THE GOVERNING FACTORS OF THE PHYSICOCHEMICAL CHARACTERISTICS OF SHESHPEER KARST SPRINGS, IRAN

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ABSTRACT: The physical and chemical characteristics of karst springs are not a sole function of flow path in the carbonatic rock mass. A number of other parameters, including the type of precipitation, soil cover, morphology of the exposed area, and the hydrochemistry of the infiltrating water into the karst system also have their own contribution. In the present study, the Gar and Barm-Firooz mountains are chosen to determine some of the governing factors of the physical and hydrochemical characteristics of karst springs. The following measurements were carried out:

1. Concentration of major ions and electrical conductivity of the fresh snow and snowpack.
2. Variation of discharge as a function of time at six sinking streams.
3. Time Variation of discharge, electrical conductivity, and air and water temperature of sinking streams at seven sinkholes.
4. Electrical conductivity and temperature of water at the surface and 40 cm beneath the soil cover.
5. Discharge, major ions, temperature and electrical conductivity of the Sheshpeer spring water were measured every twenty days for a period of three years.

The results indicate that if the physical and chemical characteristics of a karst spring are going to be used to determine the characteristics of corresponding aquifer, first the effect of external factors on the outflow should be accounted for , and then the characteristics of the karst aquifer be determined.

INTRODUCTION

In the last three decades, numerous studies have been carried out to determine the characteristics of karst aquifers using the physical-chemical properties of the discharging springs. Zolt (1961), Smith and Mead (1962), Gams (1966), and Pitty (1966, 1968) were among the forerunners in this field of research. Garrels and Christ (1965) classified the karst aquifers into two open systems, namely diffuse and conduit regimes, and concluded that total hardness variation is a suitable criterion for distinguishing between the two regimes. Shuster and White (1971) argued that the coefficient of variation of the hardness was a diagnostic criterion for diffuse or conduit flow. Jacobson and Langmuir (1974) classified the flow regimes into conduit, diffuse conduit, diffuse, and Gatesburg diffuse based on recharge sources, EC, and coefficient of variation of the discharge. Atkinson (1977) suggested that karst systems are networks of diffuse and conduit regimes in which narrow fissures and joints play the main role in storing water. Bakalowicz (1977) demonstrated that the structure of a karst aquifer cannot be defined from the coefficient of variation of chemical variables describing spring water because the distribution of the values is usually multimodel rather than normal. Scanlon and Thrailkill (1987), using the criteria suggested by the previous workers, carried out a comprehensive study of conduit and diffuse regimes. Their results were not consistent with those of previous workers and they refuted the proposed criteria for classification. Novak (1971), Ede (1972), and Cowell and Ford (1983) suggested that diffuse flow is characterized by small time variations of temperature, while large variations are indicative of conduit flow. Raeisi et al. (1993) applied the criteria proposed by various authors to determine the Sheshpeer spring flow system, and concluded contradictory results. The apparent inability of the proposed models to fully classify the karst flow systems may be due to the fact that there are many variations in the outflow responses of karst springs. The form of the spring hydrograph is not unique. Some are highly peaked, others are oscillatory, and many are broad and relatively flat (Ford 1989). Spring chemographs also have different patterns. The diversities in physical and chemical characteristics of karst springs are in response to extensive interrelated governing factors.

The governing factors of physical and hydrochemical characteristics of karst springs could be divided into external and internal factors. External factors act on the boundaries of the aquifer system, while internal factors govern the body of the aquifer system. Internal governing factors include shape, size, and thickness of aquifer, and the percentage, distribution and nature of voids (porous, fissure and conduit), lithology, epikarst, and vadose characteristics. The external governing factors include form (snow, rain), intensity, spatial and temporal distribution of precipitation, concentrated or diffuse recharge, percentage and depth of covered soil, lithology of formation around the aquifer, quality of input water to aquifer system, vegetative cover and morphology of exposed area. The objective of this study is to evaluate some of the external governing factors and their effect on the physical and hydrochemical characteristics of karst sprig water.

HYDROLOGICAL SETTING

The study area is located west of Shiraz, Iran (Fig. 1). Gar, Barm-Firooz and Mor mountains constitute the two large anticlines that extend in general direction of the Zagros mountain range. The exposed cores of the anticlines are dominantly made of the calcareous Sarvak Formation (Albian-Turonian), underlain and overlain by impermeable shales of the Kazhdomi (Aptian-Cenemonian) and Pabdeh-Gurpi For-

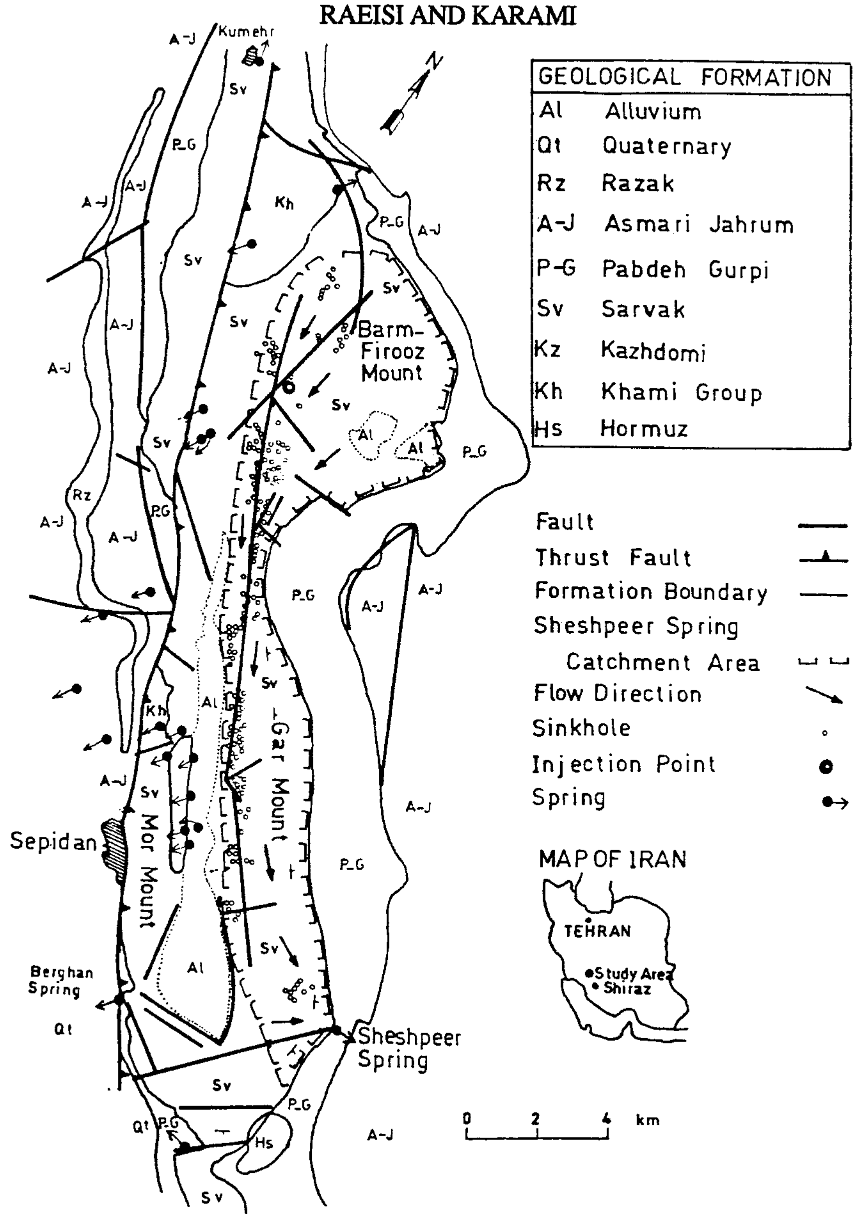

Figure 1. Geological map of the study area.

mations, respectively. The tectonic features are a main thrust, normal and strike-slip faults which have produced suitable conditions for extensive karstification. The most important karst feature is the presence of 160 sinkholes in the northern flank of Gar mount and 99 sinkholes in the Barm-Firooz mount (Fig.1). The Sarvak Formation represents the height of the study area with the maximum and minimum elevations of 3714 m and 2110 m, respectively.

Out of twelve springs emerging from the Sarvak Formation, only Sheshpeer spring occurs on the northern flank with a mean annual discharge of 3247 l/s. One of the springs, Berghan, has a mean annual discharge of 632 l/s and will be referred to later in this paper. The mean annual discharge of all other springs range from 1.41 to 68.34 l/s. Geological and hydrological methods (Pezeshkpoor 1991), and tracing experiments (Zareh and Raeisi 1994) have shown that the catchment area of the Sheshpeer spring consists primarily of the northern flank of Barm-Firooz and Gar mountains and a portion of the southern flank of Barm-Firooz mountain (Fig.1). The sinkholes are only located in the catchment area of Sheshpeer spring. Total sinkhole area is 2.58 km^2, but the catchment area of the sinkholes is larger than the sinkhole area (Kasaeyan 1990; and Marandi 1990). Raeisi et al. (1993) showed that recession curves of Sheshpeer spring indicate two different discharge coefficients and thus two different α_1 (0.0082-0.0092) and α_2 (0.0028-0.0008) discharge regimes. They divided the time into three distinct periods, namely α_1, α_2 and the wet season (w) periods (Fig. 6), **while; in what α_1** and α_2 periods coincide with the duration of α_1 and α_2 discharge regimes. Forty percent of total flow in α_1 regime is produced by the quick flow through sinkholes and large fissures and the remaining is contributed by stored water in the pore space (base flow). In α_2 regime, which coincides with dry season when no recharge from rain or snow melting occurs, the stored water in the pore space and small joints gradually discharges into the large conduits and makes up the base flow. The large conduit in the second regime does not act as a reservoir for the stored water, and merely provides a water transportation medium.

Berghan spring is located in the southern flank of Gar mount (Fig. 1). The catchment area is about 19 km² (Pezeshkpoor, 1991). Three distinct periods α_1, α_2 and wet season were also observed in the hydrograph of Berghan spring, but no considerable differences were observed between the discharge coefficients α_1 (0.0056-0.0064) and α_2 (0.0033-0.0041) (Raeisi et al. 1994). The base flow contributes 70 percent of the total flow in the α_1 regime and 100 percent of the α_2 regime. Several faults crushed the Berghan aquifer which developed high density pores and an extensive network of small pathways preventing the widening of major karstified channels (Raeisi et al. 1994).

The average annual precipitation at Berghan station (elevation 2110 m) is 750 mm. Using the regional relationship between elevation and rainfall, the average annual precipitation of the Sheshpeer catchment area is calculated to be 1350 mm (Pezeshkpoor 1991). The precipitation in winter is mainly in the form of snow, most of which is melted by mid spring. Soil cover constitutes 35 percent of the Sarvak Formation. About 95 percent of the soil belongs to the regosol and lithosol categories, and the remaining 5 percent is related to the brown soils (Karami 1993). The study area is a natural pasture.

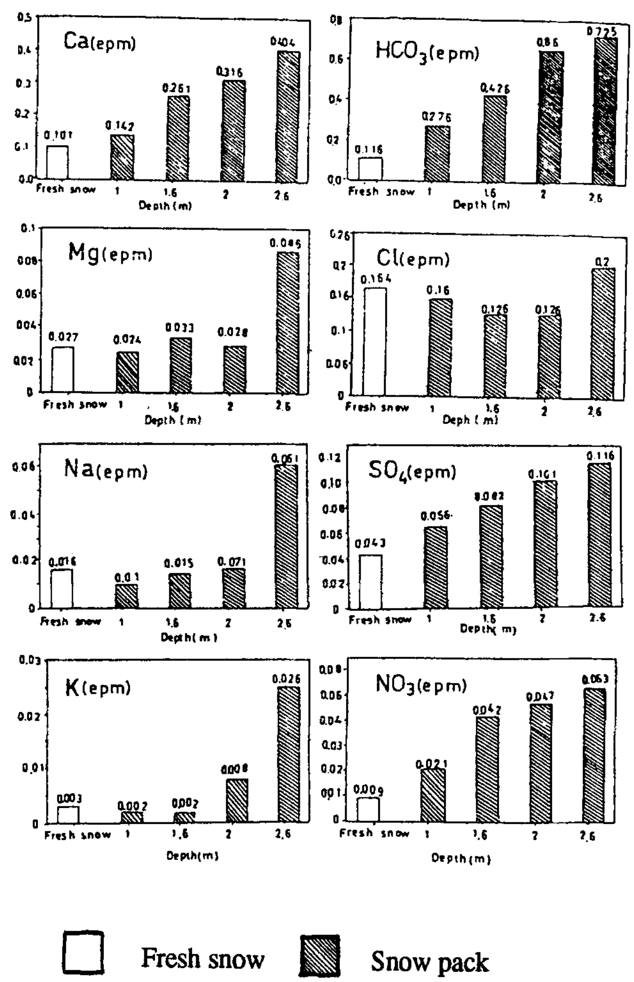

Figure 2. Concentration of major ions in fresh snow and snowpack.

METHOD OF STUDY

Four experiments were carried out in the catchment area of Sheshpeer spring to measure the physical and chemical characteristics of external factors. The experiment sites were selected on the southern flank of Barm-Firooz mountain near the injected tracer sinkhole, to be certain about the connection between the sinking water and Sheshpeer spring (Fig. 1). The fifth experiment was carried out to monitor the characteristics of Sheshpeer spring. Temperature, electrical conductivity and carbon dioxide were measured at the site. Magnesium was measured by atomic absorption and calcium, sodium and potassium were measured by flame photometric methods. Chlorine and sulfate were determined using Mor and turbidimetry methods, respectively. The discharge was measured by triangle weir or a current meter from which the stage-discharge curve was prepared.

RESULTS AND DISCUSSION

Experiment 1: Seven samples of fresh snow were collected from the catchment area of Sheshpeer aquifer from December 26, 1991 to April 7, 1992. The electrical conductivity (EC) of fresh snow ranged from 7 to 20 micromhos/cm, with an average of 12.5 micromhos/cm. A snowpack site of total depth of 3 m was sampled at depths of 1, 1.5, 2 and 2.5 m from the surface on March 23, 1992. The electrical conductivity at depths of 1, 1.5, 2, and 2.5 m was 33, 39, 66 and 94 micromhos/cm respectively. Precipitation is mostly in the form of snow during the winter, with negligible evapotranspiration and snow melt during this period (Raeisi and Porhemat, 1994). Therefore considering the snow distribution of the study area, the collected snow samples represent the fresh snow from mid January to mid March. The chemical analyses of fresh snow and snowpack are presented in figure 2. Except for chloride, all the major ions and EC show an increase with depth of snowpack. This effect may be due to the ion migration from the top to the bottom of the snowpack and eventually into the soil, a process that was also reported by Jeffries and Synder (1981). Considering the EC as representative of dissolved ions, the ion concentration of recharge water at early spring is three times more than late spring. The effect of ion migration on the chemical behavior of Sheshpeer spring will be discussed in Experiment 5.

Experiment 2: Water generated by the process of snowmelt will either flow on the ground surface as sheet or channel flow and eventually sinks into the sinkholes, or will directly infiltrate into the soil or fissures of exposed limestone. The flow rates of sinking streams were measured every two hours for six days from June 1 to June 6, 1992 (Fig.3). The sinkhole elevations ranged from 3100 to 3200 m. The maximum and minimum discharges were observed at 4:30 to 6:30 p.m.

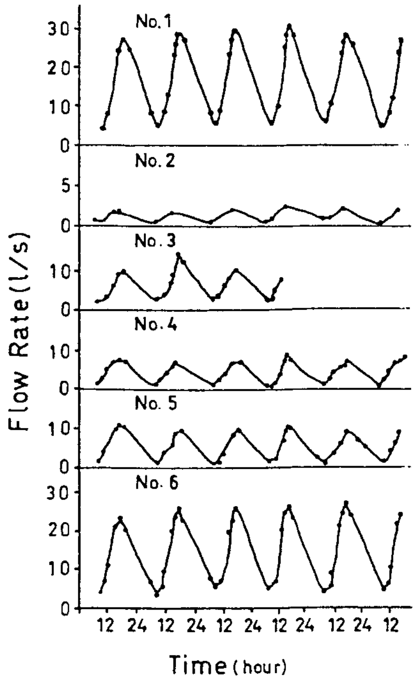

Figure 3. Time variation of flow rate of six sinking streams from June 1 to June 6, 1992.

and 7:30 to 9:00 a.m., respectively. The ratio of average daily maximum flow rate to the average daily minimum flow rate varied from 5 to 10. However, no effect of such a daily oscillatory recharge had been observed on the Sheshpeer spring hydrograph (Karami 1993; Pezeshkpoor 1991). A distance of 15 km between input and output points may be enough to suppress the effect of daily oscillations of the input flow rate. In addition, tracer tests indicate the presence of an extensive reservoir under the Barm-Firooz mountain (Zareh and Raeisi 1994). Therefore, it could be concluded that the increase in the hydraulic head corresponding to the daily peak flows may be in the order of a few centimeters. Such an insignificant increase in hydraulic head may not be capable of causing a measurable increase in the Sheshpeer spring discharge. It is obvious that in the case of a close distance between input and output and lack of extensive reservoir, the oscillatory movement of discharge could be observed at the outlet.

Experiment 3: Electrical conductivity (EC), and air and water temperatures were measured every two hours for two days at seven sinkholes, and the flow rate at six sinkholes. Sinkholes were the same as in Experiment 2 and sinkhole No. 7 is located near the same area at an elevation of 3340 m. The results are shown in figure 4. The diversities of measured parameters between the sinkholes are significant (Fig. 4). The variation of discharge among the sinkholes is related to the unequal snowpack area and catchment basin of each sinkhole. The diversities in water temperature among different sinkholes are related to the distance that the snowmelt water flows on the ground surface without snow cover to reach the sinkhole, exchanging heat with air. The water temperature

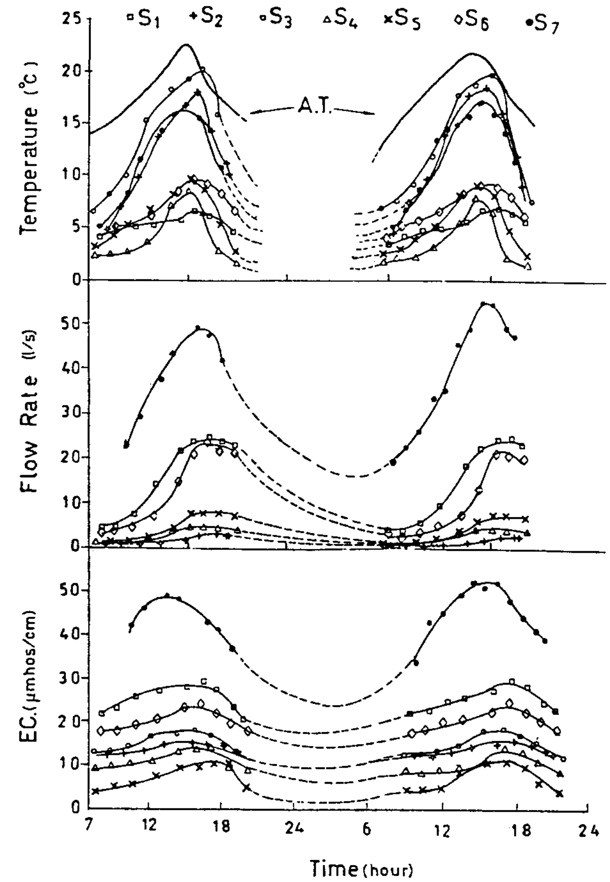

Figure 4. Time variation of flow rate, electrical conductivity (EC), and water temperature of the sinking streams (S = sinkhole), and air temperature (A.T.).

and the distance of uncovered surface stream are correlated at the 1% level. There are also diversities of EC among different sinkholes. Sheet and channel flow generated by snowmelt dissolve the surface soil ions, especially calcium and bicarbonate ions. The correlation between the EC and average distance of sinking point to the center of snowpacks (significant at the 1% level) justify diversities of the electrical conductivity between the sinkholes.

Time series of EC, flow rate, and air and water temperatures of four sinkholes are represented in figure 4. The agreement in the trend between air and water temperatures, and flow rates are quite predictable in snowmelt conditions. The strong correlation between EC and flow rate is probably caused by ion migration. At low temperatures with associated low flow rates, snowmelt occurs primarily in the upper part of the snowpack that has lower ionic concentration than the lower part. Similar to the discharge, no effect of daily fluctuations of EC in the inflow water was observed on the Sheshpeer EC chemograph (Karami 1993: Pezeshkpoor 1991). This result confirms that the inflow water may be mixing with the extensive reservoir under the Barm-Firooz mount, and equalizing the daily EC of the Sheshpeer spring water.

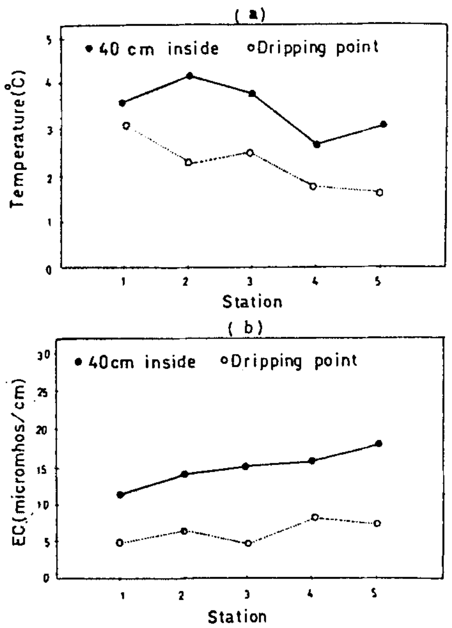

Figure 5. Temperature and electrical conductivity (EC) of snow melt at the dripping point and 40 cm below the ground surface.

Experiment 4: The temperature and EC of snowmelt water at the dripping point on the surface and at 40 cm below the ground surface were measured at five different sites on June 11, 1992 (Fig. 5). EC of water at 40 cm below the surface was 2.5 times more than EC of the water on the surface. It may be concluded that in the presence of thick soil cover and abundant organic matter, water may be close to saturation, reducing the role of the aquifer on the chemograph.

Experiment 5: The physico-chemical parameters of Sheshpeer spring were measured every three weeks between April 1990 and October 1992. The relation between time and various physical and chemical parameters are depicted in figure 6. The electrical conductivity, total hardness, bicarbonate and calcium concentrations increased with discharge in the wet period, but began to decline during the α_1 period. Ashton (1966) explained that the increase of the calcium ion concentration in the spring water at the start of a flood is due to the flushing out of water with a long residence time in the deeper phreatic zone, and a piston-like forcing of water through the spring by the large recharge flow. In addition to this process, ion migration in the snowpack may also significantly contribute to the observed increase in the parameters being monitored. EC values of 32 micromhos/cm at the depth of 1 m in the snowpack on March 23, 1992 and 5.9 micromhos/cm at the outlet point of snowpack on June 9, 1992 may be indicative of the time when EC, calcium concentration, hardness and bicarbonate began to decline in the α_1 period. The maximum difference in EC of snowpack is 62 micromhos/cm that is in the same order of magnitude as the maximum differences in EC of Sheshpeer spring chemograph (55 micromhos /cm). In the α_2 period, which coincides with the dry season, no recharge from the rain or snow melting occurs, and the base flow (diffuse flow) constitutes the whole flow of the Sheshpeer spring (Raeisi et al. 1993). The EC, calcium, bicarbonate and hardness increase at the beginning of the α_2 period and remain at a constant level during the remainder of this period. It could be concluded that at this period only, the internal parameters control the chemograph of the spring water.

EC chemograph of Sheshpeer and Berghan springs are presented in figure 7. The hydrograph of both springs have similar trends (Raeisi et al. 1993, 1994) and the ion migrations are effective on both catchment areas. The almost constant EC values imply that the high density pores and an extensive network of small pathways (diffuse flow) of Berghan aquifer or in other words internal factors mostly control the chemical behavior of Berghan spring.

CONCLUSIONS

The governing factors of physical and hydrochemical characteristics of karst springs could be divided into external and internal factors. Some of the external factors include the type of recharge (point or diffuse), percentage and depth of soil cover, daily oscillation of flow rate, EC and temperature of sinking streams, and ion migration from the top to the bottom of snowpack. Some of the internal factors are the type of regime (diffuse and conduit), lithology, shape and size of the aquifer. If the hydrograph or chemograph of a karst spring is used to determine the characteristics of the aquifer contributing water to the spring, at the first step, the effect of physical and chemical characteristics of the external factors on the outflow should be accounted for to the extent possible. Subsequent interpretations of spring hydrograph and chemograph will better reveal the nature of the karst formation that feeds the spring. In karst areas with extensive snow cover, the effect of daily variation of recharge and ion migration from the upper part to the lower part of snowpack and eventually soil should be considered in hydrochemograph interpretation. In advanced karst systems where the dissolution channels are large and the conduit flow is dominant, the hydrochemograph of a karst spring is influenced by external and internal factors; while in undeveloped karst systems with the diffused flow type, the hydrochemograph is mainly controlled by internal factors.

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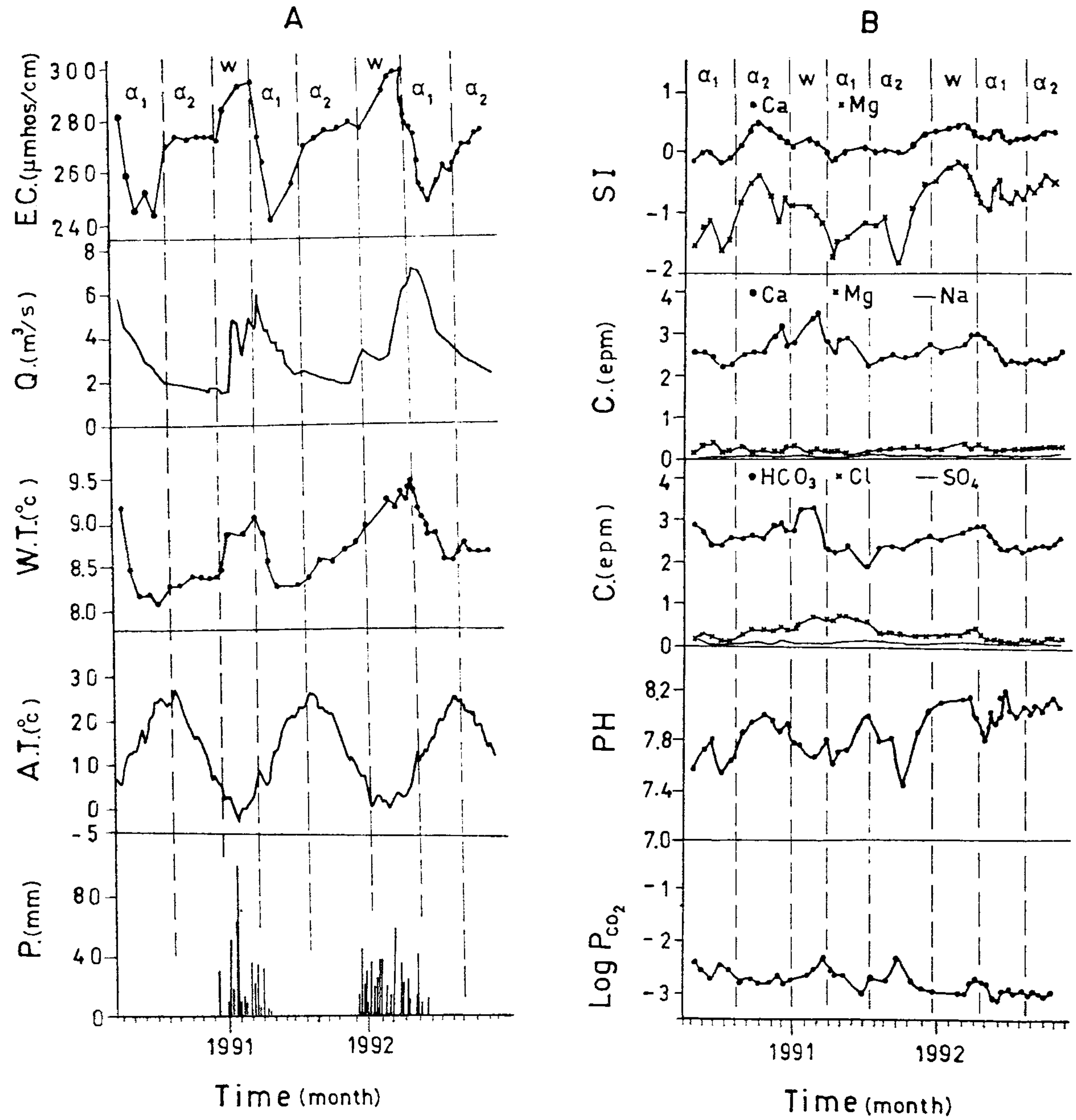

Figure 6. Time variation of physical and chemical parameters of Sheshpeer spring in the period of April 1990 to October 1992. A: EC = electrical conductivity, Q = flow rate, W.T. = water temperature, A.T. = air temperature, P = precipitation. B: SI = saturation index, C = concentration.

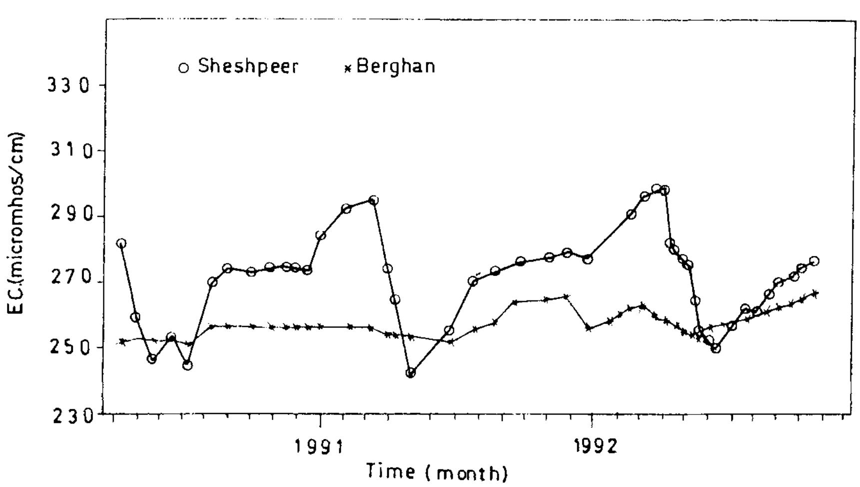

Figure 7. Electrical conductivity chemograph of Seshpeer and Berghan springs

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