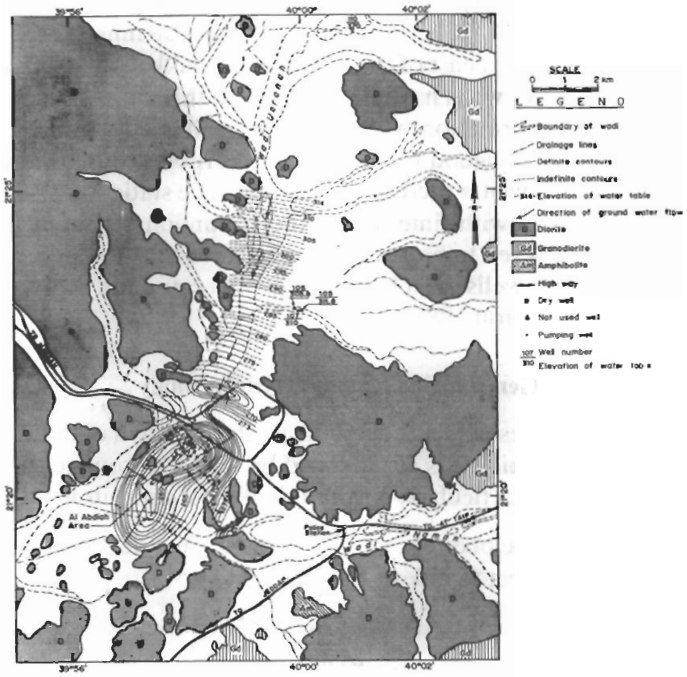


FIG. 2. Groundwater table map of Wadi Uoranah-Al-Abdiah area.

The average hydraulic conductivity of the alluvium aquifer ranges between $2.03\times10^{-3}$ to $1.35\times10^{-2}$ cm/sec, and the transmissibility ranges between 0.028 $cm^2$/sec to 0.10 $cm^2$/sec while the storativity varies between $1.2\times10^{-1}$ to $7.8\times^{-2}$ (Sharaf 1984). These values are indicative of the highly permeable and porous nature of the alluvial indicative of the highly permeable and porous nature of the alluvial sediments.

## Groundwater Chemistry

Groundwater chemistry studies were undertaken as part of a comprehensive study of groundwater of the Wadi Uoranah-Al Abdiah area. The intended hydrochemical approach involved the use of major and minor ions chemistry to provide a broad-based understanding of the hydrochemical facies (types) present. In total, the hydrochemical investigation involved over 60 groundwater samples collected from various productive and domestic pumped wells (Fig. 3). Sampling was carried out between 1981 to 1983 within different seasons. Results of the chemical analysis of representative samples are given in Table 1.

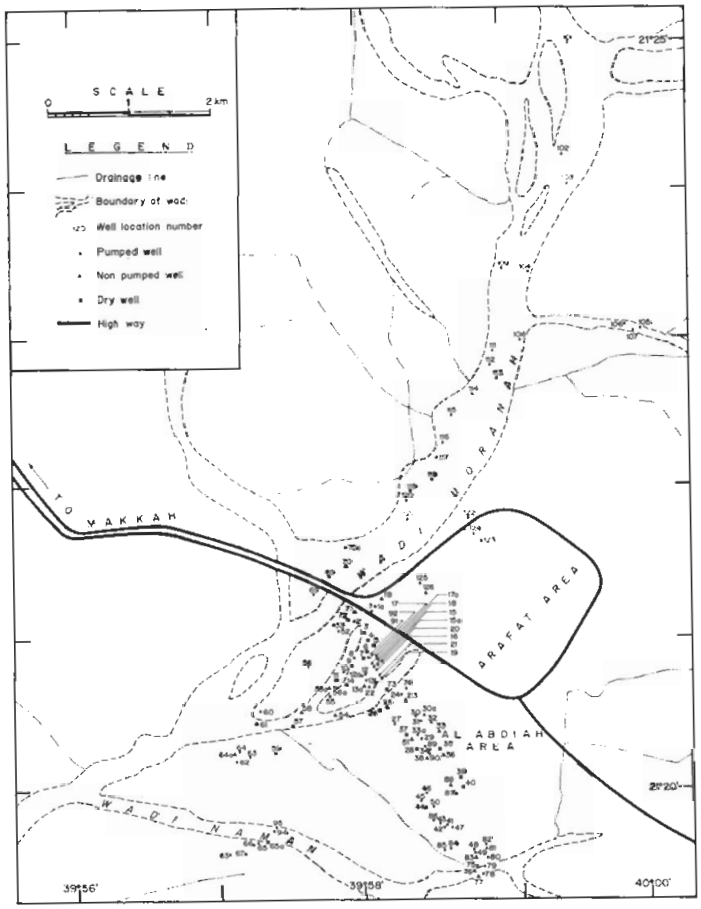


FIG. 3. Well location map.

TABLE 1. Results of the chemical analyses of representative water samples during different seasons in Wadi Uoranah-Al Abdiah area.

| Well No | Collection Date | Units | $Ca^{+2}$ | $Mg^{+2}$ | $Na^{+1}$ | $K^{+1}$ | Total Cations | $HCO_3^{-1}$ | $SO_4^{-2}$ | $Cl^{-1}$ | $NO_3^{-1}$ | Total Anions | T.D.S. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Feb. 1983 | ppm | 102 | 23 | 71 | 3.60 | | 173 | 121 | 159 | 88 | | 772 |
| | | epm | 5.08 | 1.89 | 3.08 | 0.09 | 10.14 | 2.83 | 2.51 | 4.48 | 1.41 | 11.23 | |
| | March 1983 | ppm | 120 | 33 | 82 | 4.10 | | 168 | 189 | 152 | 67.50 | | 846 |
| | | epm | 5.98 | 2.71 | 3.56 | 0.10 | 12.35 | 2.75 | 3.93 | 4.28 | 1.08 | 12.04 | |
| 30 | Feb. 1983 | ppm | 106 | 23 | 74 | 3.70 | | 163 | 120 | 160 | 116 | | 834 |
| | | epm | 5.28 | 1.89 | 3.21 | 0.09 | 10.47 | 2.67 | 2.49 | 4.51 | 1.88 | 11.55 | |
| | Apr. 1983 | ppm | 107 | 31 | 76 | 4.70 | | 146 | 185 | 141 | 78 | | 814 |
| | | epm | 5.33 | 2.54 | 3.30 | 0.12 | 11.29 | 2.39 | 3.85 | 4.14 | 1.26 | 11.64 | |
| 69 | Feb. 1983 | ppm | 228 | 116 | 578 | 2.80 | | 195 | 757 | 781 | 297 | | 3088 |
| | | epm | 11.37 | 9.53 | 25.14 | 0.07 | 46.12 | 3.19 | 15.76 | 22.02 | 4.79 | 45.79 | |
| | Apr. 1983 | ppm | 238 | 124 | 586 | 2.80 | | 164 | 770 | 816 | 110 | | 3416 |
| | | epm | 11.87 | 10.19 | 25.49 | 0.07 | 47.62 | 2.68 | 16.03 | 23.01 | 1.77 | 43.49 | |
| 70a | Feb. 1983 | ppm | 174 | 88 | 446 | 3.60 | | 219 | 458 | 596 | 292 | | 2404 |
| | | epm | 8.68 | 7.23 | 19.40 | 0.09 | 35.40 | 3.58 | 9.53 | 16.80 | 4.71 | 34.62 | |
| | Apr. 1983 | ppm | 155 | 77 | 415 | 1.90 | | 152 | 450 | 582 | 198 | | |
| | | epm | 7.73 | 6.33 | 18.05 | 0.04 | 32.15 | 2.49 | 9.36 | 16.41 | 3.26 | 31.46 | |
| 22 | Apr. 1981 | ppm | 159 | 35 | 80 | 4.00 | | 158 | 344 | 134 | – | | |
| | | epm | 7.90 | 2.92 | 3.48 | 0.10 | 14.4 | 2.60 | 7.16 | 3.80 | – | 13.56 | |
| | Feb. 1983 | ppm | 189 | 42 | 116 | 5.00 | | 158 | 327 | 248 | 136 | | 1300 |
| | | epm | 9.43 | 3.45 | 5.04 | 0.12 | 18.04 | 2.58 | 6.80 | 6.99 | 2.20 | 18.57 | |
| 1 | Apr. 1981 | ppm | 260 | 102 | 435 | 3.50 | | 195 | 660 | 732 | – | | |
| | | epm | 13.00 | 8.40 | 18.90 | 0.09 | 40.39 | 3.20 | 13.75 | 20.65 | – | 37.6 | |
| | Feb. 1983 | ppm | 283 | 136 | 551 | 5.00 | | 195 | 786 | 876 | 275 | | 3212 |
| | | epm | 14.12 | 11.18 | 23.96 | 0.13 | 49.39 | 3.19 | 16.36 | 24.70 | 4.43 | 48.68 | |
| 79 | Apr. 1981 | ppm | 115 | 19 | 7.00 | 3.00 | | 183 | 78 | 122 | – | | |
| | | epm | 5.74 | 1.60 | 0.31 | 0.07 | 7.72 | 3.00 | 1.63 | 3.44 | – | 8.07 | |
| | Feb. 1983 | ppm | 100 | 23 | 80 | 3.00 | | 170 | 127 | 145 | 95 | | 770 |
| | | epm | 4.99 | 1.89 | 3.48 | 0.09 | 10.45 | 2.78 | 2.64 | 4.08 | 1.52 | 11.02 | |
| 121 | Dec. 1981 | ppm | 90 | 13 | 56 | 16 | | 288 | 52 | 106 | – | | |
| | | epm | 4.50 | 1.10 | 2.45 | 0.43 | 8.48 | 4.73 | 1.10 | 3.01 | – | 8.84 | |
| | Apr. 1983 | ppm | 178 | 75 | 324 | 30 | | 723 | 195 | 506 | 0.9 | | 2000 |
| | | epm | 8.88 | 6.16 | 14.09 | 0.78 | 29.91 | 11.84 | 4.05 | 14.26 | 0.01 | 30.16 | |
| 106 | Dec. 1982 | ppm | 332 | 205 | 610 | 16 | | 796 | 1085 | 827 | 137 | | – |
| | | epm | 16.10 | 16.90 | 26.5 | 0.41 | 59.91 | 13.05 | 22.61 | 23.62 | 2.2 | 61.48 | |
| | Feb. 1983 | ppm | 353 | 214 | 594 | 26 | | 952 | 1143 | 884 | 31 | | 4140 |
| | | epm | 17.61 | 17.59 | 25.84 | 0.66 | 61.70 | 15.60 | 23.79 | 24.92 | 0.49 | 64.80 | |
| 24 | Feb. 1983 | ppm | 119 | 27 | 87 | 4.00 | | 163 | 151 | 213 | 103 | | 898 |
| | | epm | 5.93 | 2.22 | 3.78 | 0.09 | 12.02 | 2.67 | 3.14 | 6.00 | 1.66 | 13.47 | |
| | Apr. 1983 | ppm | 119 | 34 | 83 | 5.00 | | 158 | 199 | 149 | 81 | | 850 |
| | | epm | 5.93 | 2.79 | 3.61 | 0.12 | 12.45 | 2.58 | 4.14 | 4.20 | 1.30 | 12.22 | |
| 25 | Feb. 1983 | ppm | 115 | 25 | 80 | 4.00 | | 163 | 167 | 175 | 84 | | 868 |
| | | epm | 5.73 | 2.05 | 3.48 | 0.09 | 11.35 | 2.67 | 3.47 | 4.93 | 1.34 | 12.41 | |
| | Apr. 1983 | ppm | 104 | 29 | 74 | 4.00 | | 152 | 162 | 144 | 58 | | 774 |
| | | epm | 5.18 | 2.38 | 3.21 | 0.09 | 10.86 | 2.49 | 3.37 | 4.06 | 0.94 | 10.86 | |

## Principal Chemical Characteristics of Groundwater in the Quaternary Alluvium Deposits

The major ions chemical characteristics of groundwater from the alluvium in Wadi Uoranah-Al Abdiah area are illustrated and described. The majority of groundwater samples have sodium (Na) and chloride (Cl) as the dominant major ions in Wadi Uoranah. In Al Abdiah area, the major ions are calcium (Ca), Sulphate ($SO_4$) and chloride. The source of groundwater in Al Abdiah area is from Wadi Naaman, which is characterized by low salinity (Jamman 1978).

Durov's diagram which was developed in 1948 and modified by Chilingar in 1956 (Jamman 1978) is used (Fig. 4) to illustrate the chemical water type in the area under investigation. It concluded that the groundwater in the alluvium aquifer of this area is primary calcium sulphate, magnesium sulphate and sodium chloride waters. Bicarbonate is not absent, but has low significance; this is because the area represents a downstream part or considered as discharging area. The groundwater flow from the recharge area to the discharge areas, it dissolves many salts and the chemical water type changes from bicarbonate ($HCO_3$) into sulphate ($SO_4$) and chloride (Cl).

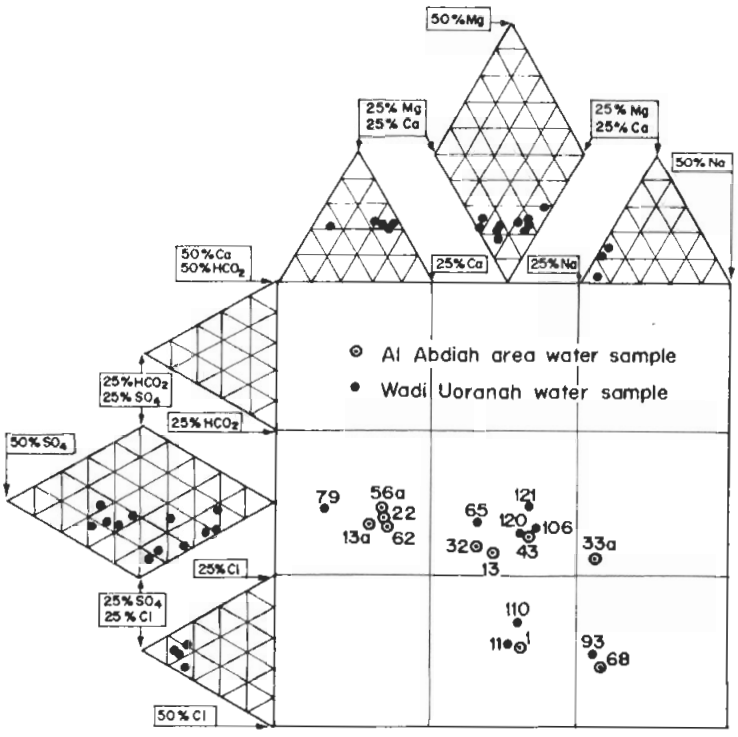


FIG. 4. Durov's diagram for the groundwater sample of the area of study.

## Source of Salinity in Groundwater of the Area

In Al Abdiah area, the salinity increases from East to West direction with the direction of groundwater flow. This is due to the groundwater dissolves different salts of the aquifer materials. The distribution of salinity increase in Wadi Uoranah is random all over the valley (Fig. 5). The main reasons for this is due to i) unfrequent discharge from the water wells, ii) the recharge in this part is very occasional (Sharaf

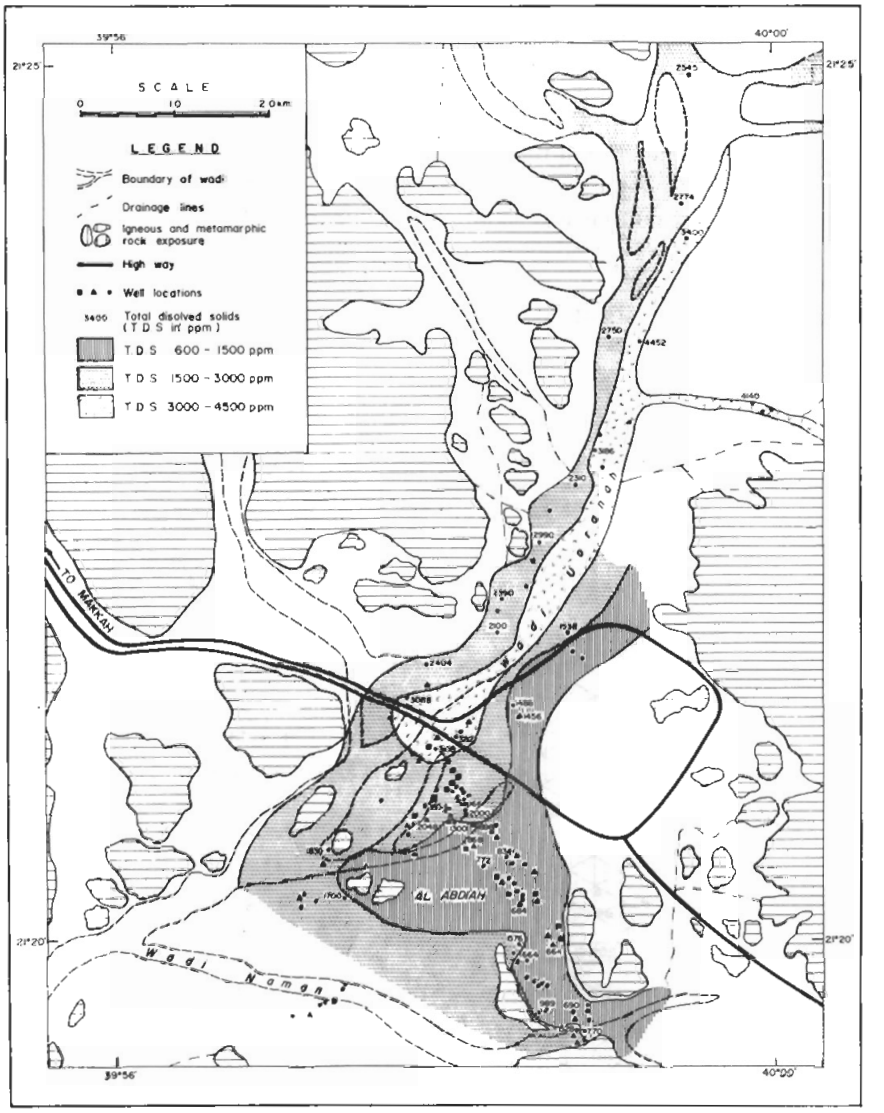


FIG. 5. Salinity map of Wadi Uoranah-Al Abdiah area.

1984), iii) the thickness of the aquifer in Wadi Uoranah is thin compared to the aquifer in Al Abdiah area which is thicker.

The conclusion of the present study indicates that the main source of salinity in Wadi Uoranah is the irrigation water which percolate into the aquifer. The second source of this salinity is the dissolving of the different fragments of the weathered igneous and metamorphic rocks, especially in the northern part of Wadi Uoranah. The salinity in this part reaches 4000 ppm.

## Groundwater Quality

Most interpretations of groundwater quality are made to determine if the water is satisfactory in quality for drinking, agricultural and industrial purposes (Piper 1944). Groundwater in Wadi Uoranah-Al Abdiah area is used mainly for irrigation purposes, because there is no other source of water in this area. For this reason, attention has been paid to evaluate the suitability of groundwater quality in relation to its use in irrigation purposes.

The high sodium percentage in groundwater may harm plant growth and soil. However, the suitability of groundwater for irrigation is contingent upon the effect of the sodium ratio. Sodium ion reacts with soil and reduces its permeability (Todd 1959), an effect is caused by replacement of calcium and magnesium in the soil with sodium. The likelihood of this process occurring can be predicted by quantity known as the sodium adsorption ratio (SAR) which is defined by

$$SAR = \frac{Na}{\sqrt{Ca + Mg/2}}$$

A useful nomogram, originally suggested by Wilcox (1948) and subjected later to some modifications by U.S. Department of Salinity Laboratory in 1954, is widely used for the evaluation of water for irrigation purposes. This nomogram consists of a plot of specific conductivity of water versus the SAR. The nomogram (Fig. 6) is divided into 16 partitions according to the salinity and sodium hazards. A study of the distribution of the different samples from the area under consideration within the Figure 6 reveals that the groundwater is suitable for irrigation for the tolerant crops only in Wadi Uoranah, and suitable for the most crops in Al Abdiah area.

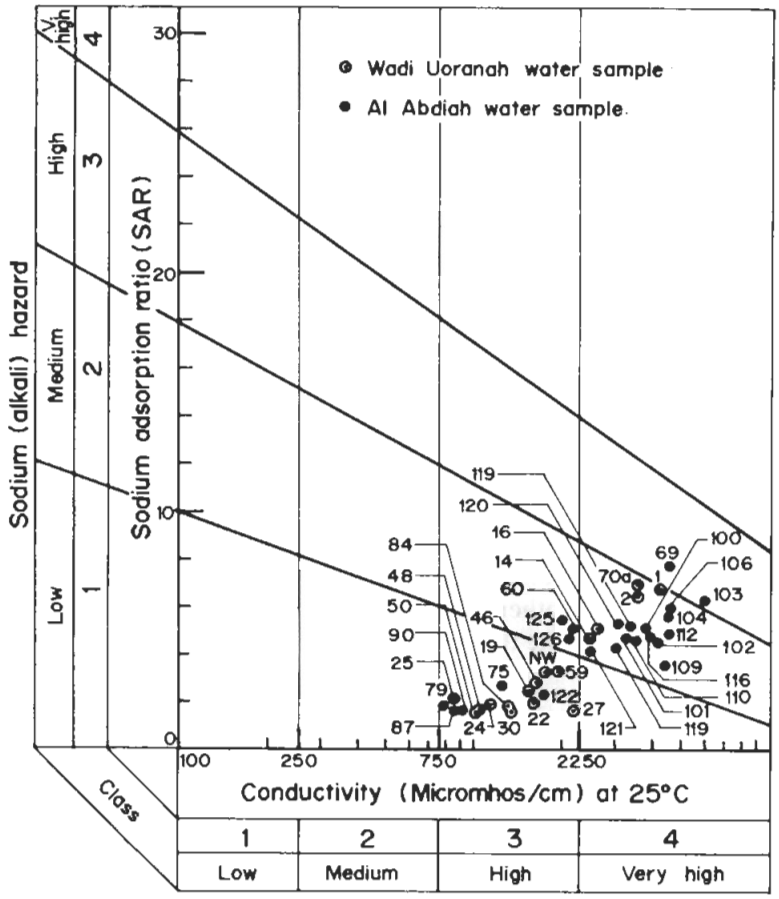


FIG. 6. Wilcox diagram for the classification of groundwater for irrigation purposes.

## Nitrate Concentration in the Groundwater

Groundwater nitrate concentration is a concern since dissolved nitrogen compounds in water may be deterious to health (Feth 1966). Furthermore, increases in nitrogen compounds in a surface water or groundwater systems with time may reflect pollution from such sources as domestic, industrial water or return flow from irrigation water.

In the area under consideration, the nitrate concentrations in groundwater ranges between 13 ppm in the southern part to 303 ppm in the northern part of Wadi Uoranah. The main source of the high nitrate content in the groundwater of this area seems to be due to the nitrate fertilizers which are used for the agriculture purpose to

increase the fertility of the soil. The rainfall and the return flow from irrigation are the main carrier of nitrate to groundwater from the soil enriched with commercially available fertilizer.

## Conclusions

The study of groundwater chemistry shows that the water contains calcium and sodium in higher concentrations more than the other cations. The most dominant anions are chloride and sulphate. It has been concluded that the groundwater is generally suitable for irrigation purposes for the tolerant crops only in Wadi Uoranah, while it is suitable for most crops in Al Abdiah area. The groundwater is moderately saline, especially nearby the cultivated areas.

The chemical analyses show that in some areas, the nitrate content is high. This is due to the use of agriculture fertilizers.

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# كيميائية المياه الجوفية بمنطقة وادي عرنة العابدية بالمنطقة الغربية ، المملكة العربية السعودية

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يتضمن البحث دراسة المظاهر الكيميائية لمياه الخزان الجوفي غير المحصور الموجود في منطقة وادي عرنة – العابدية لاستنتاج نوعية وأصل هذه المياه ، وذلك بمضاهاة ومقارنة بعض نتائج التحليلات الكيميائية للعينات التي جمعت من آبار المياه بهذه المنطقة على ضوء الأيونات الرئيسية الموجودة بها ، وإعطاء التفسيرات المعقولة لاستخدام هذه النوعية من المياه في أغراض الري بالمنطقة . كما أخذ في الاعتبار ارتفاع نسبة وجود النتروجين في منطقة الدراسة والذي يتراوح بين ٠٫٠٠ إلى ٣٠٣ جزء من المليون ، والسبب الرئيسي لهذا الارتفاع في نسبة النتروجين قد درس خلال هذا البحث .