Classification of Karst Springs for Flash Flood-Prone Areas in Western Turkey

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Abstract

Flash floods are the result of very intensive rainfall events in which karst plays an important role. A study using a hydrogeochemical approach and assessing data from several springs of different carbonate rocks in Western Turkey was made possible to classify karst aquifers' response to heavy rain events. Physicochemical measurements in wet and dry seasons and discharge rates are compared in order to explain aquifer characteristics. Groundwater samples have pH values ranging from 6,3 to 8,9, temperature (T) varying from 7 to 35°C, and electrical conductivity (EC) values going from 140 to 998 µS/cm. Groundwater samples with high EC, high T, and low dissolved oxygen (DO) values represent the deep circulating water while low EC, low T and high DO values represent the shallow circulating water. Low variations of the measurements in both the wet and dry seasons reveal that fracture permeability is predominantly controlled by diffused groundwater flow with low or high storage and conduit permeability with high storage. High variations of the measurements point a conduit permeability with low storage; and high transfer capability is predominantly controlled by turbulent groundwater flow which is found effective in flash floods.

Keywords: Flash flood, Flood-prone area, Hydrogeochemistry, Intensive rainfall, Karst

1. Introduction

Karst plays an important role in flash floods which result from very intensive rainfall events. The characteristics of flash floods are their short duration, small areal extent, high flood peaks and rapid flows, and heavy loss of life and property. Karst flash floods have specific characteristics due to special conditions for water circulation which exist in karst terrains (Bonacci et al., 2006). Due to the characteristics of groundwater flow in a karst terrain, flash flood in such a context is strongly different from that in a non-karst terrain; the groundwater volume becomes much larger in the former.

This study tries to classify karst aquifer types for karst flash flood investigation in order to define flood –prone areas by using the physicochemical properties and yields of karst springs. The recharge of karst aquifers is described as water flow into the groundwater level and deep inflow to create a groundwater reservoir. Infiltration has two different forms; areal or spatial diffusive infiltration of water that directly flows into the groundwater reservoir, and point infiltration via karst structures such as caves, sinkholes, joints. Spatial groundwater recharge process is diffusive in which water reaches the groundwater table through the intergranular of the unfractured bedrock and fractures. The other form of recharge (the point infiltration) depends on the pipe-like structures (conduits) in which water flow within conduits is laminar or turbulent.

Vertically-oriented karst features collect and quickly transport water from the surface to the underground fluvial system. The minimum diameter of karst conduits in which turbulent flow could exist should be greater than 5 to 15 mm (Ford and Ewers, 1978, Bonacci et al., 2006).

Precipitation factors, which directly affect the recharge, are the duration of precipitation, altitude and rainfall intensity and its type (Sutcliffe, 2004). In karst regions, point infiltration and sudden rainfall are correspondingly effective. Studies indicate that less than 5% of annual effective rainfall becomes groundwater recharge, whereas recharge to karst aquifers is in excess of 80% of effective rainfall. For instance, in karst regions in Saudi Arabia, 47% of the average rainfall disappears at the intersections of dolines and cracks (Milanovic, 1981). According to De Vries et al. (2002), in Portugal, which represents a dry and hot summer-climate, in karstic dolomite and marble regions 150-300 mm of the 550 mm-annual precipitation is infiltrated. Similar values are reported for karstic aquifers located in Israel representing a Mediterranean climate (Issar et al., 1990). In different regions of the former Yugoslavia, values of infiltration are calculated between 70 and 90% from the spring discharges (Milanovic, 1981). In Turkey, in Tecer limestones (Sivas-Ulaş region in the Eastern Central Anatolia), infiltration has a percentage as high as 55 % (Ekemen and Kaçaroğlu, 2001). The annual effective infiltration coefficients of the Gradole catchment in Croatia were given between 0.356 and 0.763 (Bonacci, 2001), The infiltration ratio between 0.6 and 0.9 of total precipitation were given for the mountainous karst regions in Switzerland (Malard et al., 2016).

In general, the frequency or intensity of heavy precipitation events have increased since 1901 (with a medium confidence before and a high confidence after 1951) over the mid-latitude land areas of the Northern Hemisphere (SPM, 2013). According to the country report presented by the Turkish government and the United Nations Development Programme (UNDP), precipitation decreases along the Aegean and Mediterranean coasts and increases along the Black Sea coast of Turkey. Central Anatolia shows little or no change in precipitation. The most prominent result of the climate change data is that the number of days with excessive precipitation has been increasing in Turkey and this usually causes extreme floods. Even in regions where total annual rainfall is decreasing, there is a trend for higher amount of rain that reaches the ground in heavy downpours (IPCC Report on Extreme Events, USGCRP 2009, CCSP 2008).

Despite a year in which cumulative precipitation increases, the total amount of recharge into groundwater may be less in aquifers dominated by diffused flow (Williams and Lee, 2007). This research reinforces the hypothesis that aquifers controlled by conduit permeability will have higher recharge and discharge rates unlike the aquifers dominated by diffused flow. Practically all rainfall quickly penetrates the karst underground system where it fills karst voids of different dimensions, and at the same time flows under the effect of gravity. (Bonacci, 2006). Therefore, it can be noticed that higher recharge in limestones is due to point infiltration coming from the well-developed karstic structures. However, it should be mentioned that an accurate and reliable estimation of recharge into karst aquifers is difficult because of their heterogeneous local structures (Bonacci, 2001, Fiorillo et al., 2015a; Bakalowicz, 2015).

Developed karst sinkholes allow fast percolation into the aquifer, up to 80% of heavy rainfalls. However, the very low storage combined with the high transmissivity means that most of the recharge will not be retained by the karst system, but will rapidly flow out (to springs, rivers, lakes, sea). The large response of water level to the rainfall combined with the capability of karst systems to transmit groundwater increases flooding quickly (Williams and Lee, 2007).

The other form of aquifers which is controlled by diffused groundwater flow, also can cause inter-catchment overflow and the redistribution of catchment areas at very high groundwater levels, because of fossil and inactive conduits and springs activation in vadose zone (Bonacci et al., 2006). For this reason, karst flash-flood has been identified as one of the main hazards in karst terrains. It is directly linked to the structure and hydraulic properties of the karst aquifers (Fleury et al., 2013). Karst structures should be taken into account as a component of the hydrological budget of the watershed to avoid the unexpected, uncalculated additional water coming from neighbouring watersheds (Aksoy 2016). Eris and Wittenberg (2015) showed that water transfer between neighbouring karstic watersheds in Mediterranean Turkey was considerable.

Chemical characteristics of the aquifer are functions of residence time and flow conditions in the aquifer (Freeze and Cherry, 1979). Changes in the quantity and quality of the discharge of karst springs are largely caused by recharge parameters in the recharge area such as rainfall and snowmelt (i.e., autogenic recharge) and point infiltration of streams (i.e., allogenic recharge) as well as lithology, hydraulic conductivity, residence time of aquifers that also affect changes. As a matter of fact, Jakucs (1959), Shuster and White (1971), Aydin (2005) and Demiroglu (2008) argued that the reason for the changes observed in the spring discharges was the recharge type or flow type (diffuse or conduit) with high or low storage. High number of studies have been done to define aquifer characteristics using the physico-chemical measurements (Shuster and White, 1971; Raeisi and Karami, 1997; Massei et al., 2007; Raynaud et al., 2015) by considering only one or a few physico-chemical parameters that characterize groundwater with a potential to lead an erroneous interpretation of the hydrodynamics of the karstic catchment draining into the spring (Chicanoa et al., 2001; Massei et al., 2007). In this study, it is proposed to define flood–prone areas by using physico-chemical properties and discharge rates of karst aquifers in addition to evaluating the lithological and structural features.

2. Material and Method

Representative and organized sampling of springs in Günyüzü basin, Eskişehir, Turkey, indicated that karst groundwater characteristics can be defined and used for the classification of karst aquifers regarding their contribution in generating flash flood (Demiroglu, 2008). In this manner, data related to study area as listed in Table 1 were compiled from previous studies (Atilla, 1996; Aydın, 2005; Demiroğlu, 2008) and from State Hydraulic Works, DSI of Turkey. Some springs (S3, S9, S10, S18) recharge, circulate and discharge from Paleozoic Marbles and some (S1, S2, S13, S16, S17, S19, S20) from Mesozoic limestones while others (S4, S5, S6, S7, S8, S15, S18) recharge and circulate in marbles, and circulate and discharge from Neogene limestones and sediments. S11, S12 and S14 discharge from Mesozoic melange.

The hydrogeological characteristics (topography, physical boundary and storage capacity of aquifer) were defined first. Measurements in wet and dry seasons and discharge rates were then compared in order to support and explain aquifer characteristics. High discharge rates (Q_{max}/Q_{min}), rapid change in temperature and chemical composition reveal turbulence flow conditions in developed karstic structures with low storages (Aydin, 2005; Demiroglu, 2008). Low variations of the measurements in both wet and dry seasons point fracture and matrix permeability dominated by diffused controlled groundwater flow with low or high storage, and conduit permeability with high storage. Springs in the study area are treated by using this principle to be classified as springs with or without fast response to heavy precipitation.

3. Study area and Hydrogeology

Karst aquifers with Paleozoic marbles, Mesozoic limestones and the Neocene limestones were chosen from the Western Turkey (Fig. 1 and Table 1) to understand aquifer characteristics for a possible classification in terms of their responses to heavy rainfalls. Karst features of western Turkey demonstrate the tectonic, lithologic, and climatic specificity underground flow movement, and chemical characteristics of groundwater (Gunay et al., 2015).

First group springs (S1 Döşkaya, S2 Nardin) are located in the Central Sakarya Basin (Table 2 and Fig. 2) and they recharge and discharge from Jurassic Bilecik limestone. In this area, the Harmanköy – Beyyayla Karst System (HBKS) studied by Aydın (2005), forms the highlands in the Central Sakarya Basin. The HBKS is located within the province boundaries of Bilecik and Eskişehir and extends over a surface area of 49,5 km^2. The re-crystallized and cherty carbonate rocks are known as Jurassic Age Bilecik Limestone that overlays the metamorphic basement and has a thickness of approximately 100 m of karstified layers and then a fractured layer (Aydın, 2013). Bilecik limestones have a well-developed pipe-like karstic structure ranging from 1 cm to a few tens of meters where groundwater flows in conduits in a turbulent regime. Calculated storage is between 2-5x10^6 m^3/year for Döşkaya and Nardin springs.

Second group springs are located in Çifteler and Günyüzü subbasin within the Sakarya basin, Sivrihisar-Eskişehir (Fig. 3). Sakarbaşı and Kaymaz springs (S3, S4) were studied by Güner and Güner (2002) who determined little or no change in the in situ measurements during three seasons of sampling (Table 3). The reservoir rocks of Sakarbaşı springs S3 (Sadıroğlu, Eminekin, Başkurt, Ilıcabaşı and Pınarbaşı) are composed of marbles. This is named the Gökçeyayla formation which is primarily shelf-type carbonates that were deposited during the Triassic-Upper Cretaceous. Dolomitic limestones are dominant in the lower section of the unit, while the upper section is mostly cherty limestones (Günay, 2006). The summation of groundwater discharge (233x10^6 m^3 /year) and pumped water (49x10^6 m^3/year) in this aquifer is282x10^6 m^3/year. Günay (2006) showed that recharge into this aquifer (47x10^6 m^3/year) is less than the discharge that is balanced with water coming from the neighbouring basins.

Günyüzü springs, located in the Sakarya River catchment area to the SW of Eskişehir, were studied by Demiroglu (2008) (Fig. 3). Paleozoic marbles, which are main reservoir rocks for hot and cold water, are bordered by impermeable diabase dykes at the sides and by impermeable granites and schists. Marbles, at the top of the metamorphic series, at higher elevations of the basin represent the upper part of the aquifer system. The springs are listed in Table 3. S9 (Çukurçeşme) spring recharges, circulates and discharges from this system. This shallow circulation of water has laminar flow conditions (Demiroglu, 2008). Other shallow circulated water (S5 Babadat and S6 Nasrettin Hoca) mostly recharges from the marbles but discharges from Neogene units. The groundwater total recharge and discharge were calculated as 30x10^6 m^3/year and 32x10^6 m^3 /year, respectively, in the Günyüzü basin. The difference between the recharge and discharge for this particular basin cannot be explained by the recharge from neighbouring basins because of the impermeable aquifer boundary conditions. The most likely reason is the partly developed karstic structure and fast percolation (Demiroglu et al., 2011).

Marbles at the bottom of the basin with faults, recharge and store deep circulating water where fracture permeability and diffuse infiltration (laminar flow conditions) control groundwater flow (S7 Çardak Hamamı, S8 Subaşı and S10 Yeniçıkrı). This deep circulating water discharges from Neogene units as well. However, partly developed conduit permeability and point infiltration from old karstic structures (sinkholes), fractures and joints in the marbles reveal a turbulent regime in the vadose zone(Demiroglu, 2008).

It is seen that measurements, observations and calculations given for above examples show that discharge from aquifers are always higher than the recharge into the aquifer. The difference is usually assumed to be balanced by contribution of neighbouring sub-basins. However, this is not the only way to explain the higher recharge. A more important reason particularly in karst aquifers dominated by point infiltration is the fast response of the aquifer to heavy rainfalls that are expected to become more frequent in the future. This can be linked to climate change for which spring discharge is found a robust indicator (Fiorillo et al., 2015b).

The third group springs are located in the Lake district (Fig. 5). Mesozoic limestones are the most common unit around the lake. These units belong to different time frames. Middle Upper Triassic dolomitic limestone containing different lithofacies from thin layer to medium thick bedded levels are the oldest part of the Mesozoic series. Jurassic-Cretaceous limestone contains marine sediments from the deep to shallow marine environment. Thinly bedded cherty micritic levels are also observed. Mesozoic rocks have a tectonic sliced structure. Slices are showing the ophiolitic mélange feature at the bottom of this structure (Davraz et al., 2008). Important springs are located mostly along the tectonic contact between over-thrusted limestone formations and impervious hydrogeological barriers (Günay et al, 2015)
Most of this kind of springs discharge from the Mesozoic age marine limestones. Kirkgözler springs (S19, S20) which are very important for Antalya region for drinking water and irrigation. They discharge from the boundary between the mountains Beydaglari authocthonous limestones and the impermeable ophiolite rocks (Fig. 5) located at 300 m elevation. They are characterized by a highly regulated flow regime (Özyurt, 2008). It can be said that all springs except for the Kirkgozler springs have high response capability to heavy precipitation when the dry and wet seasons in situ measurements of springs are considered (Tables 4 and 5).

A historical spring, Sagalassos (S18) in the Lake district discharges from the deeply fractured allochthonous Cretaceous-aged limestones. It is a good example with a high response capability to heavy precipitation taking place in the ancient city. Surprisingly, the natural flood risks were taken into account in Roman times at the Sagalassos ancient city. Excavations indicate that the large open areas were carefully situated within the urban fabric to collect and drain the natural floods flushing down the mountains, hence protecting the buildings from damage (UNESCO 2009).

Another example in the Lake District is Sütcüler small springs. There are no regular yield and water chemistry measurements on these springs (Fig. 6). Sütcüler is a town located on the allochthonous Limestone that faced flood disasters in November 1995 and October 2011. The area was studied by Karagüzel and Akıncı (1998) after flooding. The Ophiolite complex consists of the ultrabasic and sedimentary rocks at the base with the Jurassic-Cretaceous carbonate mass spread over a wide area and overlapped the ophiolitic rocks. Erenler Mountain, located in the north of Sütcüler, is composed of limestones and has developed karstic structures (sinkholes, dolines) on the Ophiolite complex. Plioquaternery travertines are exposed in the town and sand, gravel and block-size debris piles up at the base of steep slopes (Fig. 6). The town center is mainly founded on the travertine and ophiolite complex. There is no permanent surface water flowing in the region. Springs discharge from the limestone-ophiolite contact. These springs are activated with sudden rise in the groundwater. Here, heavy rainfall is combined with the capability of the karst system. During karst flash floods, a sudden rise in the groundwater level occurs, which causes the appearance of numerous, unexpected, abundant and temporary karst springs (Bonacci et al. 2006). Therefore, urban drainage systems must be designed by taking these springs into account, which have high response capability to heavy precipitation as considered in ancient time similar to the Sagalassos case.

4. Results and Discussions

Data compiled for the study area were analysed based on method described as follows for each group of springs.

In situ measurements are the signatures of karst aquifers but it is first needed to separate the measurements in wet and dry season in order to evaluate the seasonal variability in water geochemistry and dilution affect. As it is demonstrated in Tables 1-5, the groundwater has pH values ranging from 6.3 to 8.9, temperature varies from 7 to 35°C, and electrical conductivity (EC) values go from 140 to 998 µS/cm. Average Ca and EC values were measured as 3 meq/l and 384 µs/cm, respectively, in cold shallow circulated water discharges from Paleozoic Marbles in Gunyuzu basin (S5, S6, S9). These values were measured as 7,5 meq/l and 988 µs/cm in the Kırkgozler spring from Antalya Jurassic limestone (Atilla, 1996), and 6.4 meq/L and 596 µs/cm in the Nardin spring from the Bilecik Jurassic limestone (Aydin, 2005). The average EC value of 350 µs/cm was measured in the Kaymaz spring, which discharges from Paleozoic marbles at the beginning of the Sakarya River in the Sakarya basin (Günay, 2006). These measurements indicate that Paleozoic marbles in the Günyüzü basin and Mesozoic marbles in the Çifteler basin have similar characteristics due to the fact that marbles are less soluble than limestone.

The relationship between EC, temperature and DO indicates the existence of groups of water with different origins (Mazor 1991). Water group with high EC, high T, and low DO represents the deep circulating water (S3, S7, S8). Low EC, low T and high DO-water represents the shallow circulating water (S1, S2, S5, S6, S9).
EC measurements show that variations in physicochemical data depend not only on circulation depth and residence time but also on lithology. For example; springs S3 and S8 have nearly the same temperature and DO (26,6-30 ^{o}C / 4,36-4,81 mg/l) which represent approximately the same circulation depth and residence time. However, the EC value differences (398, 778 µS/cm) stem from lithology. Spring S3 recharges, circulates and discharges from Paleozoic marbles, whereas, spring S8 recharges and circulates in marbles, then circulates and discharges from Neogene limestones and sediments. In this respect, the chemical signature of karst aquifer mainly depends on lithology, residence time and hydrologic conditions.

For the first group of springs (S1 and S2 in Bilecik area), two years of in situ measurements in dry and wet seasons are given in Tables 2 and 4. It is clearly seen that temperature change in S1 is not as high as S2 (Table 2) but discharge rates change within two orders of magnitudes from zero-minimum to almost 400 l/s of maximum discharge rate. Based on a hydrogeological (Fig. 2) and hydrogeochemical analysis performed by Aydin (2005) it is concluded that these aquifers have a conduit permeability with low storage dominantly controlled by turbulent groundwater flow. This can be considered as an evidence in order to support that the aquifer is located in a flash flood-prone area.

It is seen that springs S3, S4, S5, S6, S7, S8, and S10 of the second group display nearly constant temperature, low variations in chemical composition and low variations for the measurements both in dry and wet seasons but springs S7, S8, and S10 display high discharge coefficients of variation when the data are analysed (Table 3). As an example, S8 (the Subası spring) has three discharge points. Hydrograph of Subaşı springs S8 (Fig. 4) reflects a correlation between monthly cumulative precipitation and discharge unlike the montly precipitation which does not replace such a correlation. Annual precipitation could influence the discharge of the following hydrological year (Fiorillo 2009, 2015b). This reterdation time in aquifers controlled by diffusive infiltration is longer than that in the point infiltration controlled aquifers. However, it is observed in Fig. 4 that the Subaşı spring discharge (64 l/s) in March 2002 suddenly rised to 173 l/s in April after a heavy precipitation of 88,3 mm in April. The total precipitation in April has been recorded as 88,3 mm more than twice compared to the average (43,98 mm) of total precipitation in April calculated for the long term from 1925 to 2005. This is shows that the vadose zone (developed fossil karstic structures) is activated after heavy rains and carries the surge to surface water and to deep aquifer. Therefore, spring S8 (Subaşı) is classified as having high response capability to heavy precipitation.

In the Lake district that accommodate spring (S10-S20) among which the Kırkgözler springs (S19, S20), the historical Sagalassos spring (S18), and Sütcüler can be mentioned. In this study, data of the first and second groups of springs in Bilecik and Eskisehir are enough for an accurate prediction of aquifer properties which is not the case for the Lake district, except for Kırkgözler springs. Therefore, the Lake district needs steady and organized sampling**.**

The most prominent effect of the change in the climate is that the number of days with excessive precipitation has been increasing in Turkey, and the amount of rain falling in heavy precipitation events is likely to increase and to be more frequent. Despite this reality, there is a general lack of awareness of the impact of karstic springs on flooding although there have been several heavy rainfall events in the karstic Southwest Turkey such as flood events in Sütcüler (Karagüzel and Akıncı, 1998). Being aware of the importance of heavy rainfall and flooding afterwards in the karst areas The General Directorate of Combating Desertification and Erosion established under the Ministry of Forestry and Water Affairs of Republic of Turkey, conducted a project financed by the World Bank on combating against desertification and land degradation in 1999 in the Sütcüler region. In this project, 2602 hectares of erosion control and 490 hectares of pasture improvement works were realized. Despite to these measures taken, a flood occurred again on December 25th, 2011 in the Sütcüler region. The drainage system must be developed by taking into account the karst springs which have high transfer capability with heavy precipitation and also considering hydrology and hydrogeology, two well connected disciplines on flood events in karst regions of Turkey.

5. Conclusions

Following concluding remarks are drawn based on analysis and discussion of the data compiled for the karst springs in the study area:

1. Measurements compiled for the study considered reinforces that the recharge of karst aquifers dominated by conduit permeability can increase by heavy rains becoming more frequent than before with possible changes in the climate.

2. Karst aquifers, which are deeply fractured, mostly allocthonous in origin, located on the steeper parts of the land and bordered by impervious rocks can transfer the considerable amount of water from different hydrological drainage basins to flood areas.

3. In this study, an approach considering groundwater temperature, physico-chemical properties and discharge rates of springs in addition to lithological and structural features is used to determine the storage and flow conditions of the aquifers. However, due to heterogeneity, each karst aquifer is site-specific and needs detailed multi-method measurements and co-operation between hydrology and hydrogeology to reach more reliable estimates.

4. This approach offers a valuable tool for the identification of flood-prone areas in large regions provided that representative and organized data sampling is available at least twice in wet and dry seasons.

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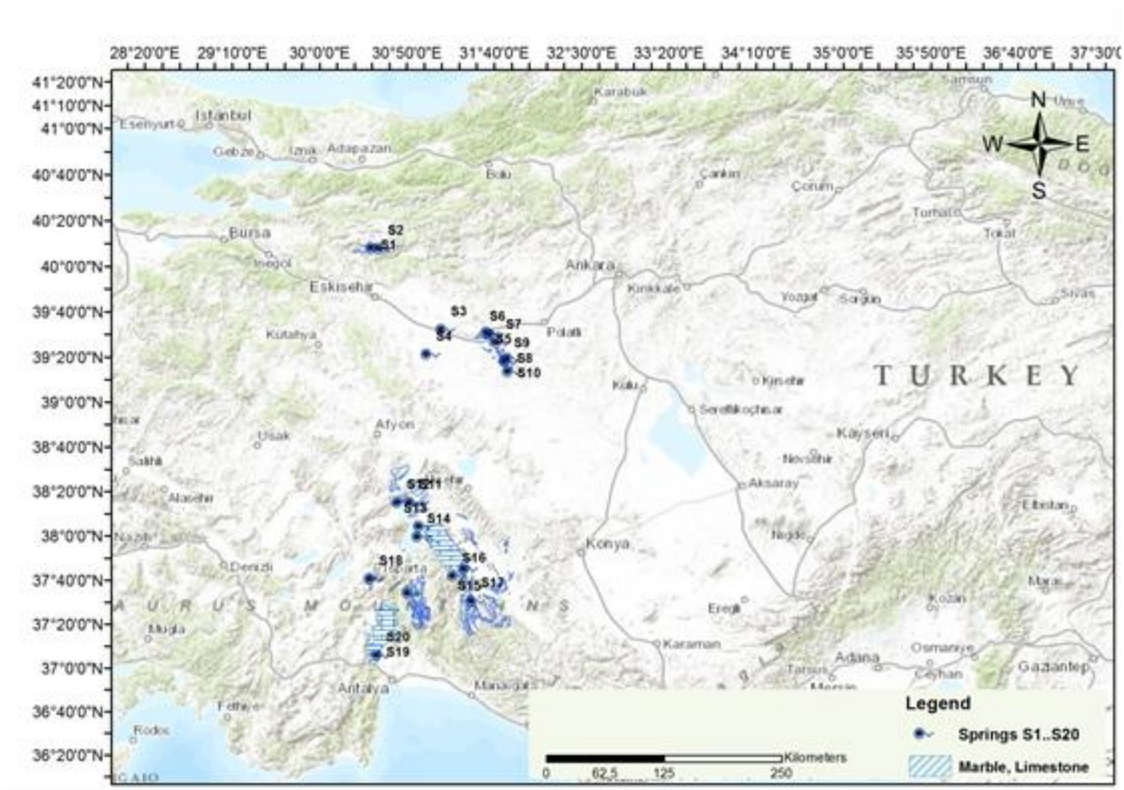

Figure1. The location map of the study area

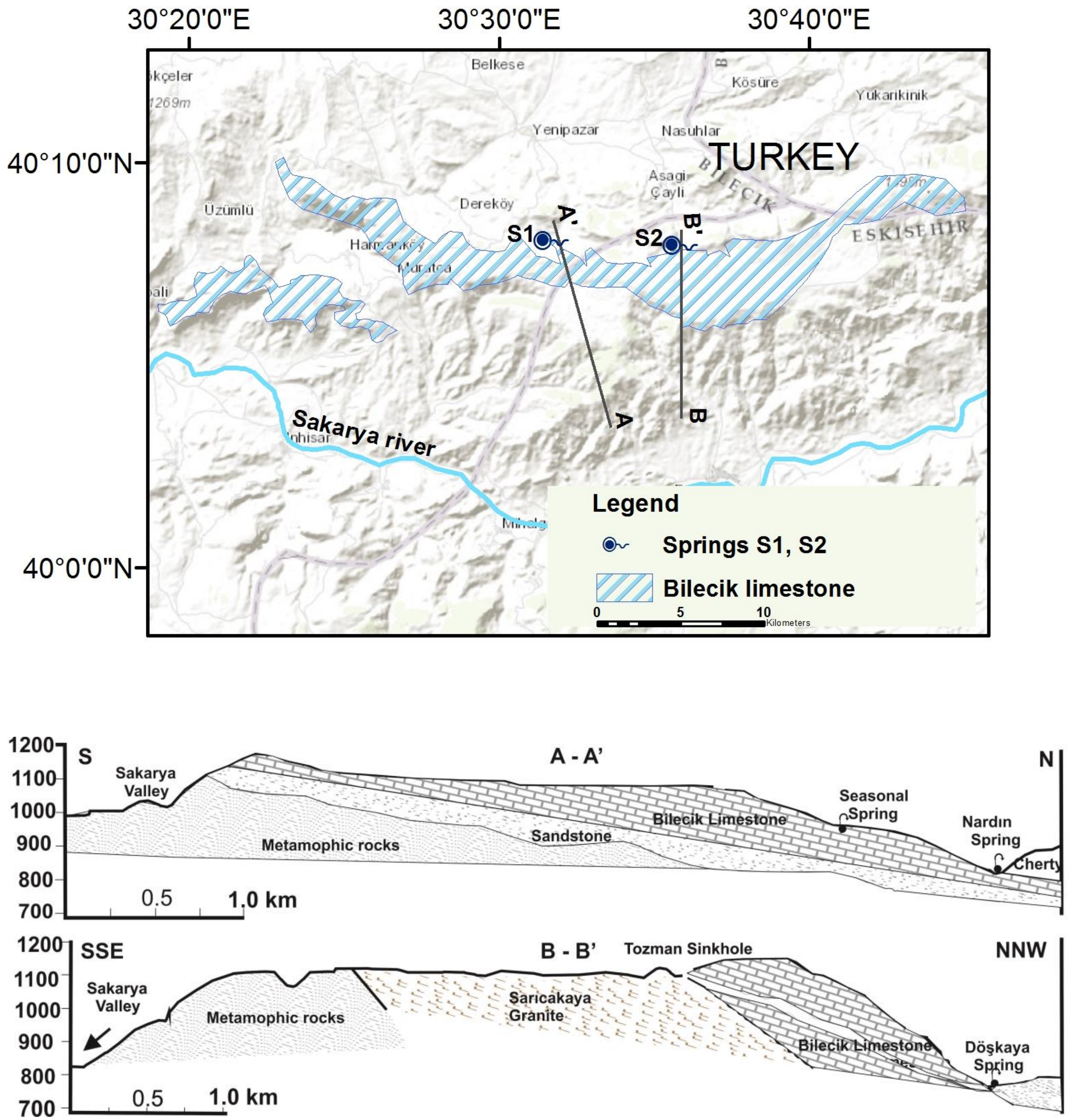

Figure 2 a) Bilecik limestones (Jkb), b) The geological cross-section of Nardin and Döskaya springs (modified by Aydın, 2013)

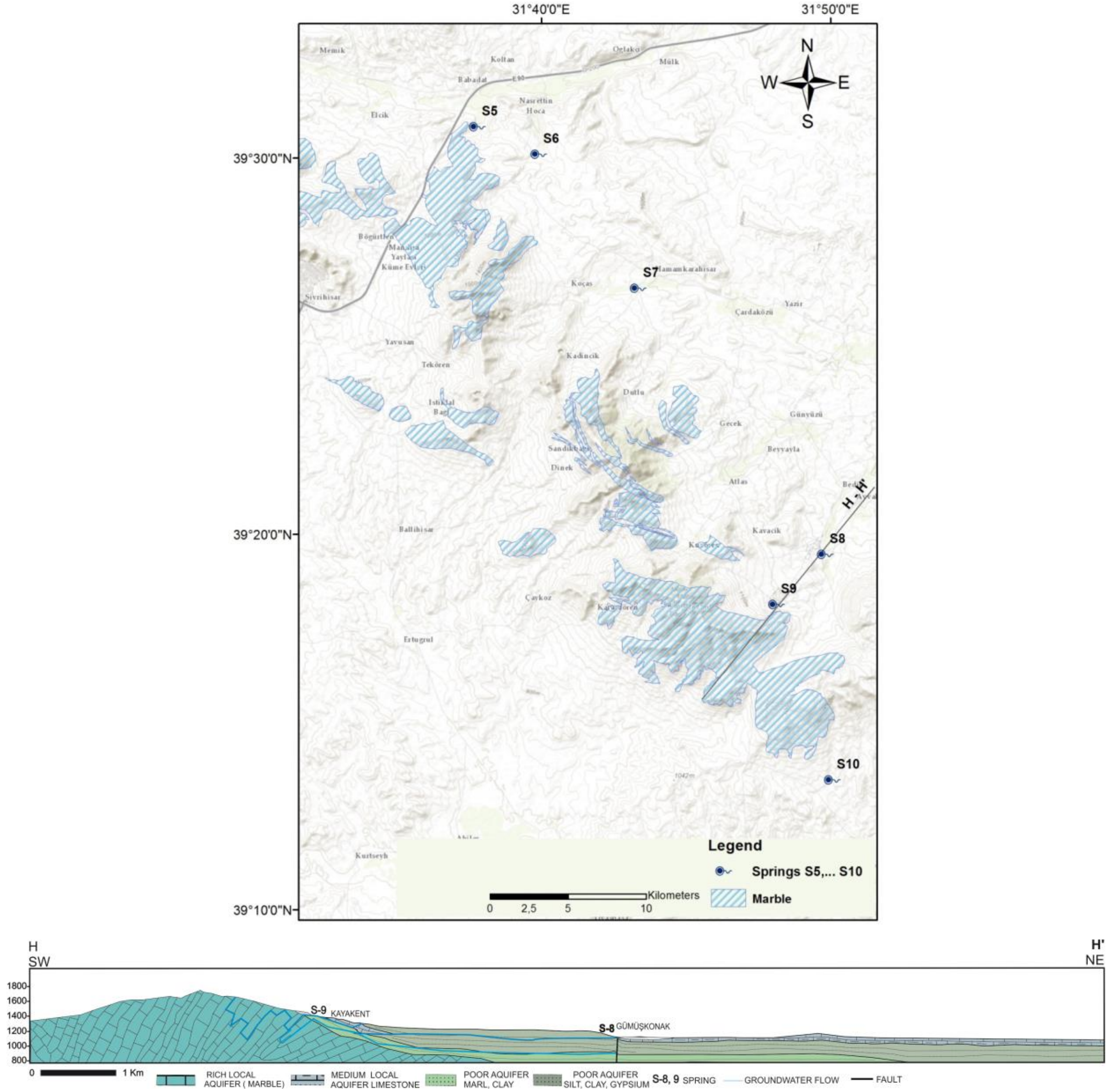

Figure 3 a) Gunyuzu marbles, b) The geological cross-section of Gunyuzu springs (Demiroglu, 2008)

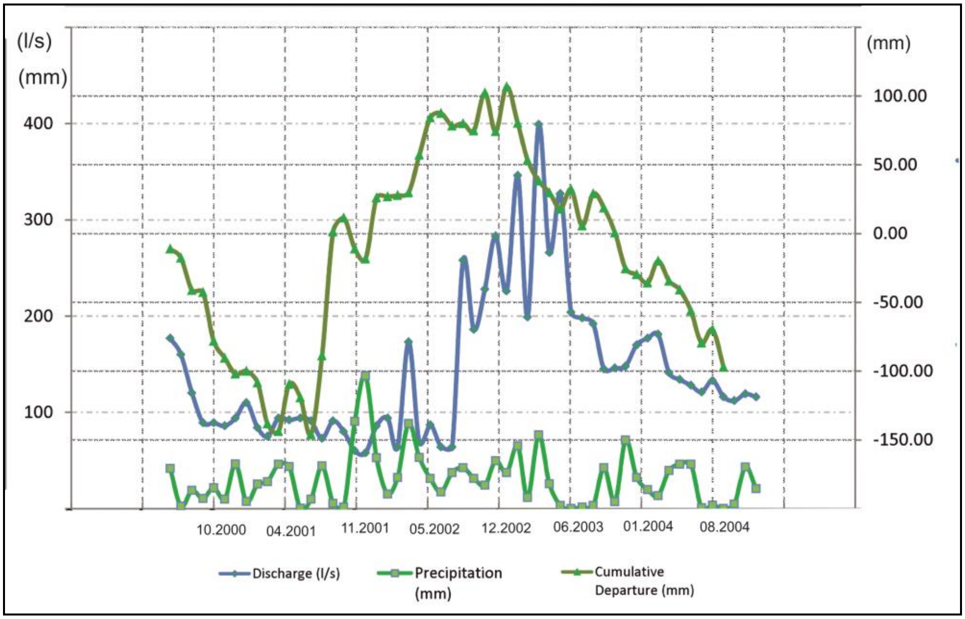

Figure 4. Hydrograph of Subaşı springs, discharge, monthly precipitation and cumulative departure

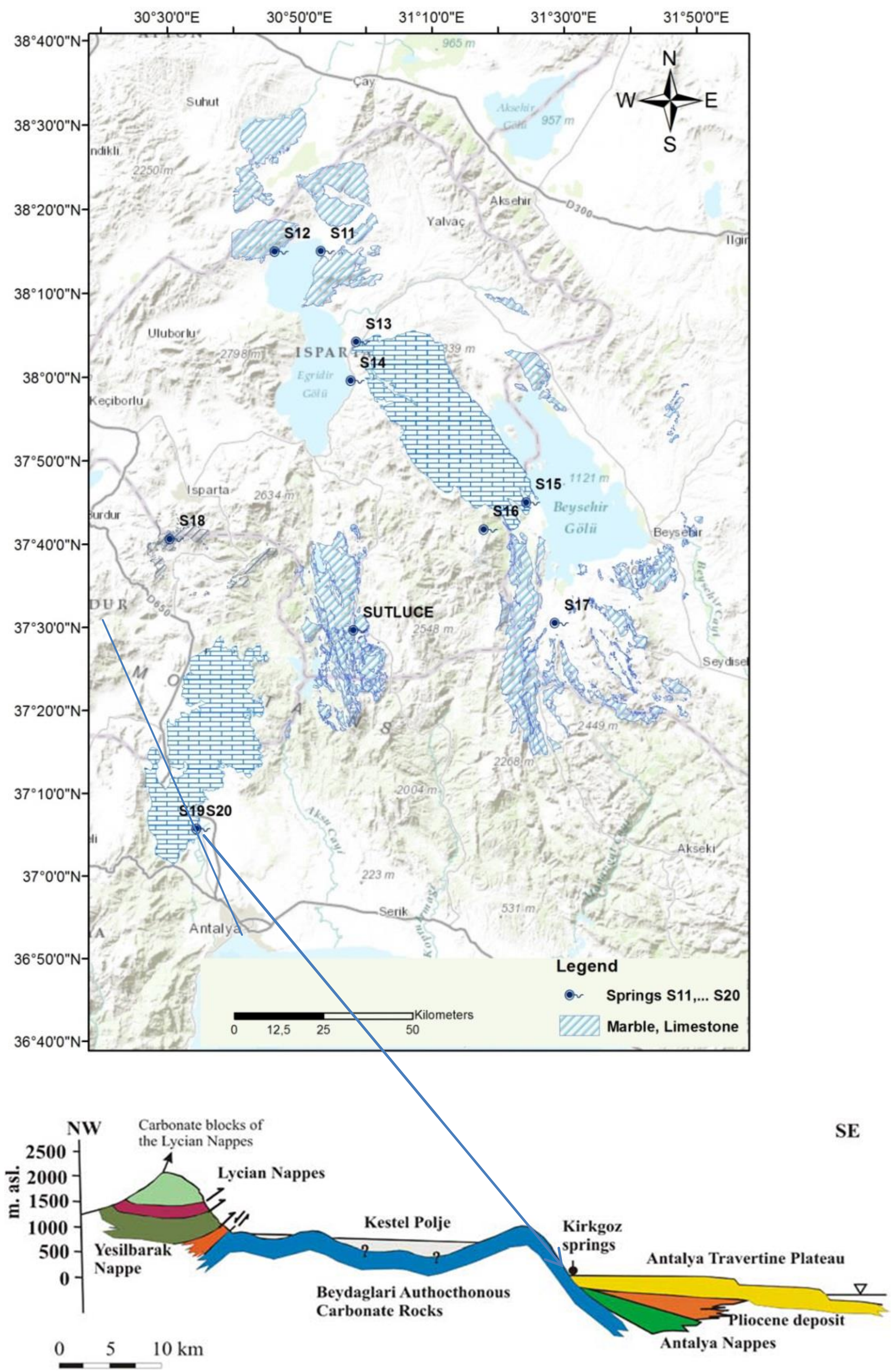

Figure 5 a) Lake district marble and limestones, b) The geological cross-section of Kirkgoz karst springs, Southern Turkey (Ekmekci, 2005)

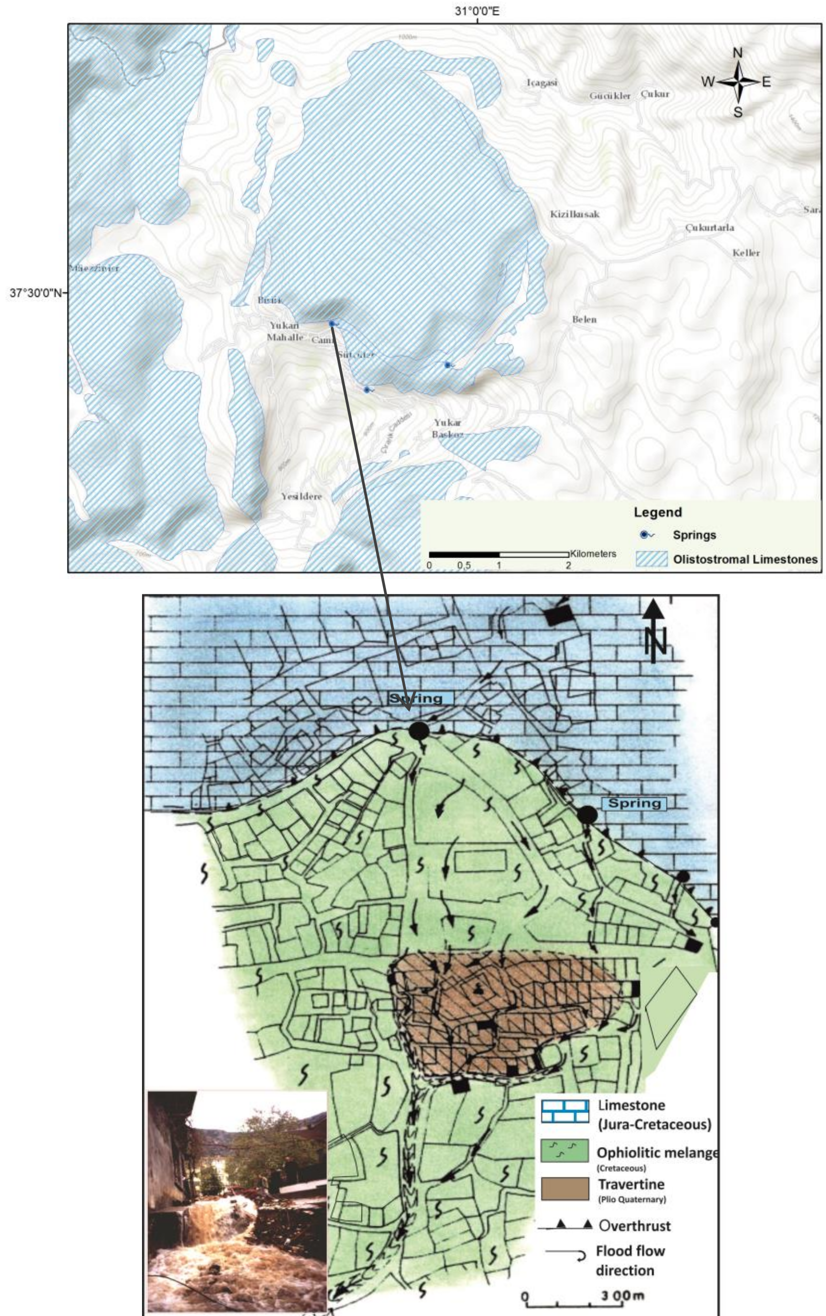

Figure 6. Map of flooding road in Sütcüler settlements (Karagüzel and Akıncı,1998)

Table 1. The location of springs (S1-S20).

No.		X	Y	Z	Aquifer Lithology	Discharge Lithology
S1	Döşkaya	289415	4445794	801	Jurassic Limestone	Jurassic Limestone
S2	Nardın	295328	4445399	926	Jurassic Limestone	Jurassic Limestone
S3	Kaymaz	345373	4378055	1015	Paleozoic Marble	Paleozoic Marble
S4	Sakarbası	332776	4357779	860	Paleozoic Marble	Neogene Limestone
S5	Babadat	382267	4374873	917	Paleozoic Marble	Neogene Sediments
S6	Nasrettin hoca	385292	4373481	943	Paleozoic Marble	Neogene Limestone
S7	Çardak hamamı	390127	4366839	925	Paleozoic Marble	Neogene Sediments
S8	Subası	399217	4353611	961	Paleozoic Marble	Neogene Limestone
S9	Çukurçeşme	396769	4351171	1011	Paleozoic Marble	Paleozoic Marble
S10	Yeniçıkrı	399431	4342506	887	Paleozoic Marble	Paleozoic Marble
S11	Tırtar	316187	4235908	926	Mesozoic Limestone	Mesozoic Melange
S12	Gençali	306013	4236098	926	Mesozoic Limestone	Mesozoic Melange
S13	Yenice	323511	4215749	925	Jurassic Limestone	Jurassic Limestone
S14	Yeşilköy	322084	4207189	952	Mesozoic Limestone	Mesozoic Melange
S15	Pınarbası	360494	4179515	1127	Jurassic Limestone	Jurassic Limestone
S16	Pınargözü	350959	4173656	1536	Jurassic Limestone	Jurassic Limestone
S17	Adakoy-Pinarbası	366447	4152589	1138	Mesozoic Limestone	Mesozoic Limestone
S18	Sagalasus	281152	4173099	1591	Crateceous Limestone	Crateceous Limestone
S19	KGM Kırkgözler	285415	4108347	300	Jurassic Limestone	Jurassic Limestone
S20	KGI Kırkgözler	285415	4108347	300	Jurassic Limestone	Jurassic Limestone

Table 2. Physicochemical data of springs S1 (Nardin) and S2 (Döşkaya) in dry and wet seasons

Dry season	T (°C)	pH	Ec (µS/cm)	DO (mg/l)	Ca (meq/l)
S1	11,9	7,23	512	10,14	8,4
S2	22,7	6,97	402	7,77	7,14
Wet season					
S1	9,59	6,84	455	11	2,2
S2	13,7	6,38	483	7,12	5,59

Table 3. Physicochemical data of springs S3,S4 (Çifteler) and S5-S10 (Günyüzü) in dry and wet seasons

Dry season	T (°C)	pH	Ec (µS/cm)	DO (mg/l)	Ca (meq/l)
S3	26,6	7,37	398	4,36	4,90
S4	23	7,28	820	ND	ND
S5	20,50	6,92	405	8,06	3,11
S6	22,75	7,17	403	7,68	3,21
S7	34,75	6,93	935	2,89	3,89
S8	30	6,94	778	4,81	4,65
S9	14,02	7.15	346	9,11	2,60
S10	22,82	7,08	590	7,49	3,58
Wet season					
S3	27,5	7,57	350	ND	ND
S4	18,7	7,28	750	ND	ND
S5	20,46	7,09	415,5	7,75	3,18
S6	22,18	7,16	404,5	7,36	3,12
S7	34,44	7,02	958,5	2,21	4,7
S8	29,92	6,86	798	4,46	4,69
S9	13,49	7,21	331	8,89	2,54
S10	22,91	6,96	603	ND	3,89

Table 4. Discharge characteristics of springs and variation in physico-chemical data

No	Q_{max} (l/s)	Q_{min} (l/s)	Q_{max}/Q_{min}	CV_Q	CV_{EC}	CV_{ca}
S1	395,8	0	∞	74,8	10,81	7,3
S2	208,9	1,5	139,3	148,8	38,58	36,6
S3	2490	1447	1,72	13,9	ND	ND
S5	100	68	1,47	22,6	4,96	6,01
S6	219	152	1,44	13,48	3,96	6,63
S7	140	39	3,58	29,39	12,3	4,2
S8	181	112	1,61	50,6	11,9	8,9
S10	108	49	2,2	36,4	10,3	8,04
S16	4078	4	1019,5	103	ND	ND
S20	22000	10000	2,2	ND	0,3	0,31

Table 5. Physicochemical data of Lake District springs

Dry season	T(^{o}C)	pH	Ec (µS/cm)	DO (mg/l)	Ca (meq/l)
S11	14	7,6	600	ND	2,66
S12	17,2	7,7	630	ND	3,21
S13	13	7,8	443	ND	4,19
S14	22,7	8,4	787	ND	2,68
S15	18,7	8,9	381	ND	4,9
S16	6,8	8,9	140	ND	1,5
S17	10,4	8,4	300	ND	3,05
S18	16,6	8,8	191	ND	2,6
S19	16,7	6,6	988	4,2	7,8
S20	16,8	6,5	998	4,4	7,8
Wet season					
S11	12,7	7,8	500	ND	2,54
S12	11,2	8,2	480	ND	2,47
S13	13,8	7,7	586	ND	2,63
S14	11,4	8,4	410	ND	ND
S15	11	8,2	357	ND	1,21
S16	7,2	8,8	154	ND	ND
S17	11	8,5	320	ND	ND
S18	10,5	8,4	214	ND	1,95
S19	16,7	7	969	6	7,44
S20	17,9	7,1	936	8,9	7,14