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A dye-tracing investigation in the Poshte-Naz Karstic aquifer, Alburz Mountain, northern Iran

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Abstract: *The tracing technique has been recently used in karstified Zagros structural belt in northern Iran. A tracer study (uranine injection) was conducted in Jurassic limestone of the Poshte-Naz area in the Alborz belt to evaluate aquifer parameters and hydraulic relations between a large (about 100 m in diameter) sinkhole and springs. A main goal of the project was to find out the source of turbidity of the Emarate drinking water supply spring (SP4) in rainy seasons. Eight springs, three wells and the Neka River were selected for monitoring and totally 989 samples in 107 days were collected. In order to select reliable sampling stations, hydrochemical analysis of major ions was carried out and for better interpretation of concentration-time curve, spring discharge was also measured. The results of the tracing by sampling water indicated only a hydraulic connection between the injection point and the Sange-Nou spring (SP8) and, whereas the charcoal bags analysis revealed tracer exits also from spring SP1, SP3, SP4, SP5, SP8, in wells W1 and W2, and in the Neka River. This paper discuses concentration/time curves from charcoal bags for qualitative analysis and tracer exit curves for quantitative analysis.*

Key words: *Posht-e-Naz, tracing, spring, sinkhole, charcoal bag*

1. Introduction

The Jurassic Lar limestone with a total area of about 400 km^2 belongs to the Alborz chain. Due to tectonics and dissolution processes, this aquifer was karstified and represents a major hydrogeological unit in the north of Iran. The Poshte-Naz (36° 34' to 36° 42' N and 53° 16' to 53° 50' E) of mostly montaneous terrain (elevation 50-1400 m) constitute a part of the Lar formation, and covers an area of about 80 km^2 (Fig .1). The local population strongly depends on water from karst areas and karstic springs, the Emarate spring in particular, which supply almost half of the Behshahr City drinking water needs. The mantled Posht-e-Naz karstic terrain with well developed karstic features (sinkholes, ponors, caves, and dry valleys) has a thickness of several hundred meters (250-300), receives over 800 mm/y of rainfall and experiences humid climatic condition. Dense vegetation cover and relatively thick soil cover this karst formation on the top. Impermeable shales and schist of Shamshak formations (lower Jurassic) underlie the aquifer at the base.

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Many karstic aquifers hold important groundwater resources that are extensively used for different purposes. At the same time, karst aquifers are seriously vulnerable to contamination resulting either from human activity or environment. Contamination can easily reach the groundwater through thin soil, swallow hole or via sinkhole, and are rapidly transported over large distances in the conduit network (Vesper et al., 2001). In general, because of specific hydrogeologic characteristics of karstic aquifers, saline water intrusion, microorganisms and turbidity are the most critical contaminants. Thus, karst groundwater requires specific protection. Proper management of karst aquifers needs a better knowledge of flow and transport mechanisms in these systems (Ozyurt and Bayari, 2007). Tracer tests, hydrochemical and microbiological investigations are suitable methods for providing a scientific basis for development of sustainable groundwater protection schemes (Bakalowicz, 2000; Drew and Hotzl, 1999).

Water tracing is a well-developed, powerful tool of the karstic hydrologist that enables catchment boundaries to be estimated, areas of recharge to be determined and sources of pollution to be identified (Ford and Williams, 1989). Groundwater tracing studies using fluorescent dyes are a commonly accepted technique to determine flow connection between accessible input and output points, to delineate karst drainage basins, and to investigate the flow behavior of karst aquifers (Wan fang et al., 2002). Many ground water problems, such as source water protection investigation, can benefit from simple point to point groundwater tracing studies (Eckenfelder, 1996). A part of the Posht-e-Naz karstic aquifer is an area extremely susceptible to contamination by suspended particles. Therefore, a tracing test was proposed in the Posht-e-Naz karstic aquifer with aim to find out the source of turbidity (sinkhole) and to evaluate aquifer characteristics.

2. Geology

The Posht-e-Naz anticline form a part of limestone highs in the south of Behshahr City and lies almost between the Neka River in the south and the Khazar fault in the north. The study area is dominantly comprised of Jurassic Lar limestone (Fig. 2), while a small part is covered by calcareous sand stone, rock avalanche and loess. In general, the water bearing Lar formation overlies impermeable Shamshak and Gorgan formations (Fig. 3).

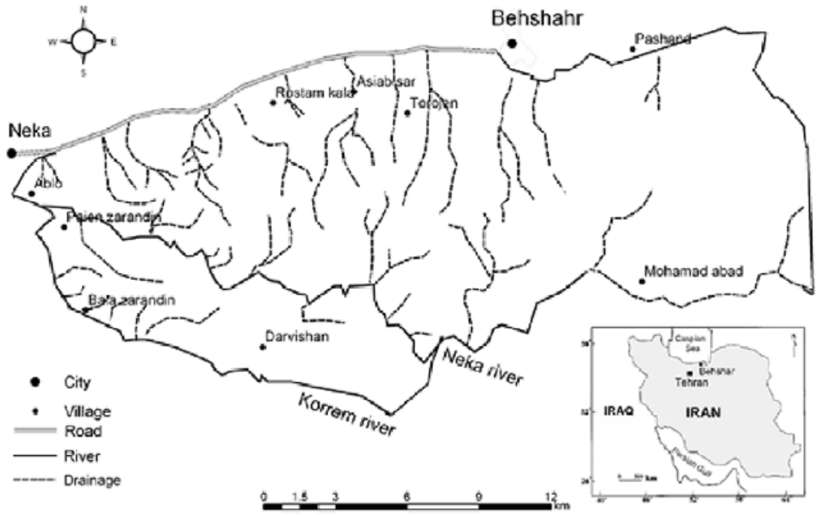

Fig. 1. Location map of the study area.

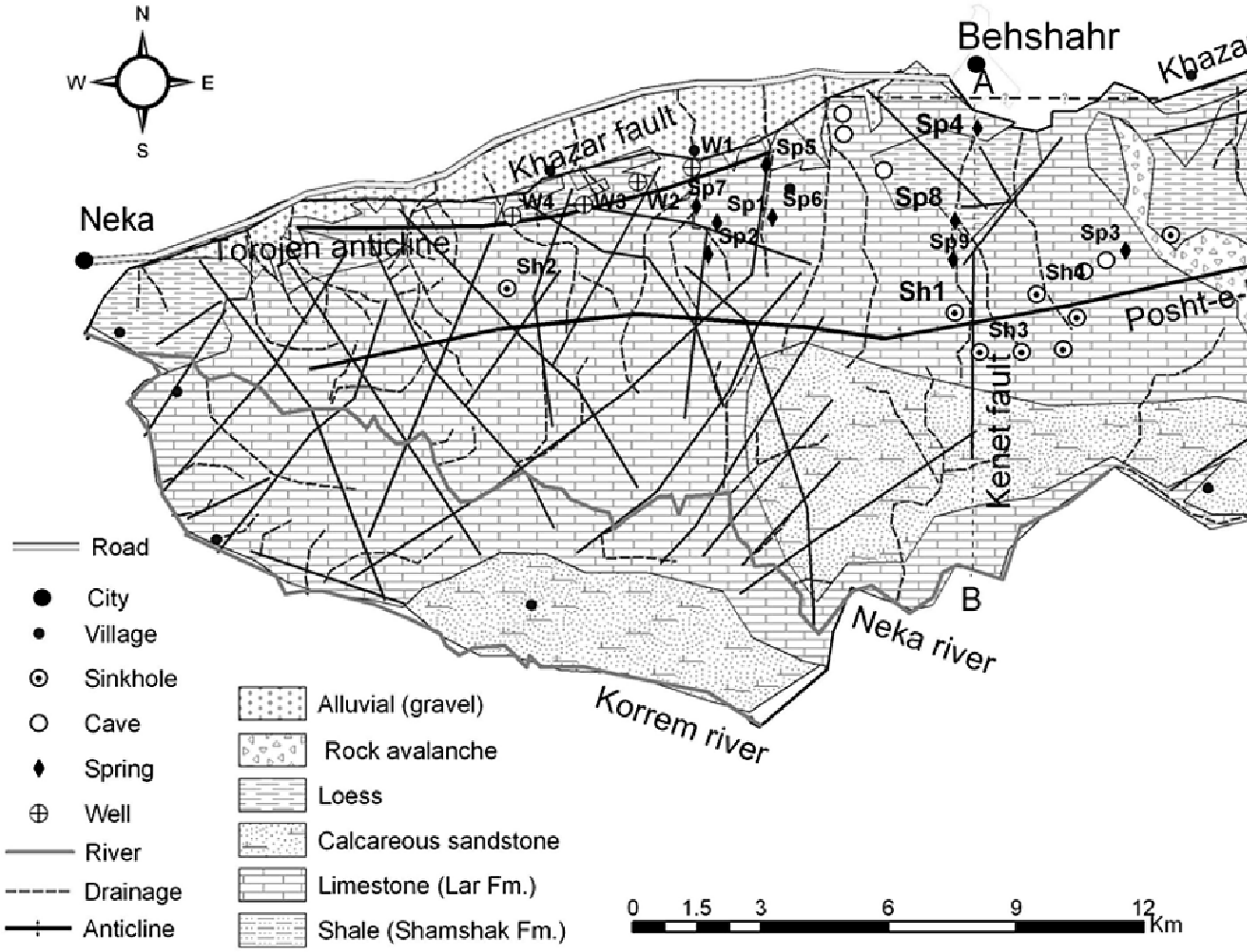

Fig. 2. Geo-morpho-hydrogeological map of the study area.

The minor and major structural features such as fractures and faults occur in the area. The main fault is the Khazar thrust fault, which control the hydrogeological properties of the karstic formation. The most widely distributed forms of the lineaments are fractures and small scale faults. The density of longitudinal, lateral and shear fractures is very significant in the study area and the fracture widening approaches to few centimeters. As shown in rose diagram (Fig. 4a), the longitudinal and lateral fractures are respectively trending N160-170 and N25-30. Two sets of shear fractures were identified, trending N45E and N35W. Apart from fractures, several normal faults extending NE-SW and NW-SE cross the karstic formation. In addition to these small scale faults, one outstanding fault (Kenet) trending NE-SW crosses the area (Fig. 2). Faults and fractures have a crucial influence on the hydrogeological properties of the karstic system, and the surface and sub-surface drainages are associated with these faults and related fractures. The Kenet fault and the lateral fractures- in particular play a significant role in connection with infiltration and leading groundwater movement.

3. Geomorphology

The well developed karstic geomorphological features are mostly concentrated on the northern limb. In addition to dry valleys, ponors, active and inactive caves, the large and deep sinkholes appear to be more frequent features on the crest of the Posht-e-Naz anticline and some of them (Sh1, Sh4 and Sh5) act as swallow holes. Lithological properties, fracture density, and rainfall frequency are controlling factors in sinkhole development in the area. They have been mainly developed by combination of dissolution and subsidence processes. Majority of the large sinkholes occurr along the Posht-e-Naz anticline axis and those located in the vicinity of the main spring (the Emarate spring; SP4) are labeled as Sh1, Sh3 and Sh4. Two to three axes of the sinkholes (Fig. 4b and c) indicate different forces with diverse magnitudes in operation, so their longer axes directed along the main linear features. Sinkholes are entrance point for contamination of groundwater systems that mainly include sedimentary solid particles of various sizes (fine sand, silt and clay). The altitude, diameter, swallow hole diameter and depth of the injection sinkhole (Sh1) are respectively 800, 200, 1 and 10 m. The largest sinkhole (Sh4) with three swallow holes occupy an area of about 20 hectares.

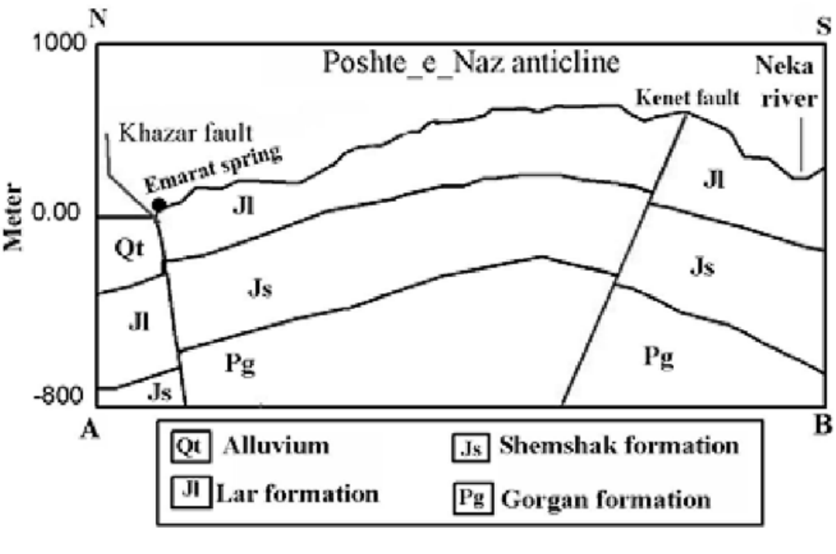

Fig. 3. Geological cross section of the study area.

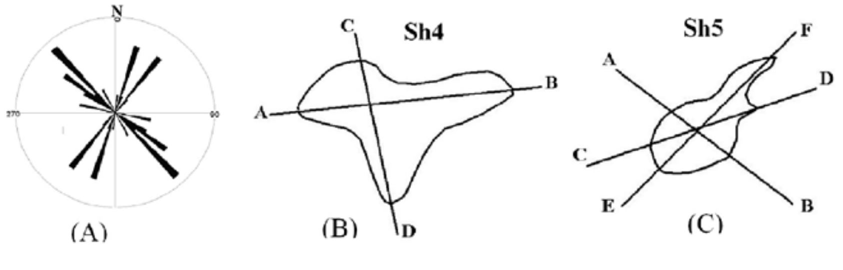

Fig. 4. Fractures rose diagram and sinkholes axes.

4. Hydrogeology

A major part of the Posht-e-Naz limestone is subjected to intense karstification, and the area under investigation mostly represents a typical doline karst. The dolines are often aligned and some of them act as swallow holes. The favorable climatic condition, lithological characteristics and tectonics features (fractures, faults and the Posht-e-Naz anticline), as well as geomorphological features and dissolution, enhance fracture porosity, impact karst groundwater potential and generate prominent aquifer systems. Diffuse recharge from infiltration through pore space and concentrated recharge through well-developed ponors, sinkholes and shafts recharge the karstic reservoir. In addition, the position of the impermeable rocks in the core of the Posht-e-Naz anticline, that hinder downward groundwater movement, play a crucial role for underground reservoir development. The Posht-e-Naz karstic aquifers are rich in groundwater and form the principal source of water supply for Behshahr City and surrounding areas. Water supply systems have been mainly based on the intake of natural discharges from karstic aquifers at springs. Due to topographic gradients, stratum dip, fault behavior, exposed fracture and coincidence of groundwater with base level erosion, groundwater is emerging in the form of springs with variable discharge in different altitudes (Table 1).

Table 1.

Springs discharge (L/s) and elevation

Spring Nos	Min discharge	Max discharge	Flow type	Elevation (m)
SP1	5	8	Diffuse	150
SP2	8	67	Conduit	180
SP3	35	120	Conduit	550
Sp4	45	120	Conduit	50
Sp5	12	28	Fracture	90
SP6	7	35	Fracture	200
SP7	4	10	Diffuse	140
SP8	3	5	Diffuse	480
SP9	2	4	Diffuse	775
Sh1 (swallow hole)	5 (input)	20 (input)	-	800

The spatial distribution of springs has been dominantly determined by small and large structural features. The collected data suggest that the shear fractures were mainly responsible for emergence of springs. The greater number of springs in the northern part of the Posht-e-Naz anticline is the most obvious hydrogeological feature in the area (Fig. 2). Among all springs, SP2, SP3 and SP4 are characterized by higher discharge, and the main spring in the area is SP4 with an average discharge of 60 L/s. The springs with higher discharge, namely SP3 and SP4 (Fig. 2), were assumed to be connected with sinkholes and the fault zone. It was believed prior to tracing that SP4 discharge is governed by recharge from Sh1 (sinkhole) and Kenet fault (Fig. 2). The Emarate spring (SP4) collects water from large parts of karstic aquifer. Hence, the contribution of the swallow hole of Sh1 in dry season is small, but it becomes considerable in the rainy period. Based on discharge fluctuation, springs SP2, SP3, SP4 were distinguished as conduits, SP5 and SP6 exhibited fracture flow and SP1, SP7, SP8 and SP9 demonstrated diffuse type. The time-discharge breakthrough curve analyses of the high discharge springs (SP3 and SP4) have demonstrated micro flow regimes.

5. Hydrochemistry

Groundwater quality in the Posht-e- Naz is generally good and concentration of the major ions has not evoked significant problems. However, a few good yielding springs used for drinking water supply, particularly the Emarate (SP4), are turbid in rainy season due by surface water input into sinkholes. From the point of view of pollution this situation is closer to surface system than to groundwater system.

The use of hydrochemical data proven to be an important tool in understanding groundwater hydrology, commonly used to depict groundwater flow regime. When detailed analysis of spring water is done, conspicuous differences in water composition indicate catchments area and anomalies in distribution of hydraulic parameters (Christy et al., 1999, Zanini et al., 2000, Nizar and Alaa, 2008).

For the same purpose, from most springs and a few wells in the northern part of the study area samples were collected as many as three times in 2006. Physico-chemical analysis of samples was carried out (Tables 2 and 3), and changes of groundwater composition in the command area were assessed.

In the course of investigation, springs SP2, SP3, SP4, SP5 and SP6 exhibited more changes in electrical conductivity (EC) than SP1, SP7, SP8 and SP9 and higher temperature fluctuation and dissolved constituents (Table 2). The EC, which depends on the amount of dissolved solids, is a reliable descriptor of karst water residence time. Thus any decline in EC and fluctuation in temperature of spring water means fast groundwater flow in the system whereas slow groundwater movement would exhibit higher EC and ions concentration and low temperature changes. EC and temperature fluctuation of SP2, SP3, SP4 indicate fast flow, SP5 and SP6 are fracture dominated, and SP1, SP7, SP8 and SP9 exhibit diffuse flow (Table 2).

As shown in table 2 and 3, the EC and ion concentration at springs indicate minor variation and can be attributed to geochemical characteristics of springs local catchments area, residence time and input water composition at swallow holes of the sinkholes. At all springs, Ca^{+2} and HCO_3 are the dominant cations and anions. Another significant cation is Mg^{+2}. Concentration of the other cations and anions are not important. In spite of point source pollution (sinkhole), nitrate concentration is low. The EC of well samples ranges from 998 to 1458 μS /cm^2 and the reason for relatively wide range of EC is mostly concerned with lithological variations, recharge rates and well positions with respect to fracture zones.

The springs water was of the bicarbonate calcium-magnesium type, while the well samples indicated more or less mixed type. The concentration of major ions were diverse at wells, and the dominant cations and anions were respectively sodium, calcium, bicarbonate and sulfate (Table 3). As a result, samples are approaching mixing line in Piper diagram (Fig 5).

In spite of temperature, EC and minor chemical composition variations at springs in low and high flow condition, the overall EC of springs water in high flow period demonstrated hydraulic connection between different parts of the Lar karstic aquifer as a result of highly fracture zones (Table 4)

During the study period, similarities in water chemistry between Sh1 and SP4, differences between these two and SP8, and similarities between Sh1 and SP8, were more pronounced as Table 5 demonstrates. These include: (1) saturation of water with respect to calcite (SIc) at Sh1 and SP4, probably accounting for their hydraulic relationship, and the positive SIc value of SP8, are attributable to diffuse flow; (2) NO_3 concentration exhibited a rise at Sh1 and SP4, as compared to other samples, on one hand, and the decrease at SP4 on the other hand, undoubtedly related to dilution; (3) closer CO_2 and

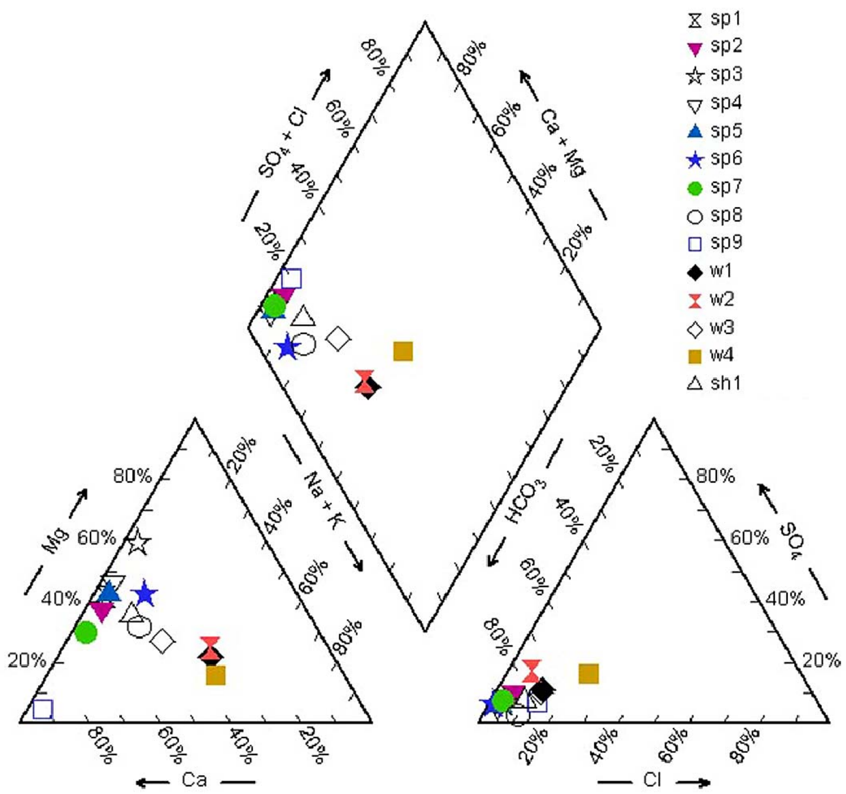

Fig. 5. Piper diagram of the water samples.

Table 2.

Eelectrical conductivity (μS /cm²) and temperature (˚C) of spring waters.

Spring Nos	Min temp	Max temp	Temp difference	Min EC	Max EC	EC difference
SP1	13	14.5	1.5	331	482	151
SP2	11	17.6	6.6	212	820	608
SP3	11	19.5	8.5	350	610	260
Sp4	12.5	20.1	7.6	334	660	326
Sp5	13	16	3.0	334	670	336
SP6	11	16.8	5.8	380	650	270
SP7	14	15.6	1.6	303	398	95
SP8	14	15.5	1.5	436	520	84
SP9	12.5	14.4	1.9	295	378	83
Sh1	13.4	16.5	3.1	202	504	302

dissolved oxygen (DO) values at Sh1 and SP4 and similarities between some other physico-chemical parameters of these springs probably evidence their hydraulic connection.

6. Tracer experiment

Prior to the tracer test it was assumed that water flows from Sh1 towards SP4, so that the objective was to confirm the underground connection between these localities. These assumptions were based on the following: (1) the position of the Kenet fault ,which extends almost N-S, to which both localities are alligned; (2) the distance between Sh1 and SP4 is shortest as compared to other sinkholes; (3) Sh1 is located in the SP4 topographic catchment area and elevation difference between Sh1 and SP4 is 750 m; (4) turbidity of SP4 with rainfall. Therefore inspection of the area suggested that the best point for tracer injection is Sh1. Springs and places where appearance of the tracer would be probable were also determined.

Tracer tests in karstic rocks make it possible to obtain information on the groundwater flow path, flow type, hydraulic relations and the other aquifer properties. A review of literature (Kogovsek et al., 1997; Pavicic and Jvicic, 1997; Stevanovic et al., 1997; Kass, 1998; Vu and Nico, 2006; Zargham et al., 2007) indicated that uranine tracing has been most widely used in karstic terrain. The observation stations were checked for natural or man made background by passive detectors prior to the dye experiment.

On October 18, 2006 at 7 pm 5 kg of uranine in the form of pre-prepared aqueous solution was injected into sinkhole (Sh1). Then, in addition to rivulet discharge into the shaft, after end of tracer injection 6000 L of water was injected into the shaft in order to clean the shaft's wall and to flush the dye tracer. Sampling was done by direct water samples and by bags with activated charcoal. Tracer experiment was monitored in 12 locations including the Neka River, springs and wells around Sh1. The observation period was extended over 107 days and in total 989 samples were collected. SP4 and SP5 were sampled in most details. Analyses were carried out with a spectrofluorometer model AU 10, with an accuracy of 0.001ppb.

Uranine first appearance was 158 hours after injection, and it was only detected at SP8 in water samples during the 107 day test. Since water sample results of injection test demonstrated a connection between Sh1 and Sp8, therefore, probably part of the water sinking at Sh1 emerges to the northeast at SP8. On the other hand activated charcoal results indicated connection between Sh1 and SP3, SP4, SP5, SP8, well 1 and 2, and the Neka River. Activated charcoal residence time distribution curves are not commonly in use for qualitative analysis. Lois & Ponta (1999) determined fracture flow path by peak dye concentration of charcoal bags in contaminated karstic terrain. Activated

Table 3.

Physico-chemical characteristics of water samples during low flow condition (Mg/L).

Sampling Nos	PH	EC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	NO_3^-	HCO_3^-	SO_4^{-2}	Cl^-	SIc	SId
SP1	7.29	491	50.1	23.2	3.7	2.0	0.43	238.3	15.8	8.2	-0.20	-0.54
SP2	7.43	398	40.08	15.8	2.8	2.6	9.03	183.1	16.8	7.6	-0.27	-0.73
SP3	7.41	497	32.06	31.6	3.5	1.3	8.53	244.1	14.9	6.8	-0.2.8	-0.35
SP4	7.15	594	52.1	29.2	4.0	1.7	12.0	287.1	13.9	7.0	-0.25	-0.55
SP5	7.21	521	50.1	24.3	3.6	3.2	3.96	251.5	13.9	6.9	-0.26	-0.62
SP6	7.28	575	50.1	30.4	19.3	1.7	6.13	262.9	15.8	3.5	-0.16	-0.33
SP7	7.28	505	62.12	17.0	3.5	2.3	6.13	232.4	16.8	7.0	-0.12	-0.60
SP8	7.65	430	38.07	14.6	16	0.8	4.0	201.4	4.8	14.2	0.03	-0.28
SP9	7.31	566	84.16	24.3	4.7	1.2	4.0	226	15.8	24.8	0.03	-1.29
W1	7.68	1264	70.14	26.8	101	3.5	-	457.6	52.8	46	0.55	0.97
W2	7.7	1051	62.12	27.9	89.6	2.4	-	433.2	76.8	25	0.51	0.97
W3	7.8	988	82.16	29.2	55.2	3.5	-	414.9	43.3	42.5	0.52	0.83
W4	7.07	1458	98.19	25.5	149.4	3.2	-	494.2	105.7	117	0.08	-0.14
Sh1	6.71	504	48.09	20.7	15	2.3	16.0	238	15.8	17.7	-0.8	-1.73

Table 4.

Some characteristics of springs in high flow period.

Springs	Temperature (˚C)	PH	EC(µS /cm²)
SP1	13	7.35	482
SP2	15.9	8.13	212
SP3	15.4	8.39	350
SP4	15.1	7.30	334
SP5	14.9	7.28	305
SP6	15.1	7.20	427
SP7	14	7.29	423
SP8	14.2	7.65	303
SP9	13	7.23	319
Sh1	13.4	8.0	303
Rain	-	6.8	220

charcoal results (Figs. 6 and 7) depicted tracer appearance time and underground network.

Comparison of Figs. 7 and 8 shows that the concentration of SP8 samples is approximately 2 times greater than the water samples concentration. This happens due to continuous absorbance of dye tracers on activated charcoal bags. The concentration of dye in SP4 samples (Fig. 6), as compared to SP8 samples, indicate more than 80 times reduced concentration.

This might be a result of tracer dilution or low concentration of tracer in SP4 direction and could be also affected by uncontrolled exit of tracer. The differences in arrival date of tracer (charcoal bag results) in SP4 and SP8 with respect to their distance to Sh1 confirm diffuse and conduit flow type for SP8 and SP4. This assumption, and samplers result of the other stations, suggest that Sh1 has also a hydraulic connection to the remaining collected sampling points.

Table 5.

Physico-chemical characteristics of samples in meq/L.

Stations	Sh1		SP4		SP8	
	1	2	1	2	1	2
Temperature ºC	18	16.5	20	15	18.3	16
PH	6.7		7.15		7.65	
TDS mg/l	312		349		159	
Ca^{++}	2.4		2.4		1.9	
Mg^{++}	1.7		2.6		1.2	
Na^{+}	0.6		0.18		0.7	
K^{+}	0.06		0.04.		0.02	
HCO_3^-	3.9		5.0		3.3	
SO_4^{--}	0.33		0.3		0.11	
Cl-	0. 5		0.2		0. 4	
NO3- mg/l	16		12		4.0	
Hardness mg/l	68		81		52	
Sic	-0.8		-0.25		0.04	
CO2 mg/l		32.2	34.7			27.5
DO mg/l		6.7		6.75		2.4
Ca/Mg	1.4		1.08		1.6	

The almost unimodal SP8 dye breakthrough curve (Fig. 8) indicates that dye appeared 158 hours after injection. Maximal concentration period was 13 days, and about 100 days later the curve returned back to its initial position. The sharp and unimodal characteristic of curve suggests one main watercourse with no large underground reservoir. The tracer test result in the SP8 catchment is shown in Table 6.

Applying a tortuosity of 1.5, the actual distance was obtained. The dominant velocity (v) was computed from actual distance (L) and time with maximal concentration (Tp). Smart (1988) equation was taken to calculate mean residence time

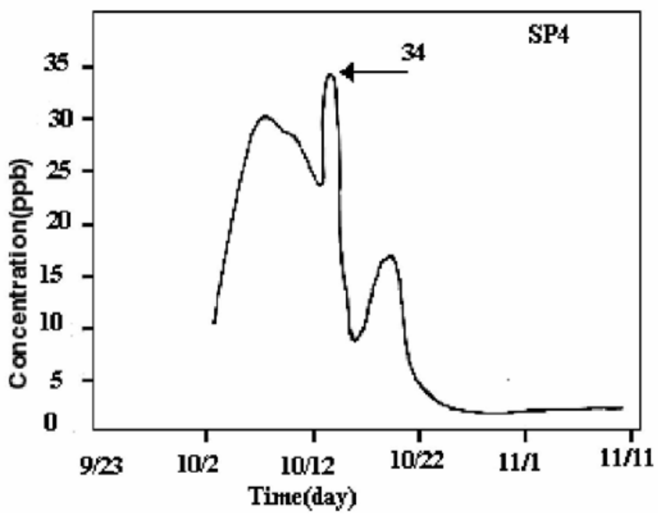

Fig. 6. Uranine concentration in charcoal bags at spring SP4.

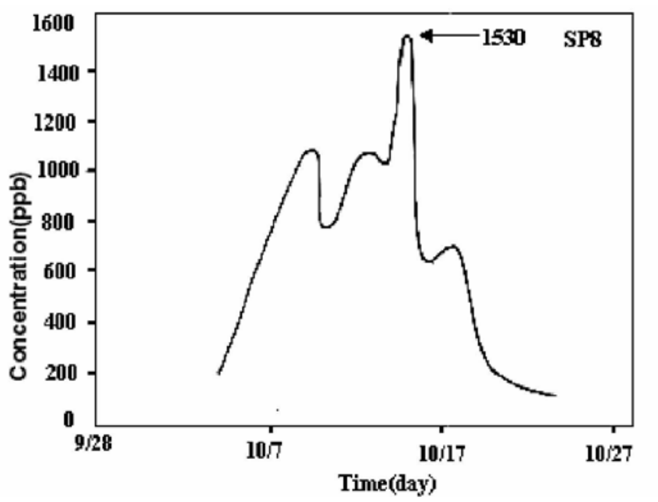

Fig. 7. Uranine concentration in charcoal bag at spring SP8.

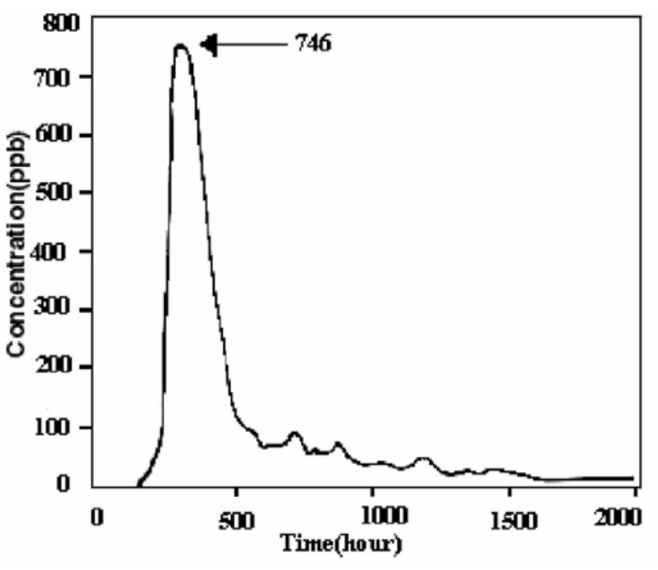

Fig. 8. Breakthrough curve results for uranine at spring SP8.

Table 6.

Calculated results of tracer test at SP8.

Dominant velocity	0.36 cm/s
Actual distance	4050 m
Mean residence time	465 hour
Skewness	30%
Dispersion coefficient	0.293x10-2 km2/h
Mean basin width	1.72 km
Flow type	Diffuse
Catchment boundary	6.96 km2

(Tr) and skewness (S). Dispersion coefficient (Dd) and the first dye appearance time were used to determine basin width, where this in turn was applied to estimate watershed boundary. The distance, velocity and dye appearance determines flow type. On the basis of injected dye mass (kg) and the area under curve (A), maximum SP8 discharge (Qm) was 12.7 L/s which is roughly in accordance with SP8 discharge in high rainfall years.

7. Conclusions

In the studied area, occurrence of well-developed geomorphological karst features, spring discharge variations and hydrochemical evidences suggest the presence of underground karst channels. The results of the tracer test with the injection into Sh1 do not support well channel connections. Even, in spite of tracer appearance (activated charcoal) in SP4, due to absence of dye in SP4 water samples, Sh1 and SP4 interconnection is unlikely to account for the source of turbidity in SP4. The karst underground flow follows privileged directions, most frequently tectonically predisposed. Then, the question is that what is the role of the Kenet fault? The low returned quantity of tracer probably suggests an uncontrolled exit. The other possible reason for not detecting tracer in water samples in SP4 and low recovery is the connectivity between different parts of the aquifer in the catchment area of the Emarate main spring (SP4) which results huge SP4 discharge and tracer dilution.

Therefore, the water-tracing test at this stage only provided some basic information regarding aquifer characteristics in limited area. For detailed understanding more tracings have to be done in different hydrologic conditions.

As the differences in water chemistry between the sampling points are not pronounced, it could be indicative interconnection among them (Sh1, SP4 and SP8).

The quantitative results of the uranine tracer test for Sang-e -Now diffuse spring (SP8) suggested the catchment area of about 10 km^2 , actual distance of 4050 m from injection point and the dominant velocity of 0.36 cm/s.

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