

Studies of groundwater chemistry of the Al-Shagaya Field-D, Kuwait

F.M. AL-RUWAIH

Department of Geology, University of Kuwait, P.O. Box 5969, Safat 13060, Kuwait

ABSTRACT

The study area, Field (D), is located in the southwest of Kuwait and occupies an area of 93.75 km². Field (D) is one of the water well fields of the Al-Shagaya area which supplies Kuwait City with brackish water. Kuwait is characterized by a dry desert climate, with cold winters and hot summers.

Geologically, the Dammam limestone aquifer is composed of chalky, siliceous dolomitic limestone of Eocene age, separated from the clastic sediments of the Kuwait Group by a basal clay and a chert layer. Groundwater moves under artesian pressure from SW to NE.

The chemical analyses reveal that the groundwater is a brackish water type with an average content of total dissolved solids of 2800 mg/l. Groundwater salinity was almost constant over the period 1977–1989, and increased in the direction of groundwater flow towards the NE. The predicted average groundwater salinity in the year 2000 will be 2835 mg/l. The groundwater is characterized by secondary salinity and shows a simple dissolution or mixing process. Two groundwater chemical types are recognized; these are the Na₂SO₄ and CaSO₄ water types. The high sulphate content in the aquifer is probably related to the dissolution of anhydrite and gypsum layers in the lower parts of the Dammam Formation. The brackish water is used mainly for agricultural and domestic purposes, and about 12% of the water is blended with distilled water for drinking.

INTRODUCTION

Kuwait is situated in the northwestern part of the Arabian Gulf and lies between Latitudes 28° 30' and 30° 15' north and between Longitudes 46° 30' and 48° 30' east. The Al-Shagaya area hosts one of the most potentially important brackish groundwater reservoirs in Kuwait; it includes five water well fields. These are: A, B, C, D and E, as shown in Fig. 1. The area under study, Field (D), occupies an area of about 93.75 km² and includes 24 production water wells.

The climate of Kuwait is characterized by hot dry summers and cold mild winters. The amount of rainfall is variable and scarce. The mean annual precipitation during the period 1962–1989 was 105.0 mm and the mean annual evaporation for the same 28-years period was 2608 mm. It is clear that the mean rainfall is considerably lower than evaporation.

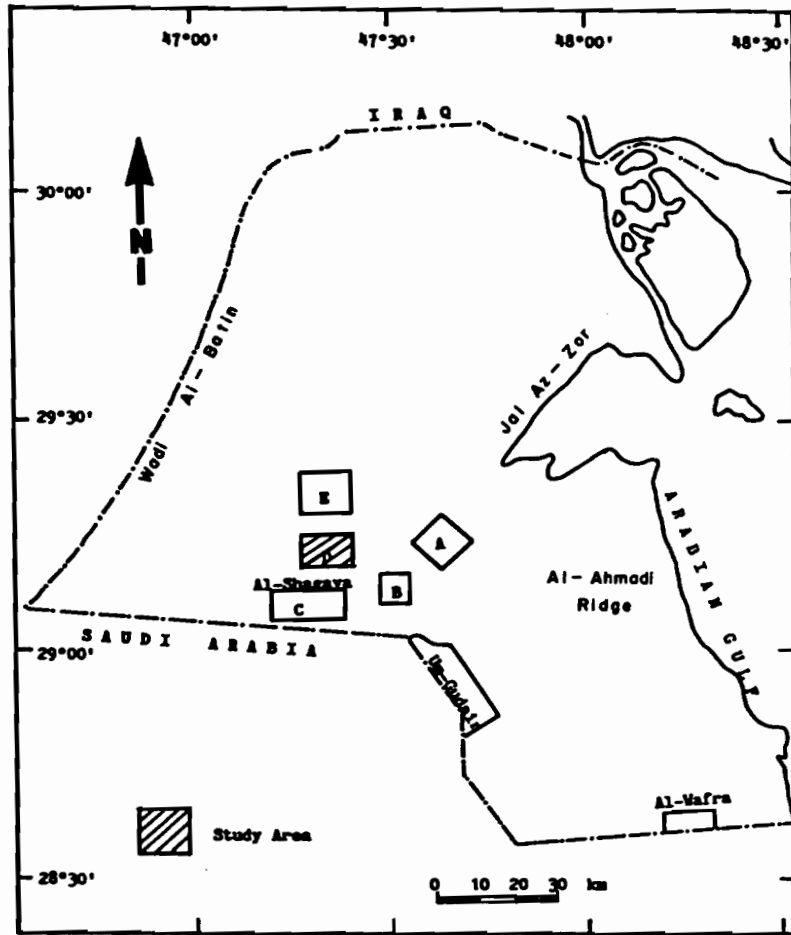


Fig. 1. Location map of the study area, Al-Shagaya Field-D.

GEOLOGY

Kuwait is a flat desert land with few hills and depressions. The maximum land surface elevation reaches 984 ft (300 m) above sea level in the southwestern corner. The height of the central area of Kuwait ranges between 600–500 ft (185–153 m), while in the eastern areas the elevation gradually decreases until it reaches sea level (Fig. 2). The general dip in Kuwait is towards the northeast and east and is about 6.5 ft/3281 ft (1.98 m/1000 m). The type of rock and physical agents, as well as the structural geology are factors affecting topographic features in Kuwait such as the Jal-Az-Zor escarpment, the Ahmadi ridge and the Wadi Al-Batin depression.

GENERAL STRATIGRAPHY

According to Owen & Nasr (1958), the known thickness of sediments underlying the Kuwait area approaches 20,000 ft (6100 m), ranging in age from Pleistocene to Triassic. The thickness of Mesozoic sediments is of the order of 14,800 ft (4270 m).

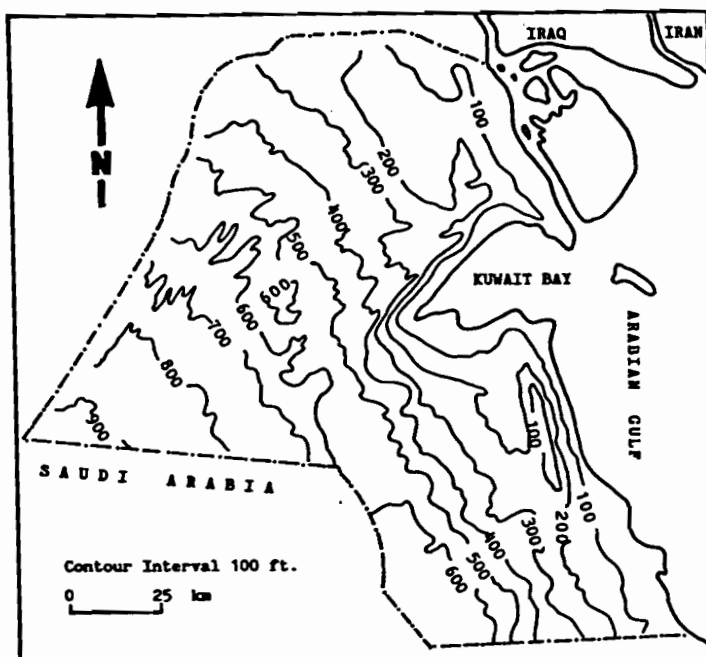


Fig. 2. Topographic map of Kuwait.

They are characterized by carbonate rocks. The Cenozoic sediments in Kuwait have been divided into two groups: the Kuwait Group and the Hasa Group (Table 1). The Dammam Formation of the Hasa Group is considered the main productive aquifer of brackish water in Kuwait. The recent surface deposits that are underlain by Pleistocene deposits are classified into eolian sands, playa deposits, desert plain deposits and sabkha deposits.

HYDROCHEMISTRY

Chemical analysis of groundwater was carried out during the period 1977–1989 in order to observe the salinity change with time and to detect the groundwater flow direction by studying trace element distribution. The relationships between total dissolved solids (T.D.S.), electric conductivity (E.C.) and ionic strength (I.S.) are explained. The classification of groundwater used to determine the groundwater chemical types and their areal distribution as well as groundwater genesis are discussed.

Eighty-six water samples were selected, analysed and interpreted. The accuracy of the chemical analyses was checked by calculating the cation–anion balance percentage, where $\pm 5\%$ of accuracy was accepted (Hem 1970). The major cations and anions and some trace elements were determined. The pH and E.C. values were determined in the field. The chemical analyses for the year 1989 are given in Table 2.

Table 1. Stratigraphic sequence of Kuwait.

| | Age | Group | Formation | Dominant Lithology | Range of thickness |
|------------|-------------|--------------|-------------------------------------|--|--------------------------|
| Quaternary | Recent | — | Marine, eolian and fluvial deposits | sands, silts, clays and gravels | |
| | Pleistocene | Kuwait Group | Dibdibba Formation | gravels and sands, mainly conglomerate sandstone, siltstone, shale | up to 350 ft (107 m) |
| | Pliocene | | Lower Fars Formation | calcareous sandstone, fossiliferous limestone, gypsiferous | 350 ft (107 m) |
| | Miocene | | Ghar Formation | quartzose sandstone, some shale in lower part | few ft to 900 ft (278 m) |
| Tertiary | Oligocene | Hasa Group | | | |
| | Eocene | | Dammam Formation | discontinuous chert cap, chalky and siliceous limestone, dolomite | 600–700 ft (185–217 m) |
| | | | Rus Formation | anhydrite, limestone, marl | 250–400 ft (76–124 m) |
| | Palaeocene | | Radhuma Formation | marly limestone, dolomite anhydrite | 600–1400 ft (185–434 m) |

METHODS OF GROUNDWATER CLASSIFICATION

Various classification methods were adopted to determine groundwater chemical types, their areal distribution and their genesis. Among the classification methods used are those of Piper (1953), Burton & Mazloun (1958) and Haddad (1981).

GROUNDWATER CHEMISTRY OF THE STUDY AREA

The study of the groundwater chemistry of Field (D) between 1977 and 1989 is based on examination of the data for chemical analysis for the years 1977, 1980, 1985 and 1989.

It was found that the average T.D.S. for the year 1989 ranged from 2648 to 3172 mg/l; and it ranged from 2830 to 4150 mg/l for 1977. Generally, the isosalinity maps for the area showed an increase in salinity towards the SE as shown in Fig. 3. The differences in salinity over the period 1977–1989 are presented in Fig. 4. The salinity differences decreased all over the field and ranged from 77 to 1066 mg/l, and appeared to increase in the SE direction.

The water quality hydrograph was used to illustrate the change in T.D.S. with time, and to predict the water quality of the Field in the year 2000 as shown in Fig. 5. Insignificant changes in water quality have occurred since 1977, and the predicted T.D.S. of the Field was calculated to be equal to 2835 mg/l in the next 10 years; this is more or less the same value as the current T.D.S. This small change in salinity is controlled by several factors such as the discharge rate, number of wells pumped,

Table 2. Chemical analysis of groundwater of Field (D), Al-Shagaya, 1989

| Well No. | EC μ mhos/cm | TDS mg/l | pH | Unit | Na ⁺ | K ⁺ | Ca ⁺⁺ | Mg ⁺⁺ | Cl ⁻ | SO ₄ ⁻ | HCO ₃ ⁻ | Dif.% epm |
|----------|------------------|----------|-----|-------|-----------------|----------------|------------------|------------------|-----------------|------------------------------|-------------------------------|-----------|
| 1 | 3400 | 2648 | 7.4 | ppm | 365 | 10.5 | 435 | 128 | 657 | 1305 | 152 | 0.16 |
| | | | | epm | 15 | 0.26 | 21 | 10 | 18 | 27 | 2.5 | |
| | | | | % epm | 32 | 0.53 | 44 | 21 | 38 | 56 | 5.1 | |
| 2 | 3560 | 2768 | 7.5 | ppm | 390 | 12 | 435 | 135 | 702 | 1305 | 136 | 0.86 |
| | | | | epm | 16 | 0.3 | 21 | 11 | 19 | 27 | 2.2 | |
| | | | | % epm | 33 | 0.6 | 43 | 22 | 43 | 55 | 4.5 | |
| 3 | 3480 | 2716 | 7.4 | ppm | 385 | 11.5 | 445 | 135 | 693 | 1334 | 170 | 0.23 |
| | | | | epm | 16 | 0.3 | 22 | 11 | 19 | 27 | 2.7 | |
| | | | | % epm | 33 | 0.6 | 44 | 22 | 39 | 55 | 5.5 | |
| 4 | 3430 | 2728 | 7.6 | ppm | 360 | 11 | 445 | 135 | 648 | 1334 | 167 | 0.47 |
| | | | | epm | 15 | 0.28 | 22 | 11 | 18 | 27 | 2.7 | |
| | | | | % epm | 31 | 0.56 | 45 | 22 | 37 | 56 | 5.6 | |
| 5 | 3610 | 2806 | 7.5 | ppm | 425 | 12.5 | 315 | 128 | 5.7 | 1363 | 172 | -0.8 |
| | | | | epm | 18 | 0.32 | 15 | 10 | 14 | 28 | 2.8 | |
| | | | | % epm | 41 | 0.71 | 34 | 23 | 31 | 61 | 6.1 | |
| 6 | 3630 | 2858 | 7.4 | ppm | 400 | 11.5 | 454 | 135 | 720 | 1363 | 170 | -0.01 |
| | | | | epm | 17 | 0.30 | 22 | 11 | 20 | 28 | 2.7 | |
| | | | | % epm | 33 | 0.58 | 44 | 21 | 39 | 55 | 5.4 | |
| 7 | 3440 | 2702 | 7.8 | ppm | 385 | 13 | 293 | 113 | 455 | 1334 | 169 | -2.2 |
| | | | | epm | 16 | 0.33 | 14 | 9 | 12 | 27 | 2.7 | |
| | | | | % epm | 40 | 0.8 | 35 | 22 | 29 | 64 | 6.3 | |
| 8 | 3430 | 2704 | 7.7 | ppm | 400 | 12 | 270 | 113 | 455 | 1305 | 155 | -2.5 |
| | | | | epm | 17 | 0.30 | 13 | 9 | 12 | 27 | 2.5 | |
| | | | | % epm | 43 | 0.74 | 33 | 22 | 30 | 63 | 5.9 | |
| 9 | 3400 | 2730 | 7.3 | ppm | 385 | 13 | 293 | 113 | 457 | 1334 | 162 | -3.07 |
| | | | | epm | 16 | 0.33 | 14 | 9 | 13 | 27 | 2.6 | |
| | | | | % epm | 40 | 0.80 | 35 | 22 | 30 | 63 | 6.1 | |
| 10 | 3310 | 2708 | 7.4 | ppm | 350 | 12 | 323 | 120 | 412 | 1363 | 166 | -1.4 |
| | | | | epm | 15 | 0.3 | 16 | 9 | 11 | 28 | 2.7 | |
| | | | | % epm | 36 | 0.72 | 38 | 23 | 27 | 66 | 6.4 | |
| 11 | 3460 | 2760 | 7.5 | ppm | 395 | 13.5 | 300 | 113 | 464 | 1334 | 168 | -2.3 |
| | | | | epm | 17 | 0.34 | 14 | 9 | 13 | 27 | 2.7 | |
| | | | | % epm | 41 | 0.81 | 35 | 22 | 30 | 63 | 6.3 | |
| 12 | 3580 | 2850 | 7.3 | ppm | 425 | 13.5 | 308 | 113 | 507 | 1363 | 168 | -2.1 |
| | | | | epm | 18 | 0.34 | 15 | 9 | 14 | 28 | 2.7 | |
| | | | | % epm | 42 | 0.78 | 35 | 21 | 31 | 62 | 6.1 | |
| 13 | 3370 | 2744 | 7.7 | ppm | 355 | 13 | 308 | 120 | 421 | 1334 | 169 | -1.6 |
| | | | | epm | 15 | 0.33 | 15 | 9 | 11 | 27 | 2.7 | |
| | | | | % epm | 37 | 0.80 | 37 | 24 | 27 | 65 | 6.5 | |
| 14 | 3330 | 2722 | 7.7 | ppm | 340 | 12 | 308 | 120 | 412 | 1363 | 163 | -2.8 |
| | | | | epm | 14 | 0.30 | 15 | 9 | 11 | 28 | 2.6 | |
| | | | | % epm | 36 | 0.74 | 38 | 24 | 27 | 66 | 6.2 | |
| 15 | 3530 | 2738 | 7.5 | ppm | 410 | 13 | 308 | 135 | 491 | 1305 | 157 | 1.17 |
| | | | | epm | 17 | 0.33 | 15 | 11 | 13 | 27 | 2.5 | |
| | | | | % epm | 39 | 0.74 | 34 | 24 | 31 | 62 | 5.9 | |
| 16 | 3340 | 2730 | 7.6 | ppm | 355 | 12.5 | 308 | 120 | 442 | 1363 | 166 | -3.01 |
| | | | | epm | 15 | 0.32 | 15 | 9 | 12 | 28 | 2.7 | |
| | | | | % epm | 37 | 0.78 | 37 | 24 | 28 | 65 | 6.2 | |
| 17 | 3510 | 2754 | 7.6 | ppm | 385 | 13 | 315 | 135 | 455 | 1363 | 164 | -0.3 |
| | | | | epm | 16 | 0.33 | 15 | 11 | 13 | 28 | 2.6 | |
| | | | | % epm | 38 | 0.75 | 35 | 25 | 29 | 64 | 6.1 | |
| 18 | 3730 | 2981 | 7.4 | ppm | 400 | 12 | 330 | 443 | 540 | 1363 | 169 | -0.4 |
| | | | | epm | 17 | 0.30 | 16 | 11 | 15 | 28 | 2.7 | |
| | | | | % epm | 37 | 0.65 | 35 | 25 | 32 | 61 | 5.9 | |

Table 2.—Continued

| Well No. | EC μmhos/cm | TDS mg/l | pH | Unit | Na ⁺ | K ⁺ | Ca ⁺⁺ | Mg ⁺⁺ | Cl ⁻ | SO ₄ ⁻ | HCO ₃ ⁻ | Dif.% epm |
|----------|----------------|-------------|-----|-------|-----------------|----------------|------------------|------------------|-----------------|------------------------------|-------------------------------|--------------|
| 19 | 3490 | 2848 | 7.5 | ppm | 440 | 12 | 330 | 143 | 451 | 1353 | 162 | 2.11 |
| | | | | epm | 17 | 0.30 | 16 | 11 | 13 | 28 | 2.5 | |
| | | | | % epm | 37 | 0.65 | 35 | 25 | 29 | 64 | 6.0 | |
| 20 | 3380 | 2771 | 7.3 | ppm | 315 | 11 | 338 | 150 | 426 | 136 | 162 | 0.1 |
| | | | | epm | 13 | 0.28 | 16 | 12 | 12 | 28 | 2.6 | |
| | | | | % epm | 31 | 0.64 | 39 | 28 | 27 | 65 | 6.2 | |
| 21 | 3380 | 2755 | 7.6 | ppm | 305 | 10.5 | 345 | 150 | 418 | 1363 | 160 | 0.32 |
| | | | | epm | 13 | 0.26 | 17 | 12 | 11 | 28 | 2.6 | |
| | | | | % epm | 30 | 0.60 | 39 | 28 | 27 | 65 | 6.0 | |
| 22 | 3360 | 2710 | 7.4 | ppm | 325 | 12 | 338 | 150 | 429 | 1363 | 157 | 0.66 |
| | | | | epm | 14 | 0.30 | 16 | 12 | 12 | 28 | 2.5 | |
| | | | | % epm | 32 | 0.68 | 38 | 28 | 28 | 65 | 5.9 | |
| 23 | 3430 | 2793 | 7.3 | ppm | 340 | 11.5 | 323 | 150 | 436 | 1363 | 164 | 0.23 |
| | | | | epm | 14 | 0.30 | 16 | 12 | 12 | 28 | 2.6 | |
| | | | | % epm | 33 | 0.68 | 37 | 28 | 28 | 65 | 6.1 | |
| 24 | 4000 | 3172 | 7.6 | ppm | 465 | 15.5 | 375 | 150 | 559 | 1537 | 165 | 1.17 |
| | | | | epm | 20 | 0.40 | 18 | 12 | 15 | 32 | 2.7 | |
| | | | | % epm | 39 | 0.77 | 36 | 23 | 31 | 63 | 5.3 | |

ppm = part per million;

epm = equivalent per million;

$$\% \text{ epm} = \frac{\text{equivalent cation or anion}}{\text{total cation or anion}} \times 100$$

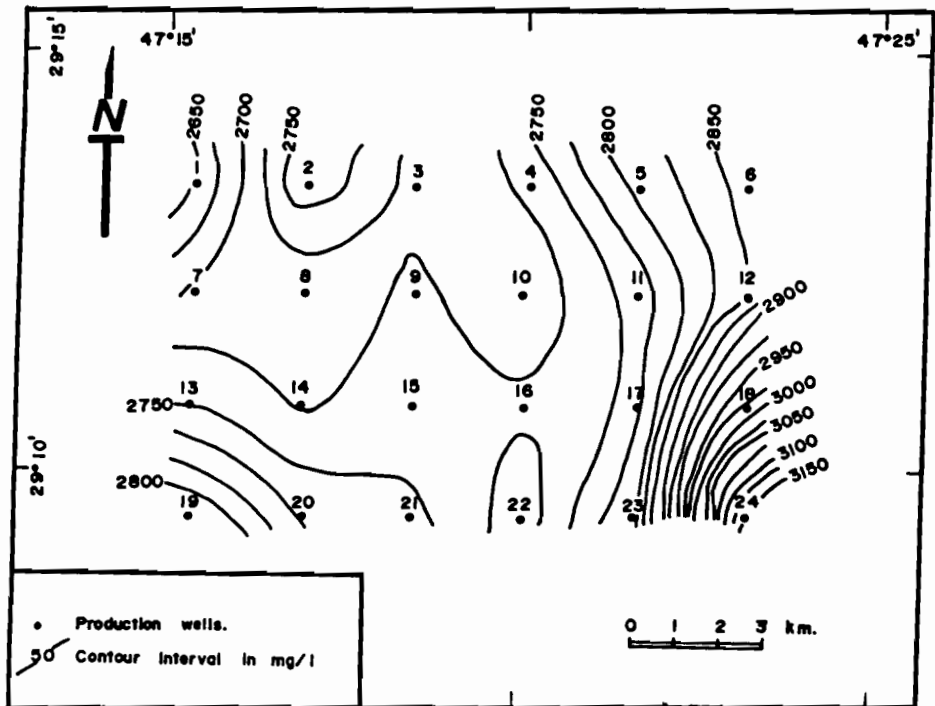


Fig. 3. Iso-salinity map of the Dammam Formation, 1989.

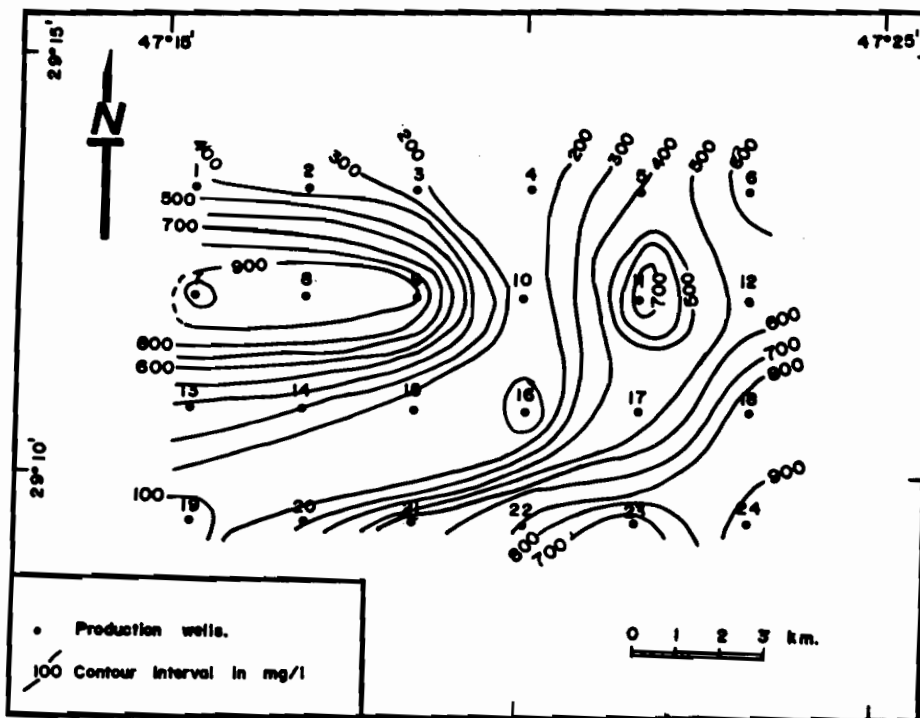


Fig. 4. Map of iso-salinity differences for the period 1977-1989.

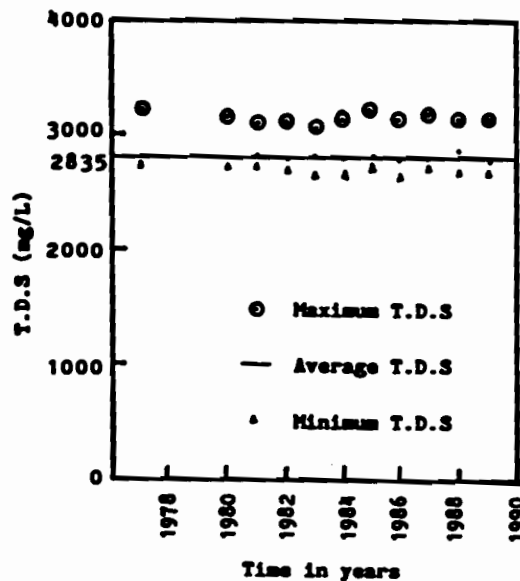


Fig. 5. Groundwater quality hydrograph.

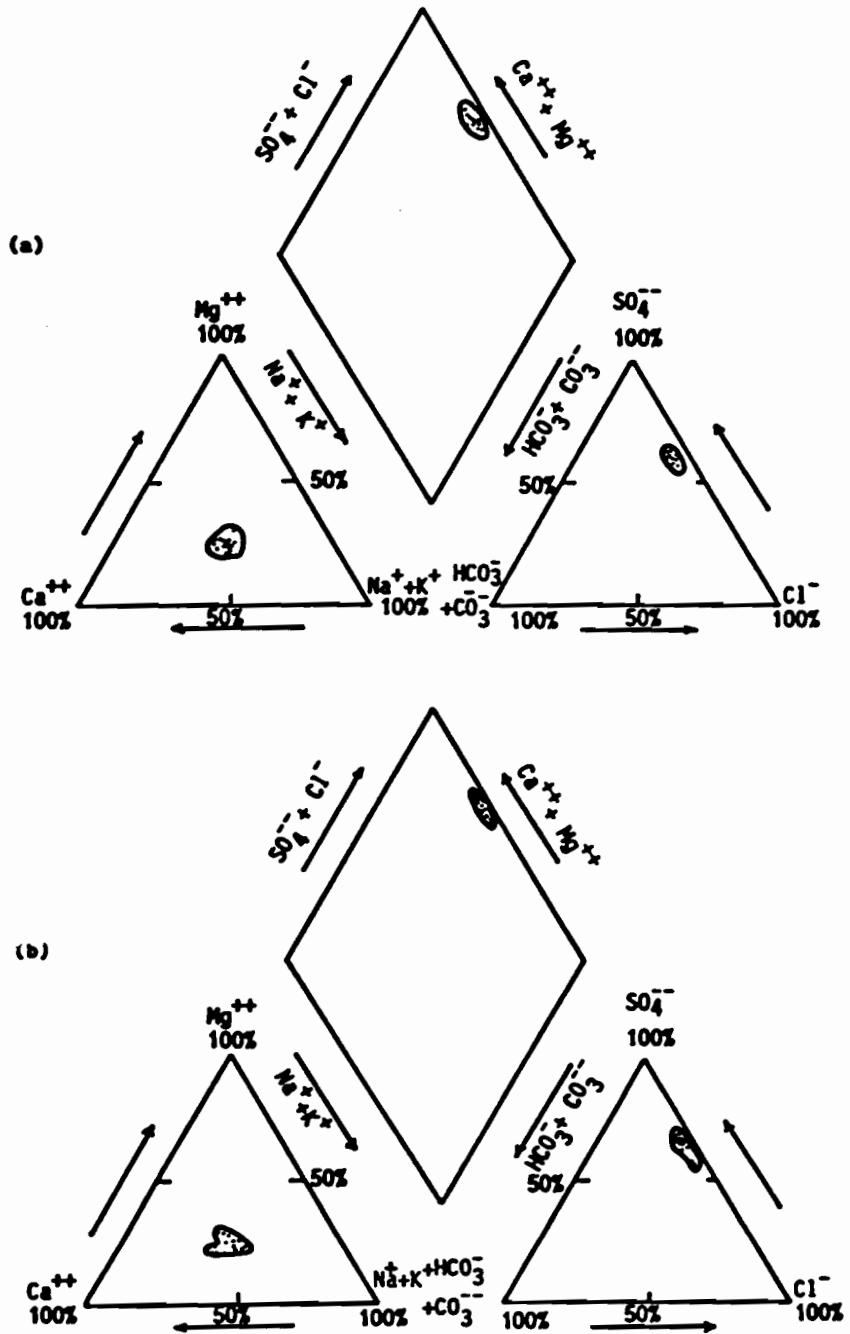


Fig. 6. Piper trilinear diagram for representative groundwater analyses, (a) 1985 and (b) 1989.

pumping period and the effect of leakage of the Kuwait Group water into the Dammam Formation.

In the application of the Piper (1953) method, it was found that most of the groundwater samples for the years 1985–1989 were located in area (6), and were characterized by secondary salinity where the alkaline earth exceeds the alkalies, and the strong acids exceed the weak acids as shown in Fig. 6. By using the expanded Durov diagram, it is clear that most of the water samples were located in the area (5) which, according to Burdon & Mazloum (1958), means that the brackish water undergoes a simple mixing process or dissolution, where Na^+ and SO_4^{2-} are the dominant cation and anion respectively as shown in Fig. 7.

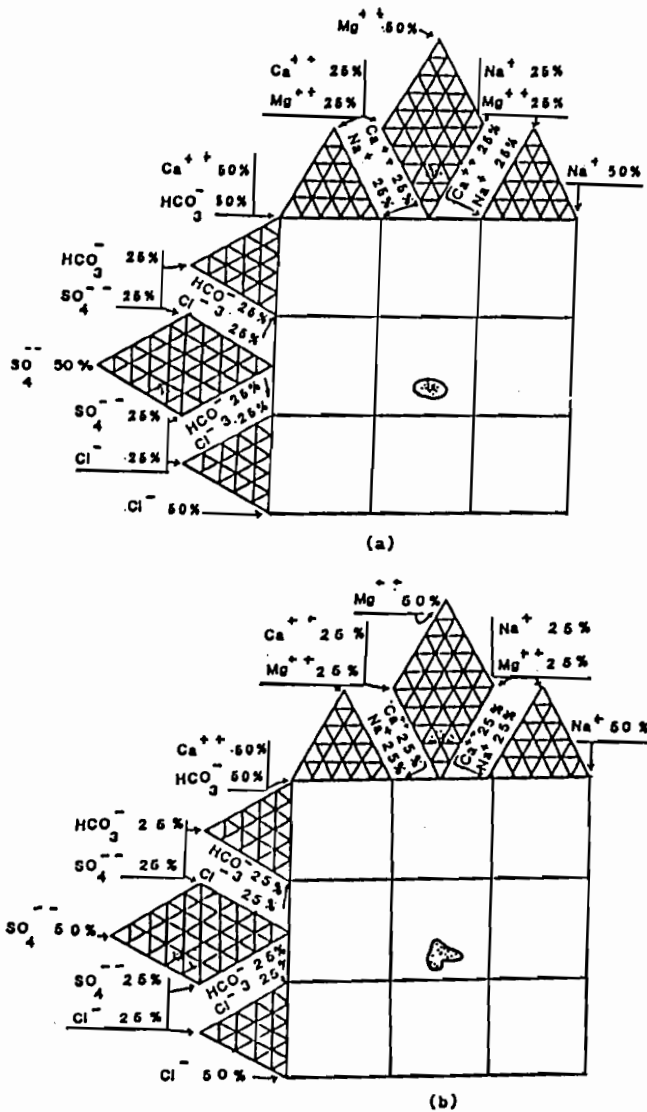


Fig. 7. Expanded Durov diagram for representative groundwater analyses of the Dammam Formation aquifer, (a) 1985 and (b) 1989.

According to Haddad's method (1981), it was found that there are two main groundwater chemical type: Na_2SO_4 and CaSO_4 .

TREATMENT OF WATER QUALITY DATA

The relationships between the various parameters such as T.D.S., I.S. and E.C. are worked out in order to express the groundwater quality. The relationship between T.D.S. and E.C. is a regression line which appears in the form of a straight line (Hem 1970):

$$\text{T.D.S.} = C \times \text{E.C.} \quad (1)$$

where the T.D.S. is expressed in mg/l, E.C. is in $\mu\text{-mhos/cm}$ and C is a conversion constant. According to Hem (1970), the range of C is from 0.54 to 0.96 which represents nearly all types of natural waters.

The E.C. and T.D.S. data of the Na_2SO_4 water type were plotted to show the relation between them (Fig. 8). It is clear that the Na_2SO_4 water type shows a low ratio of T.D.S./E.C. ranging between 0.50 and 0.66. The correlation coefficients (r) are equal to 0.86, 0.81 and 0.93 for 1977, 1985 and 1989 respectively.

The ionic strength is a measure of the interionic effect resulting from electrical attractions and repulsions between the various ions, and it is determined according to the following formula (Skoog & West 1982):

$$\text{Ionic strength (I.S.)} = \frac{1}{2} \sum_{i=1}^n C_i \times Z_i^2 \quad (2)$$

where C_i is the concentration of the i th ion in moles/l, Z_i is the oxidation number of the i th ion and n is the total number of ions. Although I.S. can be calculated from laboratory analyses, it can also be determined in the field through variables such as T.D.S. and E.C. The relationship between I.S. and T.D.S. appears in the form of a straight line equation (Sen & Al-Dakhell 1986):

$$\text{I.S.} = B \times \text{T.D.S.} \quad (3)$$

The constant B for brackish water is equal to 2×10^{-5} . Furthermore, the relationship between I.S. and E.C. appears as a straight line equation (Griffin & Jurinak 1973):

$$\text{I.S.} = K \times \text{E.C.} \quad (4)$$

where E.C. is expressed in $\mu\text{mhos/cm}$ and the constant K for all types of natural water is equal to 1.3×10^{-5} .

The calculated I.S. values for the study area using Eqn (2) are plotted *v.* T.D.S. values of Na_2SO_4 water type 1977, 1980, 1985 and 1989 (Fig. 9). The constant B ranges between 1.8×10^{-5} and 2.4×10^{-5} and the correlation coefficients for 1977, 1980, 1985 and 1989 are equal to 0.75, 0.86, 0.72 and 0.3 respectively. Substituting the T.D.S. in terms of E.C. into Eqn (3) yields K values ranging between 1.18×10^{-5} and 2.2×10^{-5} for the years 1977 and 1989.

TRACE ELEMENTS

Minor elements such as fluoride, bromide and iodide were analysed using the ion-selective electrode method, and interpreted to detect sea water intrusion and the

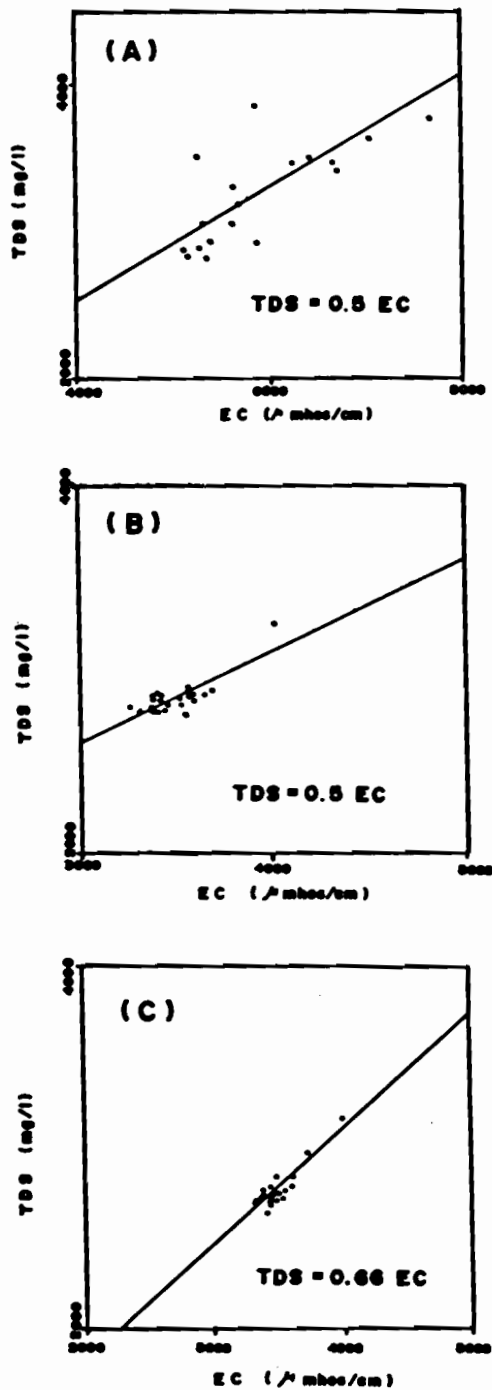


Fig. 8. T.D.S./E.C. relationship of Na_2SO_4 water-type for: (a) 1977; (b) 1985 and (c) 1989.

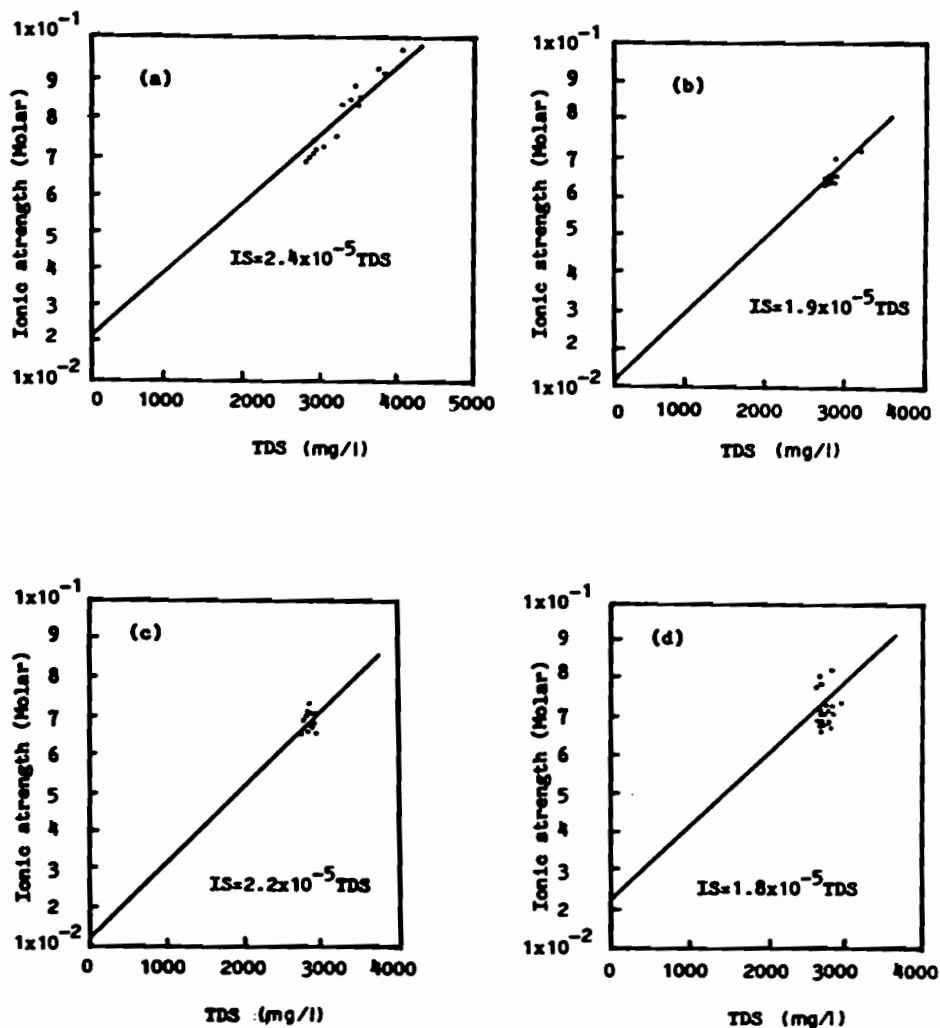


Fig. 9. Ionic strength/T.D.S. relationship for: (a) 1977; (b) 1980; (c) 1985 and (d) 1989.

flow direction. The fluoride concentration in the study area ranged from 1.55 to 3.0 mg/l in 1977 and from 1.4 to 1.9 mg/l in 1989, suggesting a slight decrease over the years 1977–1989. In addition, the average value of F^-/Cl^- is equal to 7×10^{-3} e.p.m. which is higher than that in sea water (1.2×10^{-4} e.p.m.). This means that neither the fluoride nor the chloride has reached the concentration of sea water (Lloyd & Heathcote 1985).

The bromide concentration in the study area ranges between 4.47 and 6.55 mg/l with an average value of 5.37 mg/l, which is well below values for sea water (around 65 mg/l), while the average value of the iodide concentration is equal to 0.16 mg/l which is above its value in sea water (0.06 mg/l). It is clear that the Br^- and I^- concentration values increase in the same direction of increasing T.D.S. (Figs 10 and 11).

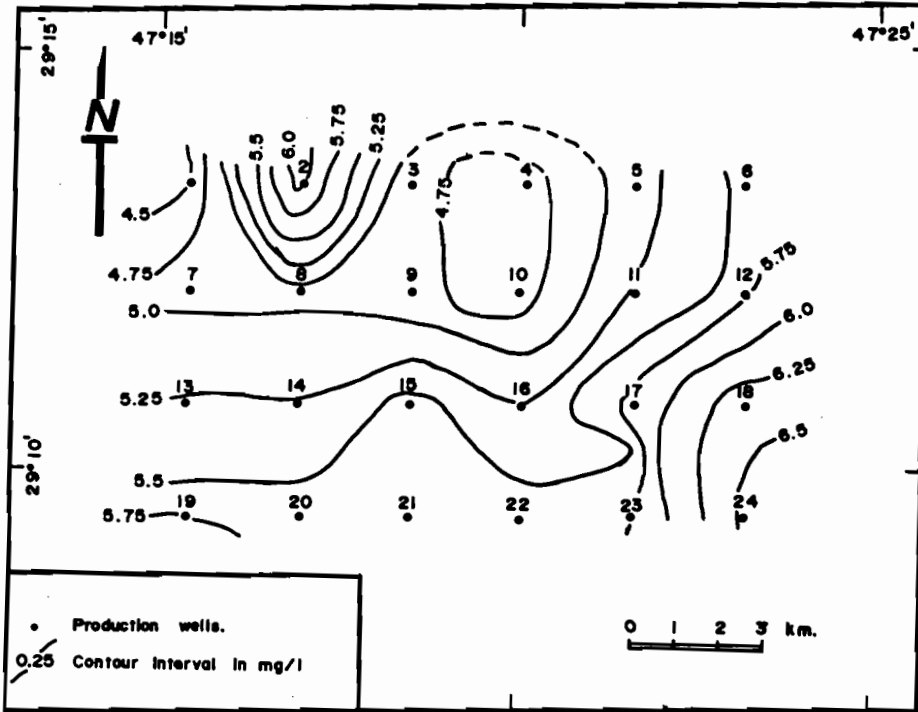


Fig. 10. Distribution map of bromide, 1989.

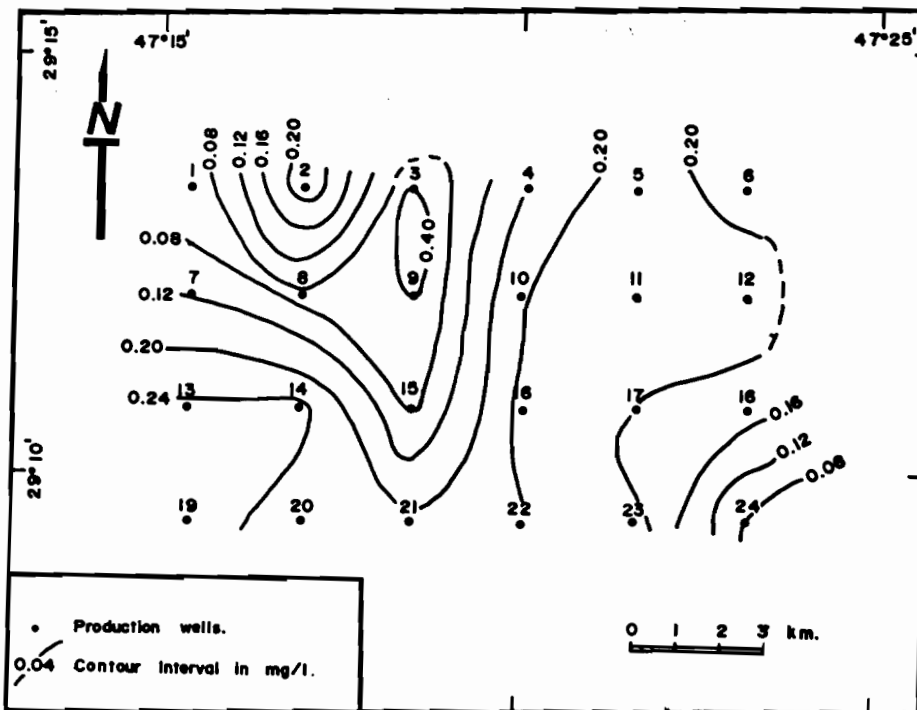


Fig. 11. Distribution map of iodide, 1989.

EVALUATION OF GROUNDWATER QUALITY

The required quality of groundwater depends upon its uses, such as for drinking, industry and irrigation. About 12% of this brackish water is blended with distilled water to provide water for drinking.

The suitability of groundwater for irrigation depends on several factors which have a direct relationship with plant and soil. These include the sodium percentage (Na%), the sodium adsorption ratio (S.A.R.), the residual sodium carbonate (R.S.C.) and the boron concentration (B) (Al-Ruwaih 1986). The chemical data of 1989 were used to evaluate the groundwater quality for irrigation purposes.

The sodium percentage (Na%) is defined by the following equation (Todd 1980):

$$\text{Na}\% = (\text{Na} + \text{K}) \times 100 / (\text{Ca} + \text{Mg} + \text{Na} + \text{K}) \quad \text{e.p.m.} \quad (5)$$

According to Wilcox (1955), when Na% is <20 the water class is considered as excellent, and when Na% is >60 the water class is doubtful. It was found that the Na% of the study area ranges between 31 and 43 e.p.m. with an average value of 38.0 e.p.m.

Richards (1954) suggested the sodium adsorption ratio (S.A.R.) instead of the Na% because of its direct relation to the adsorption of sodium by the soil. The S.A.R. is defined by the following equation:

$$\text{S.A.R.} = \frac{\text{Na}^+}{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}/2}} \quad \text{e.p.m.} \quad (6)$$

In addition, he prepared the graphic classification of irrigation water based on S.A.R. and electrical conductance. Most of S.A.R. values of the study area fall into the medium S.A.R. class (S_2) and the very high conductance (C_4) class as shown in Fig. 12. Furthermore, the average value of S.A.R. is equal to 4.4 e.p.m. which is considered an excellent water class, while the average electrical conductance is equal to 3482 $\mu\text{mhos/cm}$ which makes the water unsuitable for irrigation.

The residual sodium carbonate (R.S.C.) is defined by the following equation (Hem 1970):

$$\text{R.S.C.} = [(\text{CO}_3^{-2} + \text{HCO}_3^-) - (\text{Ca}^{+2} + \text{Mg}^{+2})] \quad \text{e.p.m.} \quad (7)$$

The average value of R.S.C. of the study area is equal to -25.24 e.p.m. This negative value is below the recommended limit and shows higher concentration of Ca^{+2} and Mg^{+2} over HCO_3^- and CO_3^{-2} .

In small amounts, boron is an important element for plant growth but in higher concentration it becomes toxic. According to Richards (1954), irrigation water has been classified into five water classes on the basis of boron concentration for the three categories of plants: boron-sensitive, boron-semisensitive and boron-tolerant. It was found that the average value of boron concentration of the study area was equal to 1.18 mg/l, which falls under class 2 in Richard's classification and indicates that the water can be used for semi-tolerant to tolerant crops.

CONCLUSION

In the study area, few or insignificant changes have occurred in groundwater chemistry in terms of T.D.S. or water types over the period 1977-1989. The salinity of the

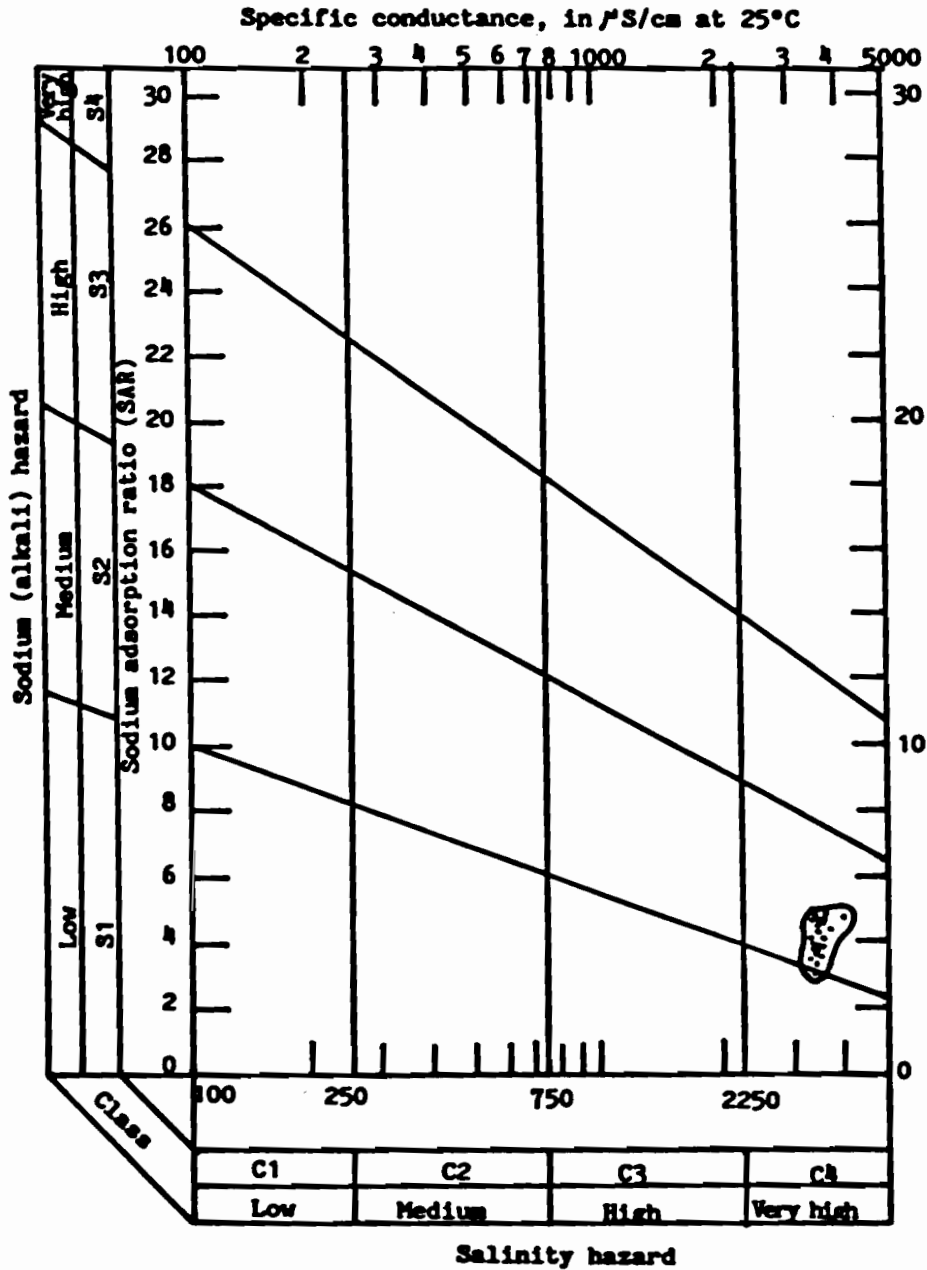


Fig. 12. Diagram for classification of irrigation water (Richards 1954).

field ranges from 2780 to 3300 mg/l. The groundwater flow direction in the Dammam Formation aquifer is from SW to NE as indicated by studying the T.D.S. and trace element values. The Na_2SO_4 and CaSO_4 water-types are the main groundwater chemical types recognized in the area, where the Na_2SO_4 water-type is

mainly located in the NE and the CaSO_4 water-type is concentrated in the S and SW of the field.

The constant factors of T.D.S./E.C., I.S./T.D.S. and I.S./E.C. range from 0.5 to 0.66, 1.8×10^{-5} to 2.4×10^{-5} and 1.18×10^{-5} to 2.2×10^{-5} respectively, reflect the constant salinity trend over the period 1977–1989. From studying the T.D.S., Na%, S.A.R., R.S.C. and boron values, it is clear that groundwater is suitable for irrigation and domestic purpose.

ACKNOWLEDGEMENT

My thanks are due to the Ministry of Electricity and Water for providing the basic chemical analyses data. My thanks are also extended to Mr Haidar Khajah and Adel Jaragh Al-Haddad for their assistance in typing the manuscript and preparing the figures.

REFERENCES

- Al-Ruwaih, F.M. 1986.** Chemical evaluation of treated sewage and brackish water for irrigation. *Journal of the University of Kuwait (Science)* **13**: 179–88.
- Burdon, D.J. & Mazloum, S. 1958.** Some chemical types of groundwater from Syria. UNESCO Symposium, Tehran, pp. 73–90.
- Griffin, R.A. & Jurinak, J.J. 1973.** Estimation of activity coefficients from the electrical conductivity of natural systems and soil extracts. *Soil Science* **116**: 26–30.
- Haddad, R.H. 1981.** A proposed numerical approach to the classification of groundwater. *Journal of the Gulf and Arabian Peninsula Studies* **2**: 47–68.
- Hem, J.D. 1970.** Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water-Supply Paper 1473: 1–363.
- Lloyd, J.W. & Heathcote, J.A. 1985.** Natural inorganic hydrochemistry in relation to groundwater. Clarendon Press, Oxford, 296 pp.
- Owen, R.M. & Nasr, S.W. 1958.** Stratigraphy of Kuwait-Basra area. In *Habitat of Oil: American Association of Petroleum Geologists Bulletin* **42**: 1252–78.
- Piper, A.M. 1953.** A graphic procedure in the geochemical interpretation of water analyses. Geological Survey, U.S. Groundwater Note No. 12, Washington, DC.
- Richards, L.A. 1954.** Diagnosis and improvement of saline and alkali soils. U.S. Department of Agriculture, Handbook 60, Washington, DC, 160 pp.
- Sen, Z. & Al-Dakhell, A. 1986.** Hydrochemical facies evaluation in Umm-Er-Radhuma limestone, Eastern Saudi Arabia. *Groundwater* **24**: 625–35.
- Skoog, D.A. & West, D.M. 1982.** Fundamentals of analytical chemistry. Saunders College Publishing, New York, 800 pp.
- Todd, D.K. 1980.** Groundwater hydrology. John Wiley, New York, 535 pp.
- Wilcox, L.V. 1955.** Classification and use of irrigation waters. U.S. Department of Agriculture, Circular 969: 1–19, Washington, DC.

(Received 18 February 1992, revised 13 December 1992)

دراسة كيمياء المياه الجوفية في حقل د بمنطقة الشقاييا - الكويت

فوزيه محمد الرويح
قسم الجيولوجيا بجامعة الكويت، ص. ب. ٥٩٥٦،
الصفة ١٣٠٦٠، الكويت

خلاصة

تقع منطقة الدراسة (حقل د) إلى الجنوب الغربي من مدينة الكويت، وتغطي مساحة قدرها ٩٣,٧٥ كم^٢. تعتبر منطقة الشقاييا من المناطق الهامة التي تمد مدينة الكويت بالمياه الجوفية قليلة الملوحة. وتتميز الكويت بجوها الحار صيفا والبارد شتاء، وبجفاف مناخها. يتكون خزان الدمام الجوفي أساسا من صخور الطباشيري والحجر الجيري الدولوميتي السيليكلي والذي ينتمي إلى عصر الأيوسين. يفصل هذا الخزان الجوفي عن طبقات مجموعة الكويت طبقة من الرواسب المفتتة معظمها من صخور طينية وصخور السيلكا. تتحرك المياه الجوفية من الجنوب الغربي إلى الشمال الشرقي تحت ضغط ارتوازي مرتفع نسبيا. لقد أظهرت التحاليل الكيميائية أن المياه قليلة الملوحة تحوي حوالي ٢٨٠٠ ملجم من الأملاح في اللتر في المتوسط، وأن هذه الملوحة ثابتة تقريبا منذ عام ١٩٧٧ حتى عام ١٩٨٩. ومن المتوقع أن يبلغ تركيز الاملاح الذائبة سنة ٢٠٠٠ حوالي ٢٨٣٥ ملجم/لتر. وتتميز الملوحة بأنها من نوع الملوحة الثانوية. ولقد أمكن تصنيف المياه الجوفية قليلة الملوحة إلى نوعين هما: نوع كبريتات الصوديوم، ونوع كبريتات الكالسيوم. وربما ترجع زيادة نسبة الكبريتات إلى إذابة طبقات صخور الجبس والأنهيدريت التي تكون الجزء الأسفل من تكوين الدمام. تستخدم المياه قليلة الملوحة في الزراعة والأغراض المنزلية، وتضاف بنسبة ١٢٪ إلى المياه المقطرة لتكوّن مياه الشرب.

