# HYDROCHEMOGRAPHS OF BERGHAN KARST SPRING AS INDICATORS OF AQUIFER CHARACTERISTICS

EZZATOLLAH RAEISI AND GHOLAMHOSEIN KARAMI
*Department of Geology, College of Science, Shiraz University, Shiraz, IRAN*

*Berghan Spring is located in the southern part of Iran, northwest of Shiraz. The catchment area of the spring consists of the southern flank of the Gar Anticline, which is made up of the karstic calcareous Sarvak Formation. There are no sinkholes or other karst landforms in the catchment area. Because of the existence of several faults, the aquifer has been brecciated and may have caused karstification to occur in most of the pores and fissures. The specific conductance, pH and water temperature were measured once every twenty days for a period of 32 months and water samples were analyzed for major anions and cations. Flow rate was measured daily during the recession, and once every three weeks during the rest of the study period. Using the WATEQF computer model, the partial pressure of carbon dioxide and the saturation index of calcite and dolomite also were estimated. Three distinct periods, the first recession, the second recession, and precipitation, were observed in the hydrograph of Berghan Spring. No considerable differences were observed between the first and second recession coefficients. Base flow constitutes 71.5%, 100% and 66.2% of total flow in the first recession period, the second recession period and the precipitation period, respectively. The variation of specific conductance, calcium and bicarbonate concentrations and calcite saturation indices are not significant during the study period, implying that aquifer characteristics control the chemical behavior of the spring. The morphology and geology of the Berghan Spring catchment area, and data from hydrographs and chemographs, show that the hydrologic system is dominantly diffuse flow. Evidence for this is shown by autogenic recharge, a brecciated aquifer, and small values and slight differences in hydrograph recession coefficients. In addition, specific conductance, calcium and bicarbonate concentrations, and water temperature did not show significant variations during the study period suggesting a diffuse flow aquifer.*

Studies have been conducted during the last three decades on the variations of physical and chemical properties of springs in order to understand the hydrogeological behavior of karst aquifers. Such studies generally began with the work of Garrels and Christ (1965) in which underground flow in carbonate rocks was divided into open and closed systems. In an open system, there is no limit on the amount of carbon dioxide available for the dissolution of calcium carbonate, whereas in a closed system, once the available carbon dioxide is used up, the dissolution of limestone terminates. Zötl (1960), and Smith and Mead (1962) used the time variations of chemical parameters to identify hydrogeological characteristics of karstic aquifers. White and Schmidt (1966) and White (1969) divided the flow in karstic aquifers into conduit and diffuse systems, based on spring behavior. Shuster and White (1971) made the same division based on time variations of temperature, specific conductance, and calcium, magnesium, and bicarbonate concentration. Newson (1972) and Ternan (1972) confirmed this division. Jacobson and Langmuir (1974), in their studies in Pennsylvania, divided karst flow systems into conduit, diffuse-conduit, and diffuse.

In a diffuse system, laminar flow occurs through interconnected fissures smaller than one centimeter. In this type of system springs are generally numerous and have small discharges. Diffuse flow is relatively uniform through the aquifer and there is small variation of physical and chemical properties in the springs. A diffuse system is mostly fed directly from carbonate rocks and the soil covering these rocks. The coefficient of variation of total hardness in diffuse flow is less than 5% and few karst geomorphological features are present in the catchment area of these springs. Turbulent flow occurs in conduits ranging from one centimeter to more than one meter and the groundwater generally discharges through one large spring. Specific conductance and other physical and chemical properties are non-uniform in conduit systems. Conduit systems are fed through sinkholes and solutional joints in bare rocks. The coefficient of variation of total dissolved solids ranges from 10 to 24%.

Bakalowicz (1977) suggested that the structure of a karst aquifer cannot be defined from the coefficient of variation of chemical variables, as was suggested by Shuster and White (1971). Atkinson (1977) also noted that the very small range in calcium carbonate concentration in resurgences from the Mendip Hills, England, would suggest that they are diffuse flow springs according to Shuster and White’s criteria, yet are known to be fed largely by conduit flow. He concluded that flow in carbonate aquifers is a combination of diffuse and conduit systems and divided them into “quick” flow and “slow percolation” flow according to velocity. Scanlon and Thrailkill (1987), using the suggested criteria by previous workers, carried out a comprehensive study of conduit and diffuse regimes in the Inner Bluegrass of central Kentucky. Their results were not consistent with those of previous workers and indicated that spring water chemistry could not be related to the physical characteristics of karst aquifers in this area. Raeisi et al. (1993) attempted to determine the Sheshpeer

Spring flow system using criteria proposed by various authors, but obtained contradictory results.

Seasonal variation in water temperature is another criterion that may be used to distinguish diffuse and conduit flow. When water flows turbulently through large conduits in a karst aquifer, spring temperature is affected by atmospheric temperature. When water flows slowly through small joints, as in a diffuse-flow system, however, spring temperature is not affected by atmospheric temperature variations because it is dampened by rock mass temperatures. Cowell and Ford (1983) found the water temperature deviation to be 5.9ºC in conduit springs and 1.32ºC in diffuse springs on the Bruce Peninsula, Ontario, Canada. Ede (1973), in a one year survey of the South Wales region of Great Britain, found the temperature of conduit springs to range from 6.5ºC to 11ºC and that of diffuse springs to vary from 10.9ºC to 11.1ºC.

The shape of the outflow hydrograph of a spring is a unique reflection of the response of an aquifer to recharge. Broad reviews of this subject have been given by Ford and Williams (1989). The analysis of spring hydrographs offers considerable potential insight into the structure and hydraulics of karst drainage systems and is further improved if the hydrographs are analyzed with corresponding chemographs. Bakalowicz and Mangin (1980, quoted from Ford and Williams, 1989) showed how the degree of heterogeneity of karst aquifers may be deduced from hydrograph and chemograph data. Raeisi and Karami (1996) suggested that if the physicochemical characteristics of a karst spring are to be used to determine the properties of the corresponding aquifer, the effect of external factors on the outflow should be evaluated first, and then the characteristics of the karst aquifer should be determined.

The objective of this study is to use hydrochemographs of the Berghan karst spring along with knowledge of the local geology to determine some of the aquifer properties, including the type of flow system. An attempt is then made to propose a probable model of groundwater flow in the Berghan aquifer.

## HYDROGEOLOGICAL SETTING

The study area is located 80 km northwest of Shiraz, in southern of Iran. This region is situated in the Zagros thrust zone. Geologic formations in decreasing order of age are the Hormuz (Palaeozoic), Khami Group (Lower Jurassic-Albian), Kazhdomi (Albian-Cenomanian), Sarvak (Albian-Turonian), Pabdeh-Gurpi (Santonian-Oligocene), Asmari-Jahrum (Paleocene-Miocene), Razak (Early Miocene), and Bakhtiari (Late Pliocene-Pleistocene) (Figure 1). The detailed lithology of these formations is described by James and Wynd (1965), and Stocklin and Setudehina (1977).

The Barm-Firooz and Gar Anticlines (Gar Mountain and Mor Mountain) are situated on the general northwest trend of the Zagros Mountain Range. The cores of the anticlines are comprised of the calcareous Sarvak Formation (Albian-Turonian) which is sandwiched between the two impermeable Kazhdomi (Albian-Cenomanian) and Pabdeh-Gurpi

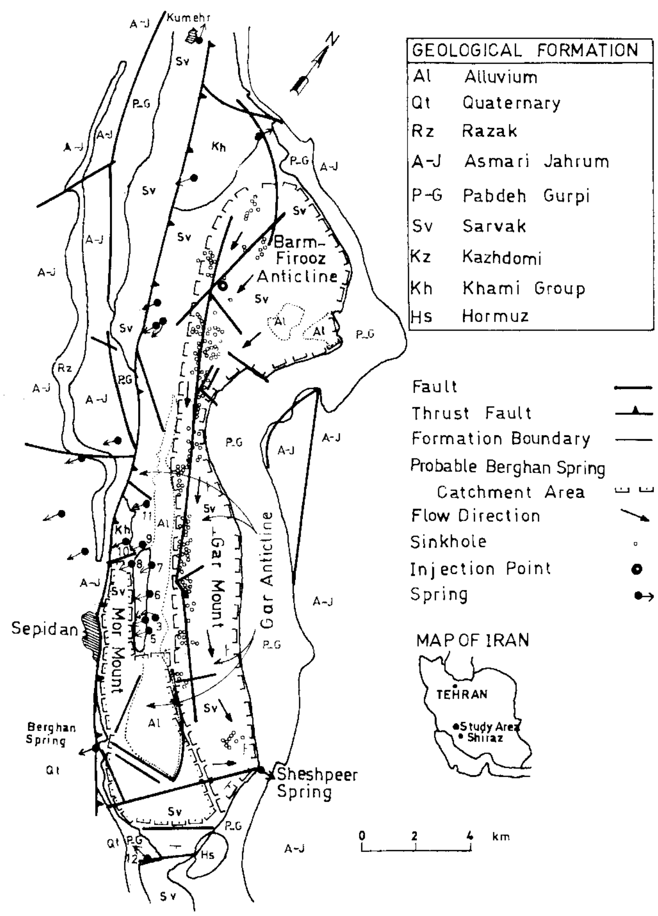


**Figure 1. Hydrogeological map of the study area (after Raeisi & Karami, 1996). Razak (Early Miocene), Asmari-Jahrum (Paleocene-Miocene), Pabdeh-Gurpi (Santonian-Oligocene), Sarvak (Albian-Turonian), Kazhdomi (Albian-Cenomanian), Khami Group (Lower Jurassic-Albian), Hormuz (Paleozoic).**

(Santonian-Oligocene) Formations (Figure 1). The most important tectonic feature in the study area is a northwest trending thrust fault (Figure 1). The southern flank of the Gar anticline (Mor Mountain) has been completely crushed. A cross section (Figure 2) shows the geological setting of the study area. The hydrogeological relationship of northern flank and southern flank of both anticlines has been disconnected by the action of thrust fault and impermeable Kazhdomi Formation.

Groundwater from the Sarvak aquifer discharges from 12 small and large springs, 11 of which, including Berghan Spring, emerge from the southern flank of the anticline, and one large spring (Sheshpeer Spring) emerges from the northern flank. Table 1 shows the elevations, mean annual discharges, and specific conductance (Spc) of these springs. The mean annual discharge of Sheshpeer and Berghan Springs is 3247 L/sec and 632 L/sec respectively, while the mean annual discharge of the other springs ranges from 1.41 to 68.3 L/sec. The probable catchment area of Berghan Spring is about 19 km$^2$

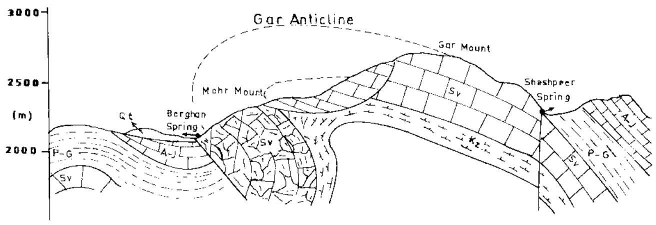


**Figure 2. Geological cross section between Berghan and Sheshpeer Springs. Qt = Quaternary, A-J = Asmari-Jahrum Formations (Paleocene-Miocene), P-G = Pabdeh-Gurpi Formations (Santonian-Oligocene), Sv = Sarvak Formation (Albian-Turonian), Kz = Kazhdomi Formation (Albian-cenomanian). From Raeisi, et al., 1993.**

(Pezeshkpoor, 1991). This catchment area is part of the southern flank of the Gar anticline (Figure 1). Dye-trace studies by Zare and Raeisi (1993) showed that water from the northern flank of Barm-Firooz anticline discharges only from Sheshpeer Spring, thus confirming the estimated boundaries of the Berghan Spring catchment area. Several normal faults and one thrust fault have resulted in an extensive brecciated zone in the catchment area of Berghan Spring (Figure 2). No sinkholes, pits, shafts, or caves are present in the catchment area of Berghan Spring. Forty percent of the catchment area is covered by soil (Karami, 1993).

Berghan Spring has one main, and two smaller resurgences, named the Eastern, Central, and Western emergences, respectively. The distance between the Central emergence and the Eastern and Western emergences is one and three meters respectively, and the elevation of the three emergences is almost the same. The Eastern, Western, and Central emergences discharge about 70, 25, and 5% of the total discharge, respectively. The average annual precipitation at Berghan Station, elevation of 2110 m, is 700 mm. The elevation of Berghan Spring is 2145 m and the catchment area is as high as 2500 m, thus precipitation in the catchment area is considerably greater. Precipitation occurs mostly in winter and in the form of snow, but most of the snow cover is melted by early April. There is no precipitation during late spring and summer.

**Table 1. Elevation, mean annual discharge, and specific conductance of the karst springs of Sarvak aquifer (after Raeisi et al., 1993).**

| Spring Name | Number on Figure 1 | Elevation meters | Mean Annual Discharge (liters/sec) | Specific conductance microsiemens/cm |
|---|---|---|---|---|
| Sheshpeer | 1 | 2335 | 3247.00 | 268.60 |
| Berghan | 2 | 2145 | 632.00 | 254.45 |
| Sib | 3 | 2480 | 34.31 | 232.01 |
| Saro | 4 | 2427 | 39.89 | 263.64 |
| Masjed | 5 | 2415 | 3.48 | 275.55 |
| Seileh | 6 | 2492 | 2.25 | 191.61 |
| Ghanat Sefid | 7 | 2544 | 21.82 | 188.45 |
| Targeh | 8 | 2468 | 4.17 | 366.45 |
| Baladan | 9 | 2495 | 1.41 | 259.11 |
| Pariz | 10 | 2483 | 9.28 | 303.45 |
| Dobardak | 11 | 2714 | 35.70 | 247.36 |
| Morikash | 12 | 2120 | 68.34 | 278.36 |

## METHOD OF STUDY

The specific conductance, water temperature, and pH of the three emergences of Berghan Spring were measured on site, and the major ions (calcium, magnesium, potassium, sodium, bicarbonate, sulfate, and chloride) were determined in the laboratory from samples collected once every twenty days from June 1991 to November 1992. Data obtained by Pezeshkpoor (1991) from March 1990 to June 1991 also were used. Calcium, sodium, and potassium concentrations were determined using flame photometric methods, bicarbonate by standard titration, chlorine by the Mohr volumetric method, and sulfate by turbidimetry in the hydrochemical laboratory of Geology Department, Shiraz University.

Carbon dioxide partial pressure ($P_{CO_2}$), calcite saturation index ($SI_c$), and dolomite saturation index ($SI_d$) were estimated using the WATEQF model (Plummer et al., 1976).

Spring flow rates were measured daily from March to September in 1990 and 1992, but only once every three weeks during the rest of the study period. Discharge measurements were not possible in every emergence of Berghan Spring; therefore total discharge of the spring was determined.

## RECESSION COEFFICIENTS OF THE AQUIFER

The hydrograph of Berghan Spring from June 1991 to November 1992, shown in Figure 3, may be divided into the first recession, the second recession, and the precipitation time periods. The first recession period starts with a decrease in discharge of the spring and coincides with the period when rainwater and snowmelt infiltrates into the aquifer. During this period, the groundwater level is relatively high, and due to the steep hydraulic gradient, water discharges at a higher rate. The second recession period coincides with the dry season when no recharge from rain or snowmelt occurs. The precipitation period starts with the beginning of rainfall and an increase in discharge.

The hydrograph data of Figure 3, were plotted on semi-logarithmic graph paper and the recession coefficients ($\alpha$) were evaluated as:

(1)

$$\alpha = (\log Q_2 - \log Q_1)/0.434t$$

where $Q_2$ is the discharge in cubic meter per second ($m^3\ s^{-1}$) at time $t_2$ (day); $Q_1$ is the previous discharge at time $t_1$; t is the time elapsed between $Q_1$ and $Q_2$. The recession coefficients of Berghan Spring are presented in Table 2. Because discharge was not measured daily in 1991, the recession coefficients were only estimated for 1990 and 1992 when daily data were

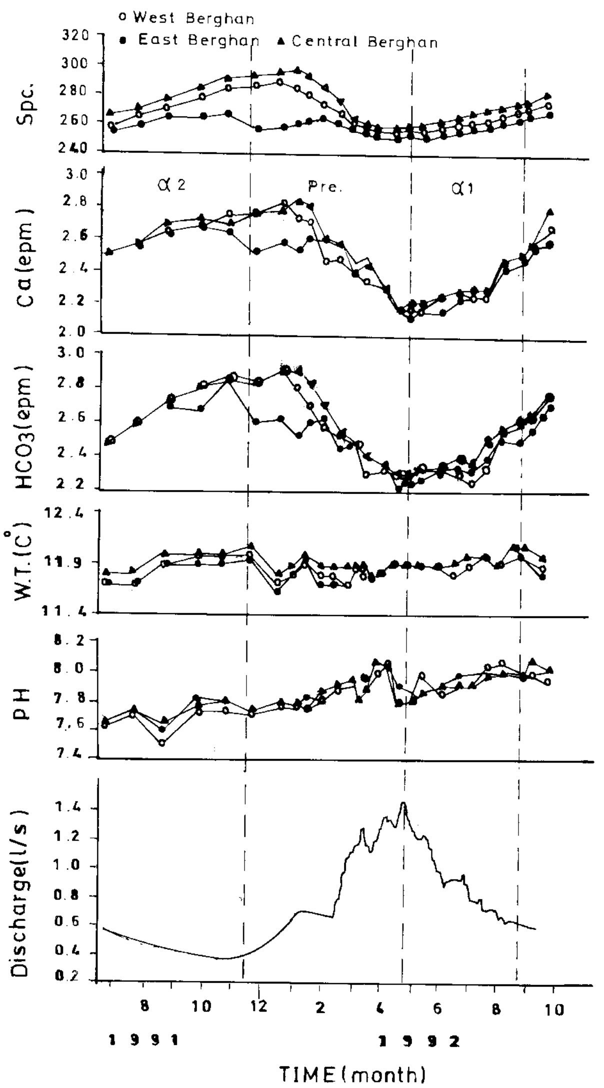


**Figure 3. Hydrochemographs of Eastern, Western and Central emergences of Berghan Spring from June 1991 to November 1992 (Spc. = Specific conductance in microsiemens/cm, epm = equivalent per million, W.T. = Water Temperature in degrees Celsius, l/s = liters per second, $\alpha_1$ = first recession period, $\alpha_2$ = second recession period, Pre. = Precipitation period.**

available. The first and second recession periods almost coincide with the elapsed time (t) of recession coefficients $a_1$ and $a_2$ respectively, considering the delay time between recharge and discharge. Even though the recession coefficients are smaller for the second recession period than the first recession period, the differences are not significant. The small values result from the delayed or prolonged response of the spring due to the crushing action of several normal faults and a thrust fault in the Berghan aquifer. Evidence for this also is indicated by the extensive breccia observed on the surface of the Berghan Spring catchment area. The crushing of limestone layers has resulted in a dense network of pores, small fissures, and joints that have inhibited the development of large conduits. Using the Berghan Spring hydrograph, the percentages of base flow and quick flow were determined by hydrograph separation techniques for the precipitation, first and second recession periods (Table 2). Base flow makes up at least 66.2%, 70.1% and 100% of the total flow in the precipitation, first recession and second recession periods, indicating that a diffuse flow system characterizes the Berghan Spring aquifer.

The small differences between the first and second recession coefficients could be related to the hydraulic behavior of the aquifer system and the ability of the porous media to retain water. Three different hydrologic zones are recognized in karst aquifers (Ford & Williams, 1989). Zone 1 (phreatic) is located beneath the low water table, and feeds the spring throughout the year. Zone 2 (shallow phreatic) is restricted to the lowest and highest fluctuation levels of the water table. The contribution of this zone to spring discharge is dominant during the precipitation and first recession periods. Zone 3 (subcutaneous or epikarst) is the vadose zone above the water table level. The thickness of this zone is dependent on water table fluctuations. Water from rain and snowmelt stored in this zone gradually percolates to the phreatic zones below (zones 1 and 2). As mentioned previously, small differences in the first and second recession coefficients ($\alpha_1$ and $\alpha_2$) are not due to the type of flow. The slightly higher discharge gradient during the $a_1$ period is caused by the slower rate of water table level drop. This slower drop during the first recession period may be explained by: first, a continuous recharge from rainfall and snowmelt; second, rapid drainage through larger fissures and pores of the vadose zone.

**Table 2. Recession coefficients and percentage of base flow and quick flow of Bergham Spring.**

| Year | Period | Recession coefficient | Base Flow % | Quick Flow % |
|---|---|---|---|---|
| 1990 | 1st recession $\alpha_1$ | .0056 | 72.9 | 27.1 |
| | 2nd recession $\alpha_2$ | .0041 | 100.0 | 00.0 |
| | precipitation | | 66.2 | 33.8 |
| 1992 | 1st recession $\alpha_1$ | .0064 | 70.1 | 29.9 |
| | 2nd recession $\alpha_2$ | .0032 | 100.0 | 00.0 |

## HYDROCHEMISTRY OF THE SPRING

Table 3 shows the minimum, maximum, and average physicochemical properties of Berghan Spring in the Eastern, Central and Western emergences. The average specific conductance, and calcium and bicarbonate concentrations increase in the Eastern, Western and Central emergences, respectively, suggesting that these emergences have three different flow routes. This has been confirmed by the geoelectrical studies of Nakhei (1993). The Eastern Spring, with its high flow rate, is probably fed by larger fissures and pores. Because of the short

**Table 3. Physicochemical properties of the Eastern, Central and Western emergences of Bergham Spring. (Spc = specific conductance in microsiemens/cm, W.T. = Water Temperature in degrees Celsius, T.D.S. = total dissolved solids in milligrams/liter, epm = equivalents per million, $SI_c$ = calcite saturation index, $SI_d$ = dolomite saturation inex, $P_{CO_2}$ = carbon dioxide partial pressure).**

| Spring Parameters | Western Emergence 25 % of total discharge | | | Central Emergence 5 % of total discharge | | | Eastern Emergence 70 % of total discharge | | |
|---|---|---|---|---|---|---|---|---|---|
| | mean | max. | min. | mean | max. | min. | mean | max. | min. |
| Spc. | 268 | 289 | 256 | 273 | 295 | 256 | 259 | 266 | 252 |
| W. T. | 11.9 | 12.1 | 11.7 | 11.9 | 12.1 | 11.8 | 11.8 | 12.0 | 11.6 |
| T. D. S. | 143 | 159 | 127 | 145 | 162 | 128 | 138 | 153 | 118 |
| pH | 7.85 | 8.06 | 7.52 | 7.87 | 8.08 | 7.64 | 7.87 | 8.04 | 7.60 |
| Ca (epm) | 2.482 | 2.831 | 2.168 | 2.517 | 2.831 | 2.179 | 2.446 | 2.681 | 2.119 |
| Mg (epm) | 0.230 | 0.292 | .185 | .233 | .315 | .185 | 0.230 | 0.330 | 0.185 |
| Na (epm) | 0.056 | 0.065 | .044 | .058 | .070 | .049 | 0.051 | .064 | 0.043 |
| K (epm) | 0.007 | 0.014 | .004 | .007 | .014 | .005 | 0.007 | .011 | 0.004 |
| $HCO_3$ (epm) | 2.544 | 2.900 | 2.250 | 2.581 | 2.900 | 2.275 | 2.497 | 2.850 | 2.225 |
| Cl (epm) | 0.191 | 0.300 | .125 | .205 | .325 | .125 | 0.190 | .300 | 0.113 |
| $SO_4$ (epm) | 0.064 | 0.088 | .040 | .067 | .086 | .043 | 0.060 | .081 | 0.038 |
| $NO_3$ (epm) | 0.031 | 0.048 | .022 | .035 | .068 | .022 | 0.028 | .048 | 0.017 |
| Ca/Mg | 10.9 | 12.6 | 9.5 | 10.9 | 12.8 | 8.8 | 10.7 | 13.0 | 7.7 |
| $SI_c$ | 0.131 | .334 | -.136 | .164 | .393 | -.008 | 0.139 | .325 | -.086 |
| $SI_d$ | -.850 | -.460 | -1.43 | -.771 | -.324 | -1.18 | -.812 | -.004 | -1.30 |
| log $P_{CO_2}$ | -2.74 | -2.38 | -2.99 | -2.75 | -2.50 | -2.96 | -2.77 | -2.46 | -2.93 |

residence time, specific conductance, and calcium and bicarbonate concentrations have lower values. The specific conductance, and calcium and bicarbonate concentrations of the emergences do not remain constant throughout the year. As can be seen in Figure 3, the differences in the above-mentioned properties between each of the emergences are more apparent in the dry season. These differences tend to diminish as the precipitation season begins and flow rates increase. Reasons for these differences may include: at low flow rates, water flows through three different routes, but with an increase in flow rate, the water table level rises causing intermixing of the three spring waters; or, infiltrated precipitation and snowmelt near the emergences contribute more to the spring discharge and due to the shorter residence time, chemical properties tend to become more similar.

The chemical and physical properties of the Eastern emergence (main emergence) of Berghan Spring were determined for a period of 32 months, longer than that of any of the other emergences; therefore, the hydrochemical behavior of this emergence has been analyzed in greater detail (Figure 4). In this figure, time has been divided into the same three periods mentioned previously; the precipitation, first and second recession periods. The variation of specific conductance, calcium and bicarbonate concentrations and calcite saturation indices are not significant. For example, the minimum and maximum values of specific conductance were 252 and 266 microsiemens/cm during the study period. This implies that aquifer characteristics control the chemical behavior of the spring. The extensive network of fissures and pores in the three hydrologic zones increases the residence time, and potentially averages these chemical properties. The slight differences in chemical behavior between the three periods could be interpreted as follows: specific conductance, calcium and bicarbonate concentrations, and calcite and dolomite saturation indices are relatively low in the first recession period. This is due to melting of snow near the emergence, which quickly reaches the spring and has little time for dissolution. In addition, Raeisi and Karami (1996) showed that snowmelt in the first recession period contains insignificant amounts of dissolved ions. In winter, major cations and anions (except chloride ions) migrate from the upper layers of the snowpack to the bottom layers and ultimately reach the soil or rock underlying the snow. This results in a reduction of dissolved solids in the snowmelt during the spring, which in turn decreases the specific conductance of the first recession period. Ion migration in snowpack is in agreement with the results of Jeffries and Synder (1981). In addition, the rapid drainage of the vadose zone during the first recession period decreases the residence time, and thus results in a lower concentration of dissolved ions.

In the second recession period, specific conductance increases as there is no dilution by recharge water, and flow from smaller pores with longer residence time contributes to the spring discharge. In the precipitation period however, the specific conductance is relatively high and contradicts the expected higher flow rates. Three reasons are presented for this reverse anomaly:

1. Ashton (1966) explained that the increase in calcium and bicarbonate concentrations at the start of precipitation in winter is due to flushing of water with a long residence time in the deeper phreatic zone; recharge forces water out by a piston-like process. The removal of old water in storage being pushed out by new recharge water was confirmed by the work of Bakalowicz et al. (1974).

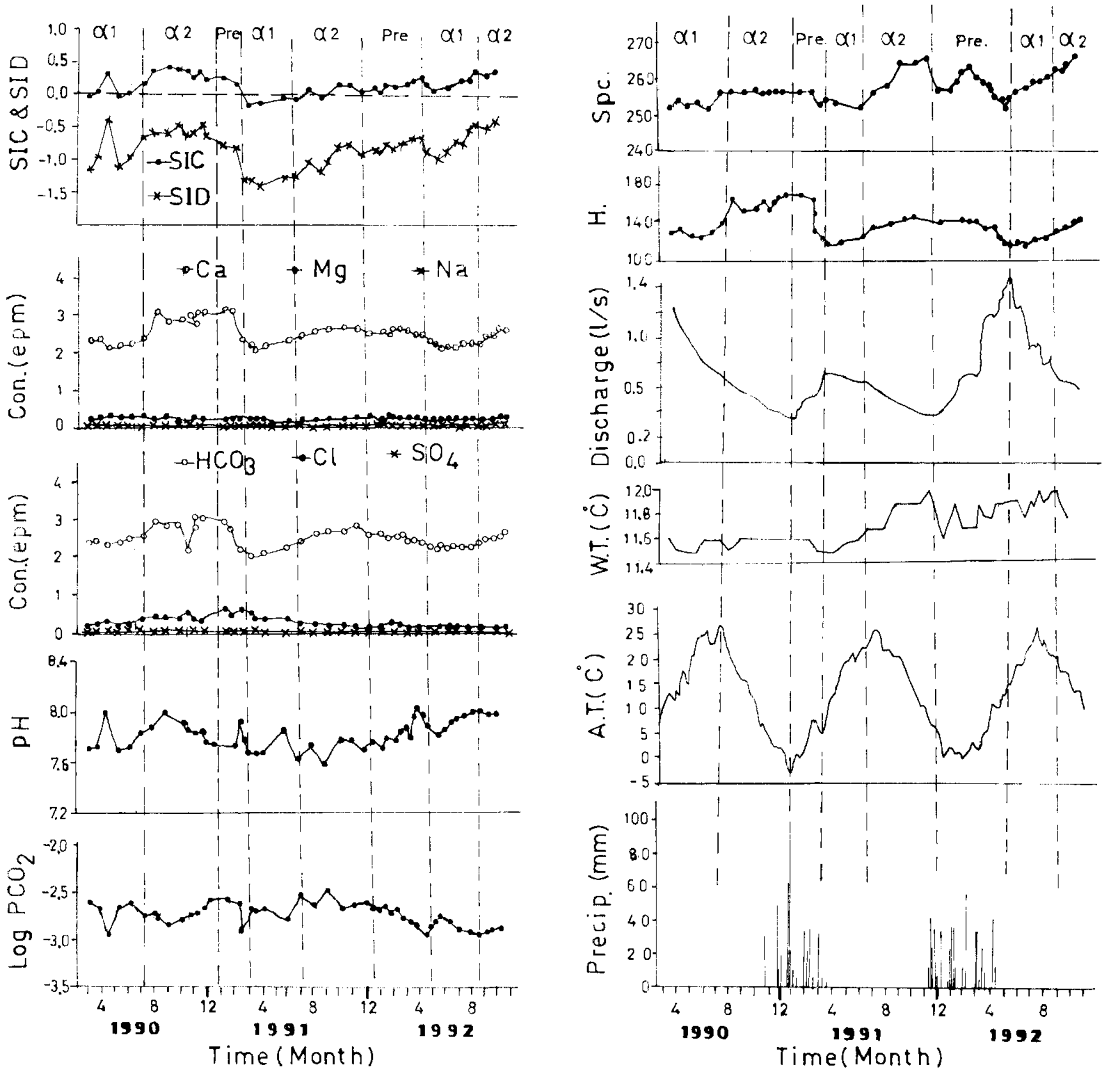

**Figure 4. Time variations of physical and chemical parameters of Berghan Spring from March 1990 to November 1992 ($SI_c$ = calcite saturation index, $SI_d$ = dolomite saturation index, Con. = Concentration, epm = equivalents per million, Spc. = specific conductance in microsiemens/cm, H. = Hardness in milligrams per liter as $CaCO_3$, l/s = liters per second, W.T. = Water Temperature in degrees Celsius, A.T. = Air Temperature in degrees Celsius, Precip. = Precipitation in millimeters, $\alpha_1$ = first recession period, $\alpha_2$ = second recession period, Pre. = Precipitation period.**

2. As mentioned earlier, 40% of the Berghan Spring catchment area is covered by soil. Evapotranspiration losses from the soil during the second recession period tend to increase chloride concentration in the soil water and hence in the underlying epikarstic zone (Ford & Williams, 1989). During the precipitation period, infiltrated water displaces water with a high chloride concentration which is observed as a small chloride peak in the Berghan karst spring (Figure 4).

3. Downward ion migration causes initial winter snowmelt to have higher amounts of dissolved ions.

The calcite saturation index ($SI_c$) shows that the spring water is almost supersaturated during the three time periods, which suggests a diffuse flow system. The dolomite saturation index indicates undersaturation as would be expected, because the aquifer is calcareous. The average water temperature and the temperature variation during the study period was 11.72ºC and 0.6ºC, respectively. Thus, it can be concluded that the spring water discharges from depths that are not affected by ambient temperature fluctuations and reaches equilibrium with surrounding rock. This also suggests diffuse flow in the Berghan Spring drainage basin.

The variation coefficients of flow rate, water temperature, specific conductance, hardness, and bicarbonate and calcium concentration were used to determine the type of flow in Berghan Spring aquifer. Although contradictory results were obtained from the criteria proposed by various authors, the overall results of this study suggest diffuse flow to Berghan Spring.

## CONCLUSION

Morphological and geological characteristics of the Berghan Spring study area suggest a diffuse type aquifer. The catchment area of the spring has no sinkholes, pits, or shafts and 40% of the area is covered by soil. Recharge is by autogenic water from precipitation and snowmelt. The aquifer has been brecciated by one thrust fault and several normal faults, as evidenced by extensive breccia in the catchment area of Berghan Spring. Karstification has resulted in a network of interconnected fissures and pores. Recharge water stored in the vadose zone gradually percolates into the phreatic zone, through a diffuse flow system.

The hydrographs and chemographs of Berghan Spring reinforce and complement the conclusions drawn above. The recession coefficients derived for the first and second recession periods are small and almost equal, indicating slow drainage from an extensive dense network of fissures and pores. Specific conductance and calcium and bicarbonate concentrations, did not vary greatly during the precipitation or first and second recession periods, also implying that the Berghan Spring aquifer is dominated by diffuse flow. The chemical and physical properties of Berghan Spring are controlled primarily by the aquifer. The small differences in some of the chemical parameters during the three time periods, and in the recession coefficients are primarily related to the input water characteristics, the ability of the brecciated limestone to retain water, the hydraulic behavior of the aquifer, and to differences in residence time.

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