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Hydrochemical Characteristics of Groundwater in the Usfan Basin, Saudi Arabia

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ABSTRACT. The Usfan basin, covering some 2,000 km^2, includes two main plains in addition to a number of wadis. These wadis drain varied rock types and geomorphological features, crossing alternate horsts and grabens which are parallel to the Red Sea Rift. Representative groundwater samples were collected from 21 sites in the wadis and plains. Adjacent to 12 of these sites, geophysical measurements were made to deduce their geoelectric sequences. The samples were analysed for major dissolved cations and anions content in the laboratory, with the specific conductance for each well being measured *in situ*.

The variation in TDS and concentration of the component ions dissolved in the groundwater along the course of each wadi and plain are interpreted in relation to the lithology of the aquifers. Construction of a linear bilogarithmic relationship between the specific conductance and both TDS (mg/L) and Σ ions (epm), allows a constant to be deduced with maximum error $\pm 9\%$ of the actual values.

Groundwater in the Usfan basin generally is of a chloride type with a predominance of Na though a few exceptions trend towards a sulphate type with dominant Ca-Mg. The groundwaters of wadis Haddat ash Sham and Shamiya, as well as those of Usfan Plain, are of secondary salinity hydrochemical facies, but those of Bayadah plain and Wadi Ghulah are of primary salinity type, while those of wadis As Suqah and Fayidah range from secondary to primary in their direction of flow. The usability of the groundwaters for domestic uses, irrigation and breeding livestock is considered.

Introduction

The investigated area lies between Lat. 21°40′ to 21°55′N and long. 39°10′ to 39°50′E (Fig. 1) covering approximately 2000 km^2. It includes two main plains, namely Bayadah and Usfan. The wadis related to the Bayadah Plain are Haddat ash Sham, Sudir, Shamiyah and As Suqah, while those related to the Usfan Plain are Fayidah and Ghulah. All these wadis have a dominant NE-SW trend in alignment with the regional faults subsidiary to the trend of Red Sea Rift.

The underlying rocks in the study area are described in the following sequence starting with the older:

1. Basement Complex of Precambrian age including granitoid rocks, diorites, granite-gneisses and to lesser extent various types of schistose rocks with much litho-

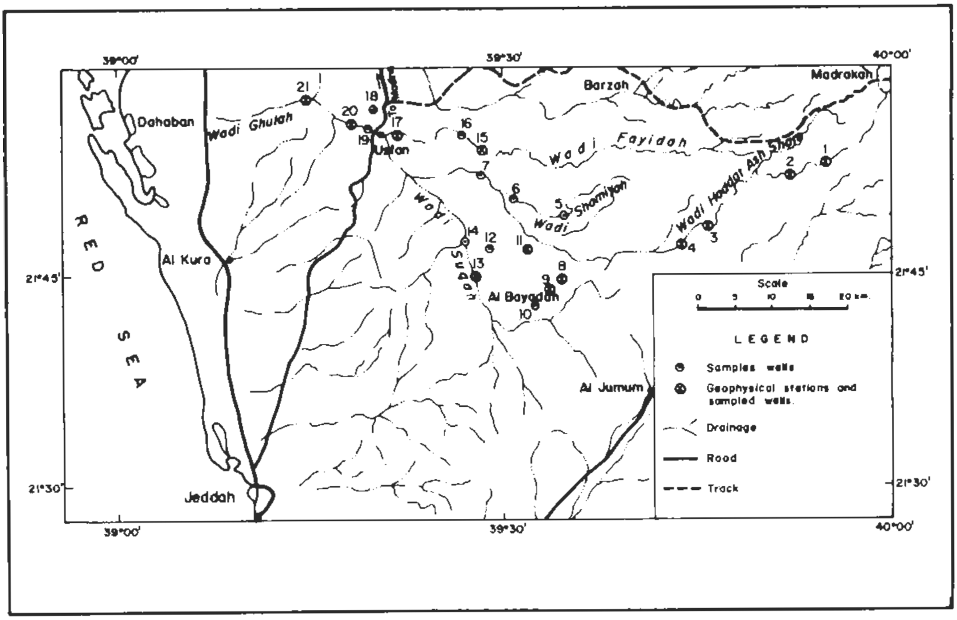

FIG. 1. Location map of the investigated wells in Usfan basin and joining wadis. (after Glen F. Brown and Roy O. Jackson, 1968).

logical variation within short distance. All these rocks are intruded by basic dykes succeeded by aplitic and pegmatitic dykes.

2. The Haddat ash Sham Formation consists of three members mapped by Bahafzalla *et al.* (1983). The lower member rests with marked unconformity on the Basement Complex, and is dated as Cretaceous or even older (i.b.d.). The authors described the lithological sequence as consisting of varied sized sandstones, conglomerates and clay-stones which may be calcareous, siliceous or gypsiferous. This formation was mapped as Shumaysi by Brown *et al.* (1962).

3. The Usfan Formation consists of a series of argillaceous and arenaceous strata together with littoral-type fossiliferous limestones. The fauna at the base of the formation are attributed to the Maestrichtian (Karpoff 1955), while the top of the formation is dated as Lower Eocene (Al-Shanti 1966). In W. Haddat ash Sham, the Usfan Formation overlies the upper member of the Haddat ash Sham Formation (Bahafzalla *et al.* 1983), although it overlies unconformably on the basement rocks in the Usfan area.

4. The Shumaysi Formation follows conformably that of Usfan near the Usfan Plain. It is mainly composed of sandstones, siltstones with interbedded oolitic ironstone bands and is dated as Eocene or Oligocene (Al-Shanti 1966). Recently, the middle horizon of the formation was dated as early Eocene (Moltzer and Binda 1981). In the Bayadah area, the Shumaysi Formation uncomformably lies on the Basement complex.

5. The basaltic plateau of Harrat Rahat is of variable thickness depending on the numbers of successive flows. Such flows belong to the Pleistocene starting in the Pliocene to continue in Quaternary up to recent times (Karpoff 1955). The basalt forms non-continuous caps overlying the upper levels of the previous rocks and formations.

6. Alluvial deposits are abundant in the floor of all the wadis. The valley deposits upstream are of pebbles in layers alternating with coarse sand, then graduate downstream to silt and clayey silt.

It is worthy to mention that the Precambrian Fatima Formation is missing in the study area.

A regional E-W cross section of the delimited area reveals the basin and range type of topography which represents the former horsts and grabens in alternate position and oriented almost N-S, parallel to the Red Sea Rift. These structures have been complicated by later geologic events and episodes of sedimentation in the graben basin. The major elements of the east-west traverse are (Fig. 2):

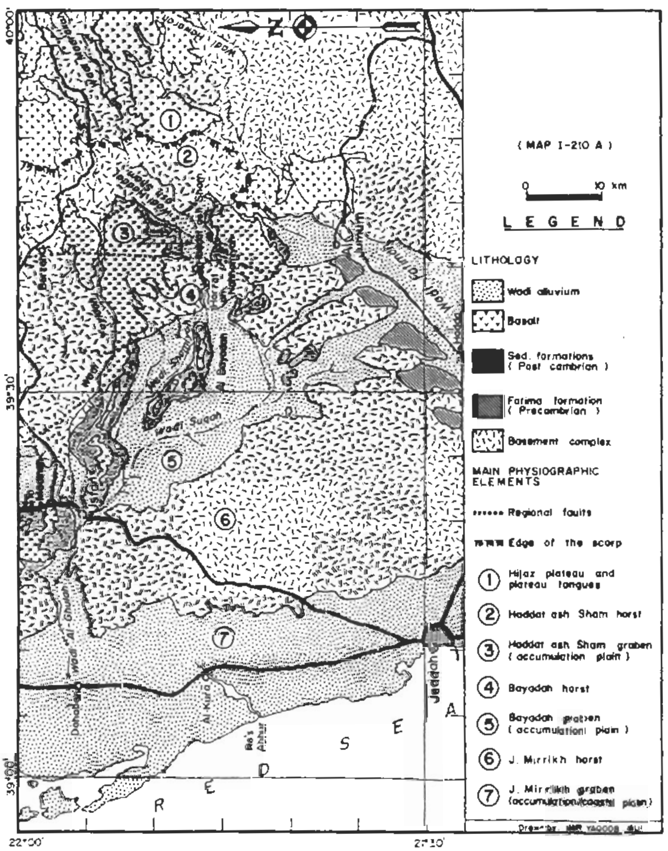

FIG. 2. Geology and the main structural elements of Usfan basin (modified after G.F. Brown *et al.* 1962).

1. Hijaz plateau, mostly capped by discontinuous basaltic sheets.
2. Haddat ash Sham horst block composed of Basement Complex rocks.
3. Haddat ash Sham graben basin, which is the site for deposition of the Haddat ash Sham, Usfan and Shumaysi Formations; these rocks are truncated and capped by the basaltic plateau.
4. Bayadah horst block, formed mostly of crystalline rocks of varied types.
5. Bayadah graben basin, including the Bayadah Plain in addition to Sudir and As Suqah wadis with the Usfan Plain at the northern tip of the graben.
6. J. Mirrikh horst block, composed of crystalline rocks in the form of somewhat steep mountains.
7. J. Mirrikh graben, which is an accumulation basin with a strip on the coastal plain.

The area under investigation has been previously studied from the point-of-view of hydrogeology and quantitative analysis of drainage basins. Al-Khatib (1977) studied the hydrogeology of 4 wadis, namely Fayidah, Gulah, As Suqah and Shamiya, on the basis of geophysical investigation and analysis of pumping tests. He recommended further study of the Usfan district. Al-Gamel (1981), during his regional study of the drainage basins in the western part of Saudi Arabia, indicated that the quality of the groundwater in many localities is not suitable for drinking purposes and in some localities it is suitable only for some vegetables and date palms.

Method of Work

The aim of this work was to study the relationship between rocks and landforms and the degree of variation in groundwaters of the Usfan basin and the suitability of such waters to varied usage. In addition, the depth of the saturated water zones and basement rocks at selected localities were geophysically determined. For this purpose, 21 water samples were collected from open and closed wells along the main wadis and plains (Fig. 1) during January-February 1983. These samples included 4 from W. Haddat ash Sham, 3 from W. Shamiyah, 5 from Bayadah Plain, 2 from W. As Suqah, 3 from W. Fayidah, 2 from Usfan Plain and 2 from W. Ghulah. Also 12 stations adjacent to sampled wells were selected for geophysical measurement.

The geophysical measurements were made using an AC Terrameter model SAS-300 ABEM for resistivity determinations by vertical electric sounding. The "V.E.S." were measured using a Schlumberger Configuration (Compagnie Generale de Geophysique, 1963) and the calculated apparent resistivities were plotted against half-electrode separations (AB/2) on bi-logarithmic papers of modulus 6.25 cm. The obtained "V.E.S." curves are quantitatively interpreted using Hummel's method with the help of two-layer theoretical curves (Mooney, 1954, Keller and Frischknecht 1970).

The specific conductance of the water samples was measured on site and the collected samples were chemically analyzed on return to the laboratory in order to determine major ion contents and to calculate the amount of dissolved solids. The re-

Table 1. Field and Laboratory data of groundwaters from Usfan basin and adjoining wadis.

Locations	W. Haddat ash Sham				W. Shamiyah			Bayadah Plain Eastern side			Bayadah Plain Western side		W. As Suqah		W. Fayidah			Usfan Plain		W. Ghulah	
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Cations mg/L																					
Ca^{+2}	42	49	66	120	99	110	597	70	74	67	156	95	175	655	62	177	148	224	1107	156	214
Mg^{+2}	20	30	7	59	66	62	317	9	62	20	106	40	145	183	7	5	79	84	514	32	57
Na^{+}	46	110	135	165	126	338	886	270	400	540	344	622	728	1062	150	209	680	101	849	871	803
K^{+}	5	2	2	4	1	1	2	2	2	1	1	1	5	1	2	1	1	5	6	3	4
Anions mg/L																					
HCO_3^-	9	19	31	19	17	25	9	30	19	27	25	50	18	17	14	28	29	13	12	28	29
CO_3^{-2}	6	6	24	3	3	3	3	3	5	13	9	18	8	9	12	3	8	3	3	9	9
SO_4^{-2}	82	142	171	358	242	482	2347	412	629	454	556	565	1179	978	247	81	756	69	507	311	424
Cl^-	130	223	194	363	371	522	1609	243	456	644	681	802	969	2589	158	571	957	734	4388	1459	1447
Calc. TDS mg/L	340	581	630	1091	925	1543	5770	1039	1647	1766	1878	2193	3227	5494	652	1075	2658	1243	7386	2869	2987
Field data																					
Sp. Cond. (micro-mho.cm)	610	990	1050	1800	1625	2650	9500	1690	2625	2900	3400	3900	5250	9240	1140	1900	4800	2200	13500	4750	4900
True Resist. of Sat. zone (ohm.cm)	29.0	1.7	27.0	8.0	-	-	-	2.1	7.0	-	7.0	-	2.0	-	15.0	-	2.1	-	-	17.0	10.8
Values of some ratios																					
Cations (epm)	5.87	9.76	9.74	18.10	15.88	25.27	94.48	16.02	26.25	28.48	31.49	35.10	52.44	93.95	10.23	18.35	43.48	22.62	134.60	48.38	50.40
Salinity (epm)	10.76	18.50	18.06	35.38	31.00	49.52	188.46	30.26	51.54	55.22	61.56	78.76	103.74	186.74	19.20	35.50	85.46	44.28	268.60	95.24	99.26
Total hardness as $CaCO_3$ (mg/L)	187	246	194	542	519	529	2792	212	439	250	438	402	1032	2388	184	462	694	904	4875	521	769
SAR	1.46	3.05	3.44	3.08	2.4	6.39	7.29	8.07	8.30	14.89	5.21	13.50	9.86	9.46	4.81	4.23	11.23	1.46	5.29	16.61	12.60
Type and grade of groundwater																					
Hydrochemical facies	Secondary Salinity Type							Primary Salinity Type					2 ry to 1 ry Salinity Type					Secondary Salinity Type		Primary Salinity Type	
Domestic consumption	Excellent			Good		Fair	Non-potable	Good	Fair			Non-potable			Excel-lent	Good	Non-potable	Good	Non-potable		
Irrigaion	Excellent									Good	Excellent	Good	Excellent				Good	Excellent		Good	
Livestock	Excellent						Medium	Excellent					Medium		Excellent				Medium	Excellent	

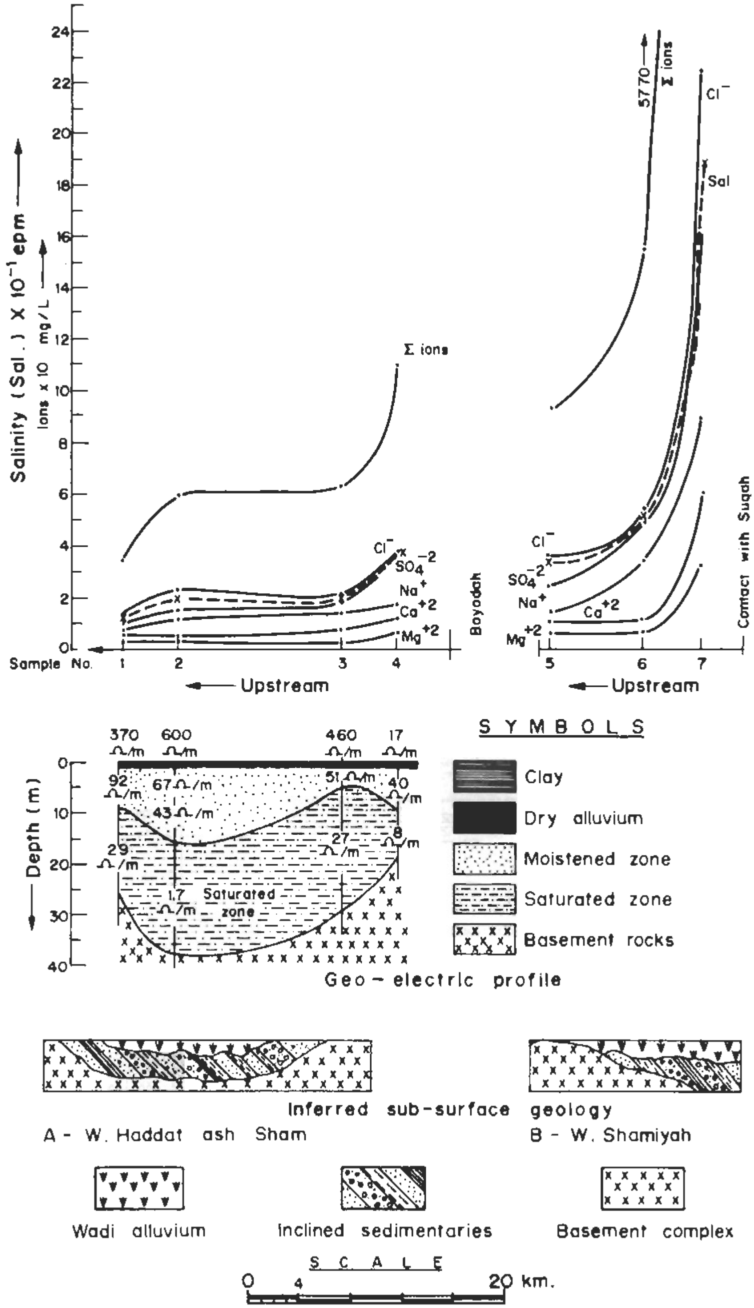

FIG. 3. Variation of ions concentrations in groundwaters of wadis Haddat ash Sham-Shamiyah course.

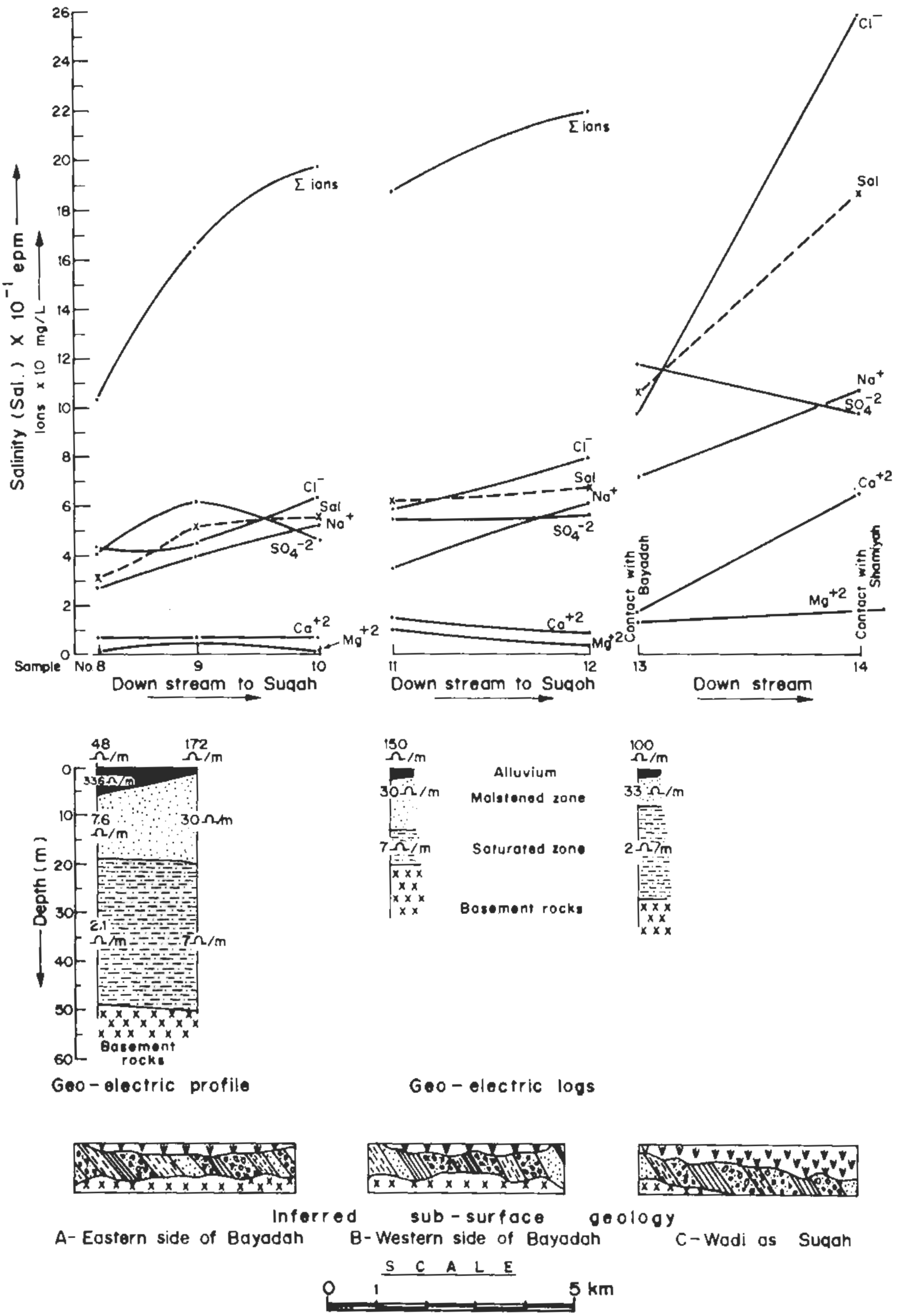

FIG. 4. Variation of ions concentrations in groundwaters of Bayadah plain and wadi As Suqah. (Symbols as Fig. 3).

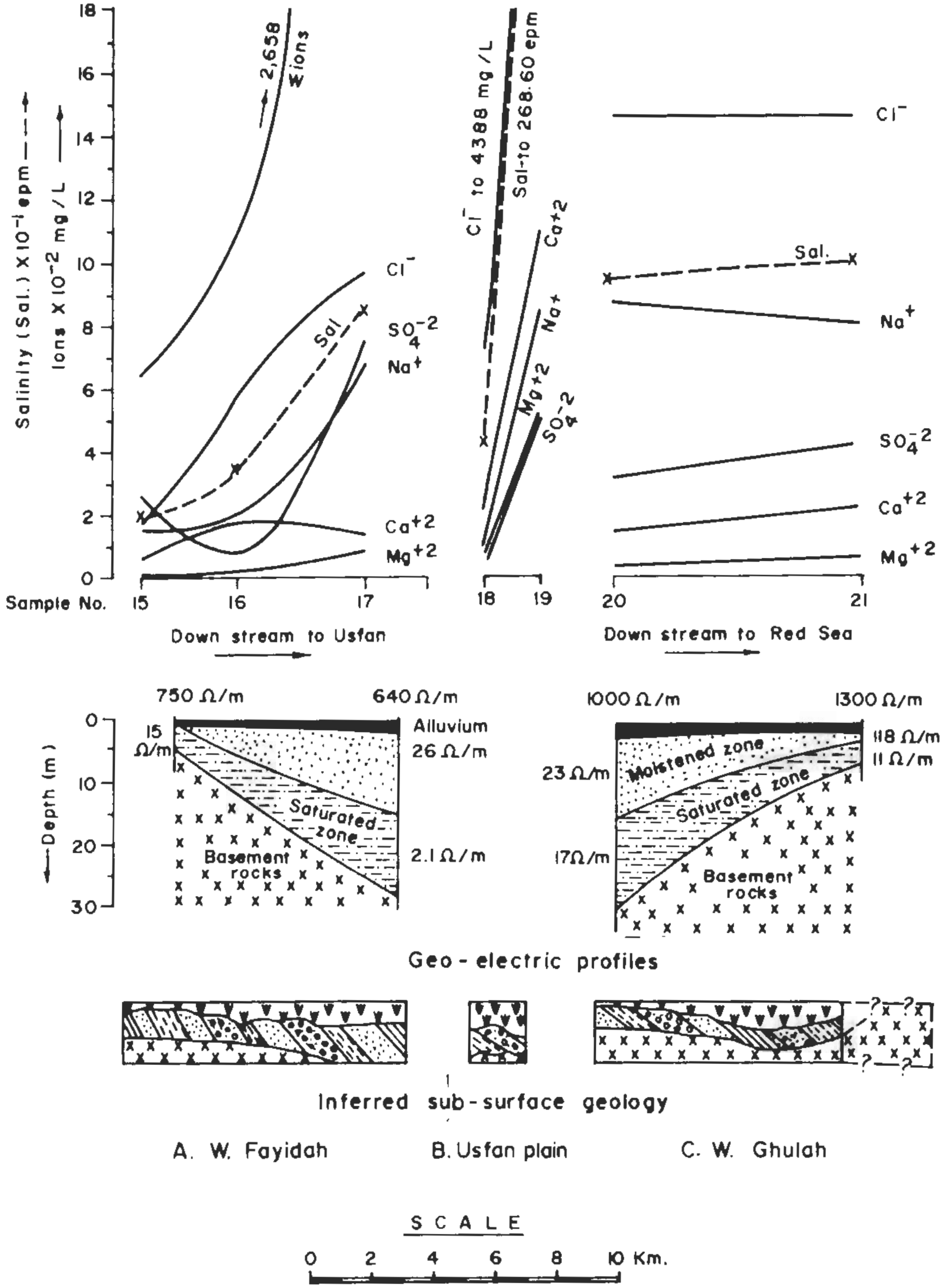

FIG. 5. Variation of ions concentration in groundwaters of wadis Fayidah, Ghulah and Usfan plain. (Symbols as Fig. 3).

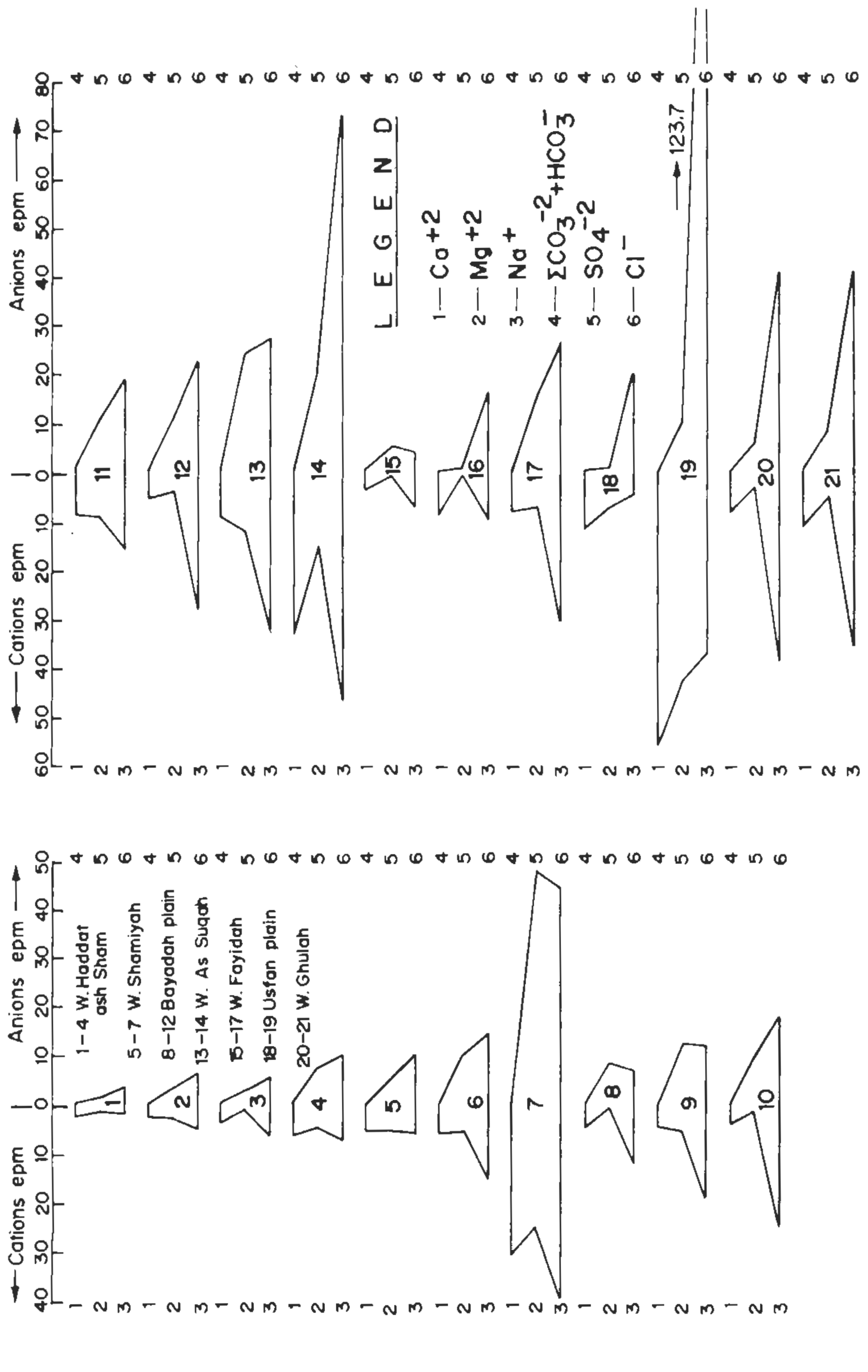

FIG. 6. Stiff diagram representing the chemical composition of soluble salts in groundwaters of Usfan basin and joining wadis.

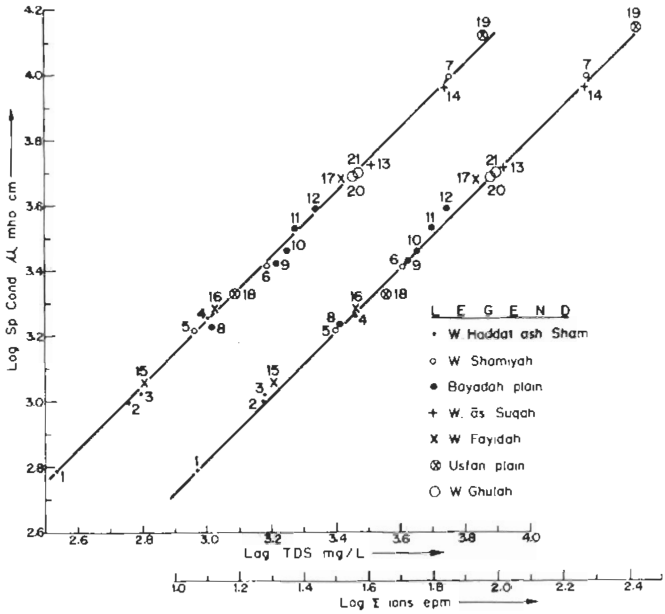

FIG. 7. Log variation curve of Sp. cond. (µmho. cm) to TDS mg/L and Σ ions epm.

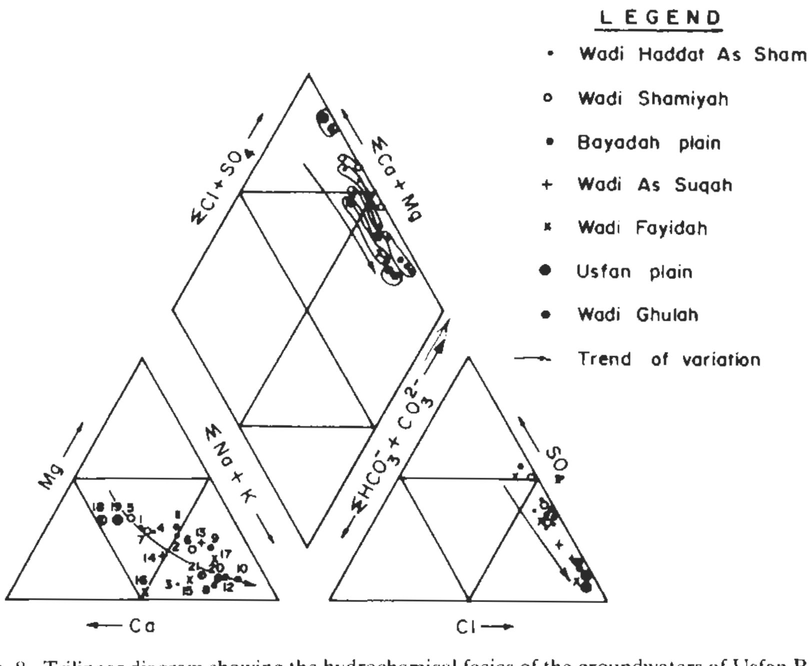

FIG. 8. Trilinear diagram showing the hydrochemical facies of the groundwaters of Usfan Basin.

sults are shown in Table 1. The variation of ion concentrations in the groundwaters along the wadis and plains under investigation in comparison with their respective geological and geo-electric profiles are graphically represented in Fig. 3, 4 and 5. The concentrations, expressed in equivalents per million (epm), are shown in Fig. 6 by use of pattern diagrams (Stiff 1951), modified by Hem (1959) and applied by Davis and de Wiest (1966). The bi-logarithmic relationship between TDS (mg/L) as well as Σ ions (epm), and specific conductance is illustrated in Fig. 7. The hydrochemical facies, in addition to the trend of variation in groundwaters of each wadi and plain are revealed in a trilinear diagram (Fig. 8) after Piper (1944) with classifications of other authors (Back 1961, Back & Hanshaw 1971, and Zeporozec 1972).

On the basis of criteria devised by the U.S. Public Health Service (1962), U.S. Environmental Protection Agency (1973, 1975), California Water Pollution Control Board (1952), and the SAR-Specific conductance diagram (Fig. 9) produced by the U.S. Salinity Laboratory (1954), the potential use of the groundwaters is considered.

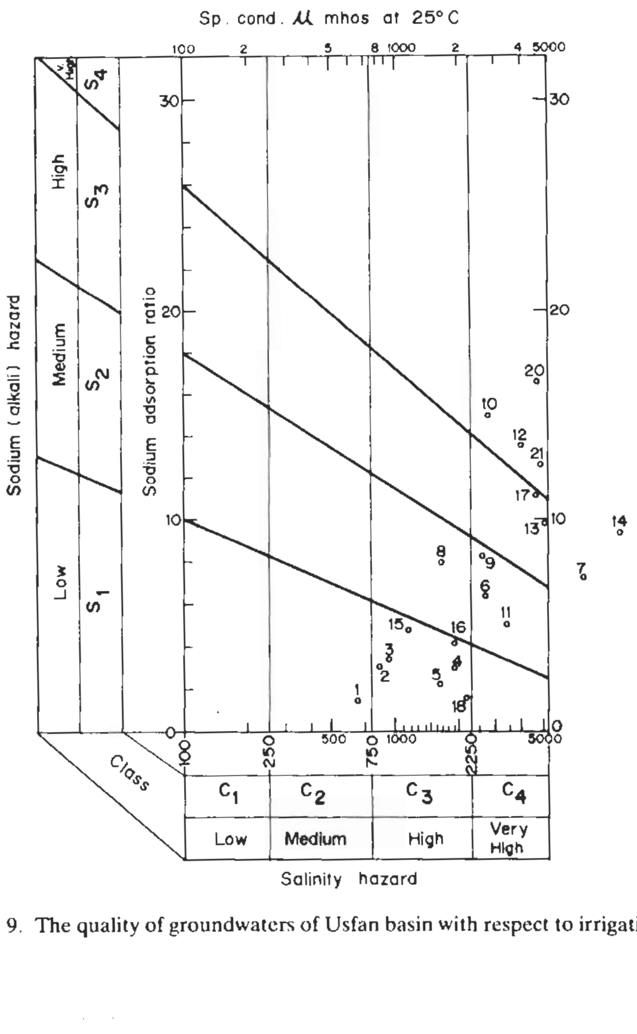

FIG. 9. The quality of groundwaters of Usfan basin with respect to irrigation.

Hydrochemistry

1. Haddat ash Sham-Shamiya Course

Wadi Haddat ash Sham is one of the wadis forming the western drainage of Harrat Rahat. The wadi extends NE to SW for about 110 km. Near south Haddat ash Sham village, the wadi is joined by W. Shamiya and W. Sudir. Wadi Haddat ash Sham originates as a gorage for 70-75 km on the crystalline basement which forms the western side of the Hijaz plateau (water sample No. 1). The wadi receives waters from W. Madrakah and other tributaries which drain a basalt area. Beyond the gorge, the wadi forms a wide enclosed plain for some 15 km, bounded on both sides by the Haddat ash Sham Formation overlain partially by the Usfan Formation and capped by basalt (water samples 2 & 3). South of Haddat ash Sham village, the wadi cuts a narrow channel in schist intruded by granitic and hybrid rocks (water sample 4).

The wadi shamiya extends NE-SW for 16 km with a width of 3 km parallel to the eastern side of Jabal Muhaysiniyah to join Wadi As Suqah near Jabal Fayidah. Starting from upstream (water sample 5) to the central (sample 6) to downstream (sample 7), both walls of the wadi are bounded by the so-called Shumaysi Formation capped by basalt.

The courses of the two wadis form an extensive gravelly flood plain with two levels of terraces. The younger and older terraces are 1-2 m and 4-6 m higher, respectively, than the floor of the wadi. Both terraces are generally patchy and degraded consisting of assorted boulders in addition to sandy and silty alluvium. The floor of both terraces downstream of W. Haddat ash Sham and the whole channel surface of W. Shamiya, are covered by thick riverine alluvium. Agricultural activity is practiced on the terraces.

The dissolved solids content in the groundwaters shows a gradual increase downstream from 340 mg/L to 630 mg/L some 8 km from the mouth of the wadi. Then the rate of increase becomes higher (See Fig. 3) as far as the mouth of the wadi (1,091 mg/L) and continues at the same rate for about 8 km along Wadi Shamiya (1,543 mg/L). Thereafter is an abrupt increase of salinity (5,770 mg/L) as far as the discharge point at Wadi As Suqah. The shapes of the patterns representing ion concentrations in waters along this course are similar (See Fig. 6) pointing to their unified type. One difference is the continuous increase of the area of the patterns from upstream of W. Haddat ash Sham to the discharge of W. Shamiya. In the same trend, there is increase of the values of SO_4/Cl (0.63 to 1.46), SAR ratios (1.46 to 7.29) and specific conductance (610 to 7,500 μmho. cm).

2. Bayadah Plain

The Bayadah Plain lies to the north of Jamum. It is tripizoidal in shape tapering to north-west and south-east and with a maximum width of 35-40 km. It is bounded by both Harrat Nahhamiyah and Jabal Muhaysiniyah on the eastern side and Jabal Mirrikh on the western side. The wadi As Suqah runs across the plain trending SE-NW, parallel to the western fault of the grabens with very low gradient between J. Muhaysiniyah and the Usfan Plain. Then the wadi joins Wadi Shamiyah and before joining Wadi Fayidah near Usfan village.

Thick alluvial deposits, mostly gravels, and boulders, cover the whole plain. In some parts, these alluvial deposits are overlain by wind blown sand and silt with the silty cover becoming thicker northwards. The crystalline rocks, exposed as dissected hills and ridges, are composed mainly of schists and amphibolites intruded by diorite and varieties of granitic rocks. Dykes of basic rocks and aplite are also associated with the intrusives. It appears that these rocks had undergone tectonic activity followed by subaerial erosion. The Shumaysi Formation presently outcrops as isolated bodies in the plain after being affected by differential peneplaination and overlain by basaltic plateau. Modern farming practice is undertaken in dispersed parts of the plain.

The most northern groundwater on the eastern side of Bayadah Plain (sample No. 8) is of similar composition as that of the discharge of W. Haddat ash Sham (sample No. 4).

On both the eastern and western sides of the Bayadah Plain, there is a pronounced increase in TDS as well as Na and Cl ions in the direction of a W. As Suqah, though the levels are higher on the western side (Fig. 4). Both Ca and Mg concentrations are relatively low with the trend of the divalent ions being the reverse of the monovalent ions which are characterised by higher contents and rapid increase in concentration. This may point to base exchange of Ca and Mg by Na, as well as exchange of SO_4 by Cl. The concentration of both TDS and the component ions show a continual increase from eastern to western side, which indicates the probable flow of Bayadah groundwater to the western side.

At the junction of the Bayadah Plain and W. As Suqah, the groundwater at the discharge point of the former (sample No. 12) and that relatively upstream of the latter have similar ion content. With NW flow direction and before merging in Usfan Plain the groundwater becomes more enriched in Cl<Na<Ca<Mg with decline in SO_4 concentration. Thus base exchange is not noticeable but SO_4 – Cl exchange is more pronounced. The similarity of shapes in the graphic representation of the Bayadah Plain and W. As Suqah groundwaters (Fig. 6) visualizes the interpretation of the variation of the dissolved ions in these waters. The gradual increase of dissolved solid content in groundwaters from the upper reach at Haddat ash Sham to the discharged area of W. As Suqah (Fig. 6) shows a continual increase in the size of the successive patterns with non-changing outlines of their shapes.

3. Usfan Plain and Adjoining Wadis

Wadi Fayidah runs almost NE-SW for about 50 km with V-shaped valley. Then it joins W. As Suqah at the Usfan Plain. Wadi Ghulah starts from the Usfan Plain and extends for >20 km westward to merge with the coastal plain near Dhaban town.

The headwaters of W. Fayidah starts SW of Madrakah village entrenched in ridges of the Arabian Shield. The relief of the basement is jagged and rough. In the upper reaches and for 10 km NE-SW, flat areas are lacking except for a few benches or spurs masked by large boulders and gravel. Some 20 km from the headwaters, the wadi crosses Shumaysi Formation strata down to its discharge end. The contact between basement rocks and Shumaysi Formation is mostly obscured except in a few hills east of Fayidah village. The Shumaysi beds follow the regional NW-SE trend with dips of 25°-30° to NE. Basaltic rocks about 25 m in thickness cap the rocks forming the walls of the wadi. But basalt is in the form of isolated patches in the upper zone of the wadi. Locally, at the downstream and on the southern side, basalt shows step faulting running NNE-SSW. There are 3 levels of terrace remnants of different height namely 10-12m, 6-8 m and 1-2 m above the present channel level. The highest one is mostly composed of large boulders while the second is formed of gravel and sand and the latest is silty terrace. The lower two levels are mostly cultivated.

The Usfan Plain form a structure running NW-SE parallel to the Red Sea Rift. The plain is bounded to the west and south by basement rocks, to the north-east by both Usfan and Shumaysi Formations and by the former on the north-western boundary. The Usfan Formation is composed of fossiliferous limestone, varied coloured sandstone and siltstone. The beds show quite steep dips up to 24° to the east and trend nearly N-S. They are capped by a basaltic plateau and the slopes are covered by basaltic debris and boulders. The basalt plateau is formed of three flows. The lower grey type of 10 m thickness is vesicular, amygdaloidal and severely weathered. The amygdalas are filled with calcite and/or chert. The blackish middle flow of 23.6 m thickness is hard but highly fractured with its accessory magnetite partly oxidised to hematite. The top flow (27.5 m thick) is of columnar structure and vesicular texture. Both the middle and top flows are olivine basalt while the lowest basalt is of hornblende type. Volcanic tuffs of 10-15 cm thickness mark the contact between the lower and the middle basaltic flows.

West of the Usfan Plain, the width of W. Ghulah is ≈4-5 km and increases downstream to attain its maximum width of ≈15-16 km north of Dahaban, then it merges into the sands and gravels of the coastal plain. The wadi course crosses varied types of rocks. In its upstream area, west of Usfan village, chlorite and sericite schists are exposed. The schists are much folded and faulted. The wadi appears to cross an anticlinal fold of schist for 5 km. The limbs of the fold dip 35° to NW and 25° to SE with the axis running N 45°E. This is followed by the Shumaysi Formation which has a regional dip of 18-20° to NNE. Both schists and sedimentary strata are overlain by basaltic rocks. Furthermore, in the downstream direction, granitic rocks peep out, as isolated hillocks, from degraded and completely planed terrain. The granitic rocks are highly exfoliated. Two stages of granitic intrusions can be distinguished, namely the relatively older highly weathered grey granite and the younger pink granite intruded by porphyritic andesite. The schists adjacent to the granitic terrain, are partly granitized. The wadi alluvium is mostly gravelly and sandy. Most of the wadi plain is covered with wind blown sand and silt.

The groundwaters in Wadi Fayidah shows a wide range of TDS. In the recharge zone with basement complex as country rock, TDS is only 652 mg/L but increases by 1.5 fold at the contact of the Shumaysi and basement rocks. By the outlet of the wadi, TDS is 4 times that further upstream. Mg is only pronounced in the downstream part of the wadi. The variation of the soluble ion content in the wadi groundwater (Fig. 5) points to the base exchange of Na by Ca and exchange of SO_4 by Cl particularly in the contact zone of Shumaysi and basement rocks (sample No. 16). As reflected from the geo-electric profile, the saturated zone is inclined downward with pronounced increase in thickness in the direction of the discharge zone. The upper surface of groundwater is within the level of the basement rocks in the upper most reaches of the valley while it is at 15 m depth from wadi level at the end of the wadi.

In the Usfan Plain, the soluble solid concentration of well sample No. 19 is abnormally high (7,386 mg/L), yet three years previously its TDS was similar to the groundwater in the well of sample No. 18 (1,243 mg/L). The increase of salinity is accompanied by increases in the component ions in the following sequence $Cl<Ca<Na<Mg<SO_4$. The proximity of the sea and the low-level conditions of the Usfan Plain suggest the possibility of sea-water intrusion. But the high value of the Ca/Mg ratio (2.7) as well as a value of Ca/Na in excess of unity exclude the influence of sea water. Comparing the groundwater samples of the Usfan Plain, despite their wide variation in dissolved solid content, the concentration frequencies of the component ions show the same sequence. Also the values of Ca/Mg, Cl/SO_4, Cl/Na ratios of the waters of the two wells have the same character. Moreover, the pattern shapes (Fig. 6) representing the ion contents in the two sample (No. 18 & 19) are more or less identical. So, the abnormal increase of salinity of sample No. 19 can be attributed to the effect of excessive pumping that results in up-coning from a lower brackish water. The characteristic feature of the predominance of Ca over Na is attributed to liberation of Ca from the fossiliferous limestone member of the Usfan Formation forming the aquifer in the plain.

Along the water course of 8 km in Wadi Ghulah, the dissolved solid content varies slightly to increase downstream by only 118 mg/L. But the behaviour of the component ions is different. The Cl content is nearly constant being 1,453±6 mg/L, while Na shows a slight decrease; SO^4 and Ca show nearly parallel rate of pronounced increase but Mg is of relatively lower concentration. This may be attributed to the effect of base exchange as well as dissolution of cementing material from the Shumaysi Formation, *i.e.* gypsum and carbonates.

Variation of Salinity and Conductivity

Generally, in the groundwaters of the Usfan basin, Cl is the dominant anion while concentrations of HCO_3 and CO_3 are very low. Also K is the least abundant of the cations and the values of the Ca/Mg ratio is always more than unity. As groundwaters move along flowlines from recharge to discharge areas, their chemistry is altered. This alteration is revealed in Table 1 and Figures 3 to 6, tends to evolve chemically towards a composition comparative with that of sea water. Such a relationship is graphically illustrated by changes in dominant ion species through the increase of the degree of preponderance of Cl over SO_4 as well as Na over Ca. Also Ca, Mg and SO_4 increase at a rate less than that of TDS. This is in accordance with the conclusions of Chebotarev (1955) and Domenico (1977). The rate of the increase of salinity, total hardness, TDS and component ions in the groundwater flows along the wadis is variable. This is attributed to the variable effects of different rock types in the saturated zone, irrigation and ion change phenomenon. The TDS of the groundwaters increases by their contact with sedimentary rocks of marine origin (Davis and de Wiest 1966). It is observed that the amount of derived ions in groundwater is least in the Haddat ash Sham Formation but increases by contact in those of Shumaysi and Usfan. The circulation of the groundwater through several cycles of irrigation tends to increase TDS concentration by evapotranspiration and the leaching of soluble matter from soil and unsaturated zone. The degree and type of ion change are variable being either that (Ca+Mg) for Na and/or SO_4 for Cl. This depends on the affinity of absorption of different clay minerals in the aquifer and the concentration of soluble ions in the flow (Hanshaw and Coplen 1973).

Comparing the TDS of the sampled groundwaters with their analogous electrical resistivity (Table 1), any relationship is absolutely lacking. Electrical resistivity profiling can quickly and cheaply locate the general position of the aquifer. The sensitivity of the method depends on the relative uniformity of geology and topography as well as minimal extraneous electrical interference (Urish 1983). But the resistivity controls the gradient in electrical potential that is created in a formation under the influence of an applied current (Mollard 1973). The absolute lack of TDS-Resistivity ion relation is attributed to the effects of variable factors in addition to the degree of salinity of the groundwaters. Such factors include rock type, density and porosity of the saturated zone (Kotb *et al.* 1983). The total dissolved solids (ppm) is numerically related to its analogous specific conductance by the constant (A) which is of variable value. This relationship is not simply due to the effect of the differences of the kind, charge, size and mobility of the component ions of TDS. But by plotting the TDS (ppm) and Σ ions (epm) against the specific conductance, (μmho. cm), linear bi-logarithmic relations can be constructed (Fig. 7). The slopes of the linear relations indicate that the values of the constants are 0.575 and 51.283 with respect to TDS (mg/L) and Σ ions (emp), respectively, with the maximum error not exceeding $\pm 9\%$ of the actual values. Thus:

Specific conductance (μmho. cm at 25°C)

$$= 0.575 \times \text{TDS (mg/L)}$$
$$= 51.283 \times \text{ions (empm)}$$

This linear relationship may also be seen as further evidence of the unified source of the groundwaters of the Usfan basin. The maximum error not exceeding 9% of the actual values is attributed to the varied concentrations of the sulphate and chloride soluble solids which have different degrees of disassociation.

Hydrofacies and Usability

The hydrochemical facies of groundwaters in the Usfan basin are revealed from the trilinear diagram (Fig. 8) developed by Piper (1944) and modified by Back (1961) and Back & Hanshaw (1971). The majority of the groundwater samples are of sodium type with exception of 2 samples from each of wadis Haddat ash Sham, Shamiyah and the Usfan Plain. These samples are of non-dominant cation type and characterized by less than 0.5 for Na/(Ca + Mg) ratio. The trend of these samples extends to the direction of the boundary of the calcium type. With respect to the anions, all groundwater samples are of a chloride type with exception of one sample from each of wadis Shamiyah, Fayidah and Bayadah Plain. The groundwaters of the Usfan Plain as well as those of wadis Haddat ash Sham and Shamiyah are mostly of non-carbonate hardness more than 50 percent being of secondary salinity type. Those of Bayadah Plain and Wadi Ghulah are of non-carbonate alkali over 50% being a primary salinity type as their chemical properties are dominated by alkali cations and strong acid anions. The groundwaters of both wadis As Suqah and Fayidah grade from secondary to primary salinity as flowing towards the discharge zone. It may be concluded that the general trend of variation in the groundwaters of the Usfan Basin is from secondary to primary salinity hydrochemical facies to plot in direction of right hand vector of the central diamond-shaped plotting field.

For domestic uses, the scale designed by Davis and de Wiest (1966) is adopted. The groundwaters of W. Haddat ash Sham, the recharge zone of Wadi Fayidah, the discharge zone of W. Haddat ash Sham, as well as the groundwaters upstream of both W. Shamiyah and the eastern side of Bayadah Plain and the non-disturbed well of Usfan Plain are of good grade. In the direction of downstream flow, the groundwaters become of fair quality except for the discharge zone of wadis; Shamiyah and Fayidah being non-potable. The total flows of wadis As Suqah and Ghulah as well as the disturbed well in the Usfan Plain are also non-potable.

Many factors are considered in evolving the usefulness of groundwater for irrigation, such as TDS and the relative proportions of some of the constituents. SAR values and their relation to specific conductance (U.S. Salinity Lab. Staff 1954, p. 80) determine the grade of the groundwaters with respect to irrigation purposes (Fig. 9). The groundwaters of Wadi Haddat ash Sham and those upstream of wadis Shamiya (No. 5) and Fayidah (No. 15 & 16) and the undisturbed well of Usfan Plain (No. 18) are of low sodium and high salinity hazards except the most upstream of W. Haddat ash Sham which are of medium salinity. Trending from the recharge zone downstream direction, the sodium hazard of the groundwaters grades to medium value to reach high hazard with very high salinity. Thus all groundwaters of the Usfan basin are of excellent grade for irrigation except those of wells No. 10 & 12 (downstream of Wadi Fayidah).

Specifications for breeding livestock have been suggested by California Water Pollution Control Board (1952) and U.S. Environmental Protection Agency (1975). On their criteria the majority of the groundwaters of the Usfan basin are of excellent grade being suitable for breeding all types of livestock. Only the groundwaters of downstream of Wadi Shamiya as well as those of Wadi As Suqah and the disturbed well in the Usfan Plain are of medium grade being suitable for breeding horses, cattle and adult sheep.

References

Al-Gamel, S.A. (1981) Regionalization of Groundwater Quality in Western Saudi Arabia, Thesis, M.Sc., Fac. Earth Sci., K.A.U., 154 p.

Al-Khatib, E.A.B. (1977) *Hydrogeology of Usfan District,* Thesis, M.Sc., Institute of Applied Geology, King Abdulaziz University, Jeddah, 302 p.

Al-Shanti, A.M.S. (1966) Oolitic iron deposits in Wadi Fatima between Jeddah and Mecca, *Saudi Arabian Dir. Gen. Miner. Resour. Bull.* **2,** 51 p.

Back, W. (1961) Techniques for mapping hydrochemical facies, *U.S. Geol. Surv. Prof. Paper,* **424-D:** 380-392.

Back, W. and **Hanshaw, B.** (1971) Geochemical interpretations of groundwater flow system, *Wat. Res. Bull.* **7:** 1008-1016.

Bahafzalla, A., Basahel, A.N., Mansour, H.H. and **Omara, S.** (1983) Geologic mapping and stratigraphy of the sedimentary sequence in Haddat ash Sham area northeast of Jeddah, Saudi Arabia, *Arab Gulf J. Scient. Res.* **1:** 423-442.

Brown, G.F. and **Jackson, R.O.** (1958) Geographic map of Southern Hijaz Quadrangle, Kingdom of Saudi Arabia. *U.S. Geol. Surv. Misc. Geol. Investig. Map* 1-210B.

Brown, G.F., Jackson, R.O., Bogue, R.G., and **Maclean, W.H.** (1962) Geologie map of southern Hijaz quadrangle, Kingdom of Saudi Arabia. *U.S. Geol. Surv. Misc. Geol. Investig. Map.* **1-210A.**

California State Water Pollution Control Board (1952) Water-quality criteria, *California State Water Pollution Control Board* Publ. **3.**

Chebotarev, I.I. (1955) Metamorphism of natural waters in the crust of weathering, *Geochim. Cosmochim. Acta.* **8:** 22-48, 137-170, 198-212.

Compagni Generale de Geophysique (1963) *Master Curves for Electrical Sound, 2nd* ed., European Assoc. Exploration Geophysicists, The Hague, 49 p.

Davis, S.N. and **de Wiest, R.J.M.** (1966) *Hydrogeology,* John Wiley & Sons, New York, 463p.

Domenico, P.A. (1977) Transport phenomena in chemical rate processes in sediments, *Ann. Rev. Earth Planet. Sci.,* : 287-317.

Hanshaw, B.B. and **Coplen, T.B.** (1973) Ultrafiltration by a compacted clay membrance: II. Sodium ion exclusion at various ionic strength, *Geochim. Cosmochim. Acta,* **37:** 2311-2327.

Hem, J.D. (1959) Study and interpretation of the chemical characteristics of natural water. *U.S. Geol. Surv. Water-Supply Paper* **1473,** 363 p.

Karpoff, R. (1955) Observation preliminaire sur le socle ancien de l'arabie, *C.r. Somm. Soc. Geol. Fr.,* : 105-106.

Keller, G.V. and **Frischknect, F.C.** (1970) *Electrical Methods in Geophysical Prospecting,* Pergamon Press Ltd., Oxford, 517 p.

Kotb, H., Hakim, H. and **Zaidi, S.** (1983) A geochemical and geophysical investigation of ground water in Wadi Fatima, *Bull. Fac. Earth Sci., K.A.U.* **5:** 135-152.

Mollard, J.D. (1973) *Landforms and Surface Materials of Canada: A Stereoscopic Air Photo Atlas and Glossary,* J.D. Mollard and Associates Ltd. Regina, Sask., Canada.

Moltzer, J.G. and **Binda, P.L.** (1981) Micropaleontology and palynology of the upper members of the Shumaysi Formation, Saudi Arabia, *Bull. Fac. Earth Sci., K.A.U.* **4:** 57-76.

Mooney, H.M. (1954) Depth determination by electrical resistivity, *Mining Engr.* **6:** 915-918.

Piper, A.M. (1944) A graphic procedure in the geochemical interpretation of water analyses, *Trans. Am. Geophys. Union* **25:** 914-923.

Stiff, H.A., Jr. (1951) The interpretation of chemical water analysis by means of patterns, *J. Petrol Tech.* **3:** 15-16.

Urish, D.W. (1983) The practical application of surface electrical resistivity to detection of ground water pollution, *Ground Water* **21:** 144-150.

U.S. Environmental Protection Agency (1973) Water quality criteria 1972, *EPA R3* **73033,** Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency (1975) Water programs, national interim primary drinking water regulations, *Federal Register* **40,** No. 248.

U.S. Health, Education, and Welfare Dept. (1962) Public health service drinking water standards. U.S. Public Health Service Publ. 956.

U.S. Salinity Lab. Staff (1954) Diagnosis and improvement of saline and alkali soils, *U.S. Dept. Agr. Handbook No.* **60.**

Zeporozec, A. (1972) Graphical interpretation of water quality data, *Ground Water* **10:** 32-43.

الصفات الجيوكيميائية المميزة للمياه الجوفية بحوض عسفان في المملكة العربية السعودية

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يضم حوض عسفان بمساحة ٢٠٠٠كم٢ سهلين أساسيين هما البياضة وعسفان ، بالإضافة إلى عدد من الوديان تخترق عديداً من الصخور المختلفة وأشكال جيومورفولوجية متباينة وضهور وأخاديد متتابعة متوازية لأخدود البحر الأحمر . جمعت عينات ممثلة للمياه الجوفية من ٢١ موقعا بالوديان والسهلين ، وتم تقدير محتوى كل منها من الكاتيونات والأنيونات الذائبة وقيست درجة الموصلية النوعية بكل موقع ، كما تم استنتاج القطاع الجيولوجي بكل موقع باستخدام القياسات الجيوفيزيقية الكهربية .

وقد تم إيضاح تأثير نوعيات الصخور التي تخترقها المياه الجوفية على التغيير في محتواها الملحي من نوعيات وكميات الأيونات الذائبة من خلال إنشاء علاقة لوغارتمية خطية بين درجات الموصلية النوعية ومايقابلها من كمية مواد صلبة ذائبة (مجم/لتر) ومجموع الأيونات الذائبة (مكافيء/جزء في المليون) أمكن التوصل إلى معادلة يمكن تطبيقها للتنبؤ بكمية المواد الصلبة الذائبة أو مجموع الأيونات بخطأ لايزيد على ٩٪ بقياس درجة الموصلية النوعية .

والمياه الجوفية بحوض عسفان في أعلى الوديان من النوع الكلوريدي ويسود أيون الصوديوم عند مصابّها وقليل منها من النوع الكبريتاتي ويسود أيوني الكالسيوم والمغنسيوم . وقد تم تحديد مدى ملائمة المياه الجوفية بحوض عسفان للاستهلاك البشري والري وتربية الماشية .