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Discussions

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 and karst plays an important role in flash floods.
A study ,using a hydrogeochemical approach, assessing data from several springs of different carbonate rocks in Western Turkey was made to classify karst aquifers' response to heavy rain events. Physicochemical measurements in wet and dry seasons and discharge rates were compared in order to explain aquifer characteristics. The groundwaters have pH values ranging from 6.3 to 8.9, temperatures (T) vary from 7 to 35°C, and electrical conductivity (EC) values go from 140 to 998 µS/cm. The groups that have high EC, high T, and low dissolved oxygen (DO) values represent the deep circulating waters. Low EC, low T and high DO values represent the shallow circulating waters. 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 show conduit permeability with low storage but high transfer capability is predominantly controlled by turbulent groundwater flow which effective in flash floods.

Keywords: Flash flood, Karst, hydrogeochemistry

1. Introduction

Flash floods are the result of very intensive rainfall events and karst plays an important role in flash floods. The characteristics of all 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).
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 forms in two ways, areal or spatial diffusive infiltration of water directly flow into the groundwater reservoir, and point infiltration via karst structures such as caves, sinkholes, joints. Spatial groundwater recharge process is diffusive in which water is reaching the groundwater table throughout the intergranular of the unfractured bedrock and fractures. The other recharge form (the point infiltration) depends on the pipe-like structures (conduits) in which water flow is laminar or turbulent within conduits. Chemical characteristics of the aquifer are functions of residence time and flow conditions (Freeze and Cherry, 1979). The study of groundwater temperature and chemical properties are the best and most reliable tools to understand aquifers. They provide initial, simple, cheap steps to determine the storage and flow conditions.

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In general, precipitation and the frequency or intensity of heavy precipitation events have increased since 1901 (medium confidence before and 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. Precipitation factors, which directly affect the recharge, are durations of precipitation, altitude and rainfall intensity and its type (Sutcliffe, 2004). In karst regions point infiltration and sudden rainfalls 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 runoff disappeared at the intersections of dolines and cracks (Milanovic , 1981). According to De Vries et al. (2000), in Portugal, which represents a dry, hot summer, in karstic dolomite and marly regions 150-300 mm of the annual precipitation (550 mm) 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 Yugoslovia, values of infiltration are calculated between 70% and 90% by means of spring discharges (Milanovic, 1981). In Turkey, in Tecer limestones (Sivas-Ulaş region) infiltration percentage is defined as 55% (Ekemen et al., 2001). Therefore, it can be mentioned that higher recharge in Mediterranean region limestones is due to the point infiltration coming from well-developed karstic structures. Despite a year in which cumulative precipitation increases, the total amount of recharge may be less in aquifers dominated by diffused flow. This research reinforces the hypothesis that aquifers controlled by conduit permeability will have higher recharge and discharge rates. Developed karst sinkholes allow fast percolation into the aquifer, up to 80% of heavy rainfalls. However, the very low storage combined with the high transmissivities means that much of the recharge will not be ‘retained’ by the karst system, but will rapidly flow out (to springs, rivers, lakes, sea). The large water level responses to rainfall combined with the capability of karst systems to transmit groundwater quickly will increase flooding (Williams and Lee, 2007). Due to the characteristics of groundwater flow in karst terrain, flash flooding in such a context is strongly different from that in non-karst terrain, the groundwater volume being much larger. Such phenomena may cause serious damage, including the loss of life. For this reason, karst flash-flooding has been identified as one of the main hazards in karst terrains. It is directly linked to the structure and hydraulic properties of karst aquifers (Fleury et al, 2013). The main structure and hydraulıc properties causes of karst-flash-flood can be summarized as the high point infiltration rate, fast turbulence groundwater flow and small storage capacity of the karst aquifer.

Material and Method

Some karstic aquifers, Paleozoic marbles, Mesozoic limestones and the Neocene limestones were chosen in Western Turkey to define the aquifer characteristics (Fig. 1 and Table 1). Data are used from previous studies (Atilla, 1996; Aydın, 2005; Demiroğlu, 2008) and additional data are obtained from State Hydraulic Works. Some (S3, S9, S10, S18) springs recharge, circulate and discharge from Paleozoic Marbles, some (S1, S2, S11, S12, S13, S16, S17, S19, S20) recharge, circulate and discharge from Mesozoic limestones and some (S4, S5, S6, S7, S8, S14, S15, S18) recharge, circulate in marbles and circulate and discharge from Neogene limestones and sediments. Measurements in wet and dry seasons and discharge rates were compared in order to explain aquifer characteristics. High discharge rates (Qmax/Qmin), rapid chemical composition change and temperatures reveal turbulence flow conditions and developed karstic structures. Low variations of the measurements in both the wet and dry seasons reveal that fracture permeability is dominated by diffused controlled groundwater flow with low or high storage and conduit permeability with high storage. High variations of the measurements show conduit permeability with low storage is dominated by turbulent groundwater flow (Aydın, 2005; Demiroğlu, 2008). Springs in the study area are classified according to this principle and springs defined which have high response ability to heavy precipitation.

3. Geology and Hydrogeochemistry

First group springs (S1 Döşkaya, S2 Nardın) are located in the Central Sakarya Basin (Fig. 2). Recharge and discharges 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, which is composed of Jurassic Bilecik limestone, is located within the province boundaries of Bilecik and Eskişehir and extends over a surface area of 49.5 km2. The re-crystallized and cherty carbonate rocks are known as Jurassic Age Bilecik Limestone. 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 well-developed pipe-like karstic structures ranging from 1 cm to a few tens of meters where groundwater flows in conduits in a turbulent regime. Two years of dry and wet season's in situ measurements and chemical analyses data show rapid chemical composition change and temperatures. High variation of measurements and high discharge rates (Qmax/Qmin) (Table 2, 4) reveal that conduit permeability with low storage is dominantly controlled by turbulent groundwater flow. Therefore, these aquifers can classified as Flash Flood-Prone areas

Second group springs are located in Çifteler and Günyüzü subbasin within the Sakarya basin, Sivrihisar – Eskişehir (Fig. 3). Sakarbaşı springs and Kaymaz spring (S3, S4) were studied by Güner and Güner (2002) who determined little or no change in the in situ measurements during 3 seasons of sampling (Table 3). Sakarbası springs (Sadıroğlu, Eminekin, Başkurt, Ilıcabaşı and Pınarbaşı) reservoir rocks are marbles and are named as the Gökçeyayla formation. The Gökçeyayla formation 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). Günyüzü springs, located in the Sakarya River catchment area to the SW of Eskişehir, were studied by Demiroğlu (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 spring listed in Table 2, S8 (Çukurçeşme) recharges, circulates and discharges from this system. This shallow circulation of water has laminar flow conditions. Other shallow circulated water (S5 Babadat and S6 Nasrettin Hoca) mostly recharges from the marbles but discharges from Neogene units. 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, S9 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 where reflections of these on discharge rates of the Subaşı spring (S9) have been observed (Demiroğlu, 2008). EC results show that variations depend not only on circulation depth but also on lithology. For example, S4 and S8 have nearly the same temperature and DO (26,7 – 30 °C / 4,36 - 4,81 mg/l) which represent approximately the same circulation depth and residence time. But EC value differences (350, 798 µS/cm) stem from lithology differences. S4 recharges, circulates and discharges from Paleozoic marbles, whereas, S8 recharges and circulates in marbles, then circulates and discharges from Neogene limestones and sediments.

It has seen that springs (S3, S4, S5, S6, S7, S10) display nearly constant temperature, low variations in chemical composition and low variations for the measurements both dry and wet season while springs (S8) display high measurement variations when all data are considered (Table 2, 5). S8 (Subaşı) spring is classified as having high response ability to heavy precipitation.

Third group springs are located in the Lake district (Fig. 4). 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 period that gray limestone contains marine sediments from the deep to shallow marine environment. Thinly bedded cherty micritic levels are also observed. Mesozoic rocks have tectonic sliced structure. Slices are showing the ophiolitic mélange feature at the bottom of this structure. Mesozoic age marine limestones are on the olistostromal limestones. A lot of springs discharge from these carbonates.

The most important spring groups are called Kırkgözler springs (S19, S20) which are very important for Antalya region for drinking water and irrigation. Kırkgozler springs group discharges from the boundary between Beydagları authocthonous limestones and the impermeable ophiolite rocks (Fig. 4) 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 Kırkgozler group have high response capability to heavy precipitation when the dry and wet seasons in situ measurements of springs are considered (Tables 4 & 5).

Sagalassos spring (S18) has high response capability to heavy precipitation takes place in the ancient city. Surprisingly, the natural flood risks were taken into account in Roman times at 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).

The Sütcüler town located on the Olistostromal Limestone had flood disasters in November 1995 and again in October 2011 (Fig. 5). The area was studied by Karagüzel (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 those limestones and has developed karstic structures (sinkholes, dolines) on the Ophiolite complex. Pliokuaterner travertines are exposed in the town and sand, gravel and block-size debris piles up at the base of steep slopes (Fig. 5). 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. There are no regular yield and water chemistry measurements on these springs. These springs activated with sudden rise of groundwater. Here, heavy rainfall combined with the capability of the karst system. During karst flash floods a sudden rise of groundwater levels occurs, which causes the appearance of numerous, unexpected, abundant and temporary karst springs (Bonacci et al. 2006).

Taking these springs into account, which have high response capability to heavy precipitation, drainage systems must be developed.

4. Results and Discussions

In situ measurements are the signatures of karst aquifers. The groundwater has pH values ranging from 6.3 to 8.9, temperatures (T) vary from 7 to 35°C, and electrical conductivity (EC) values go from 140 to 998 µS/cm. Average Ca and EC values were defined as 3.8 meq/L and 330 µs/cm, respectively, in cold water discharges from Paleozoic Marbles in Gunyuzu basin (S5, S6, S9). These values were measured as 5.7 meq/L and 988 µs/cm in the Kırkgozler spring discharge from Antalya Jurassic limestone (Atilla, 1996) and as 6.4 meq/L and 596 µs/cm in the Nardın spring discharges from the 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). According to these results, it has been mentioned that Paleozoic marbles in the Günyüzü basin and Mesozoic marbles in the Çifteler basin have similar characteristics. Besides, marbles are less soluble than limestone. The EC-Temperature and DO relationships indicate the existence of water with different origins. The groups with high EC, high T, and low DO values represent the deep circulating waters (S3, S7, S8). Low EC, low T and high DO values represent the shallow circulating waters (S1, S2, S5, S6, S8, S9). EC results show that variations depend not only on circulation depth but also on lithology. For example, S4 and S8 have nearly the same temperature and DO (26,7- 30°C and 4,36, 4,81 mg/l) which represent approximately the same circulation depth and residence time, but EC value differences (350 and 798 µS/cm) stem from lithology differences. S4 recharges, circulates and discharges from Paleozoic marbles, whereas, S8 recharges and circulates in marbles, moreover, circulates and discharges from Neogene limestones and sediments. Springs (S3, S4, S5, S6, S7, S8, S10, S19, S20) in the study area display nearly constant temperature, low variations in chemical composition and low variations for the measurements in both dry and wet season. Springs developed in karstic structures allow fast recharge and discharge representing high discharges rates (Qmax/Qmin) and rapid changing chemical composition (S1, S2, S9, S11-S18). Heavy rainfalls directly affect this kind of karstic areas.

The most prominent result of the climate change data 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. There is a general lack of awareness of the impact of karstic springs on flooding. The impact of karstic discharges on flooding (Karagüzel, 1998) is defined in Sütcüler. General Directorate of Combating Desertification and Erosion under the Ministry of Forestry and Water Affairs of Republic of Turkey, finished a project financed by the World Bank on combating against desertification and land degradation in 1999 in the Sütcüler region. Under the 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 taking into account these karstic springs which have high transfer capability with heavy precipitation. This research is an important step for the defining of effective karstic springs in flash floods. This approach for the identification of flood-prone areas provides a valuable tool for recognizing studies of large regions, but representative and organized sampling requires at least twice in wet and dry seasons. In this study, the first and second group of data are enough for a precise and accurate prediction of aquifer properties, but in the lake districts, except for Kırkgözler springs, steady and organized sampling is needed.

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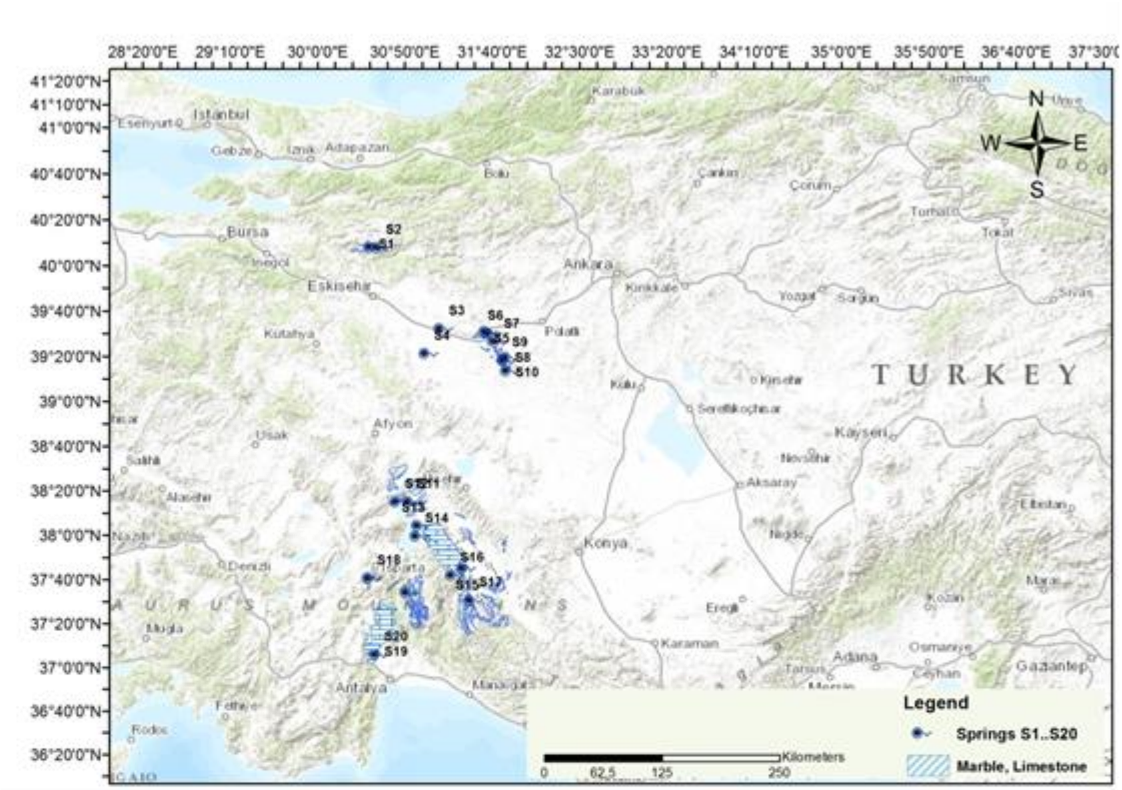

Figure1. The location map of the study area.

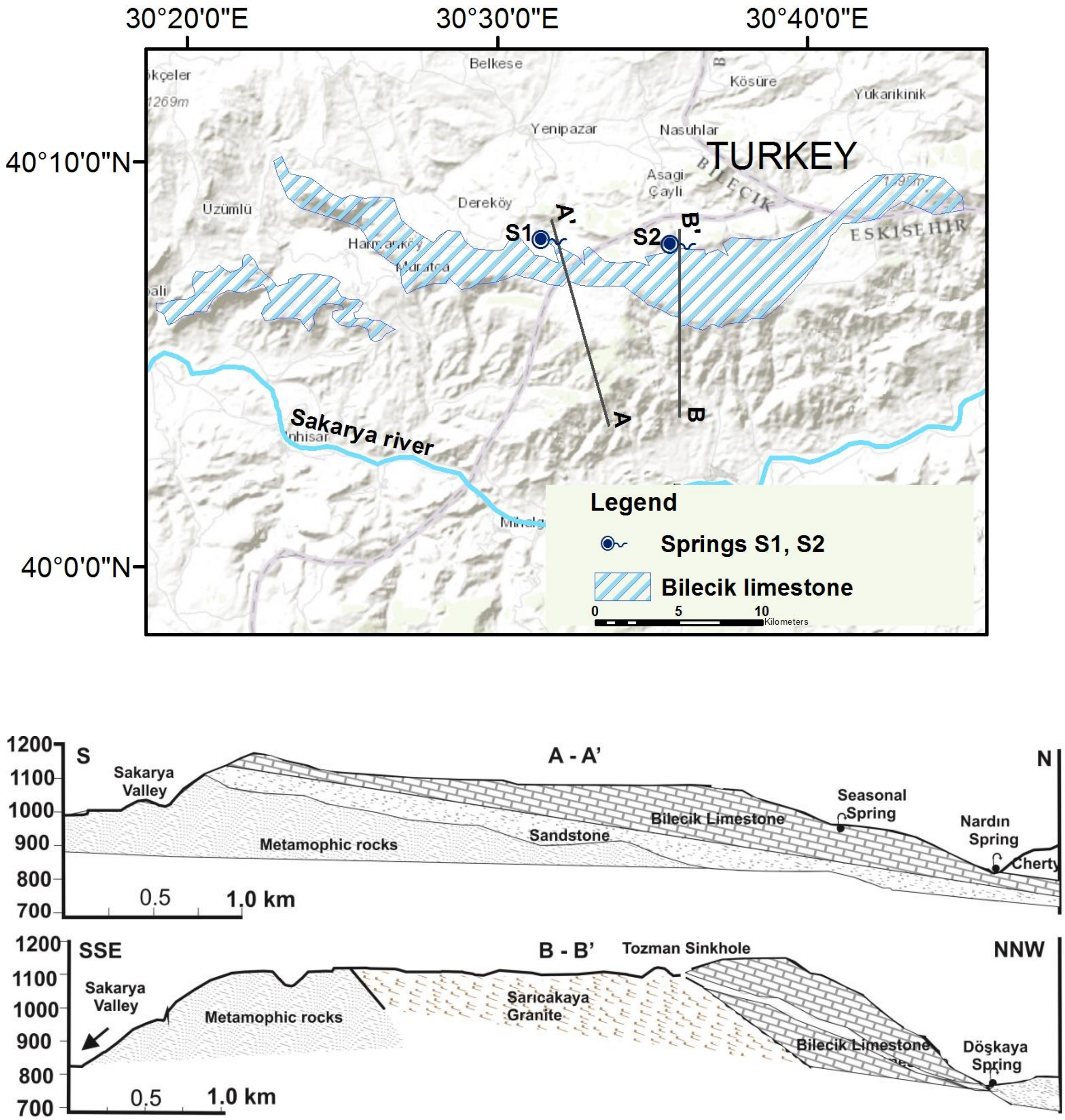

Figure 2 a) Bilecik limestones (Jkb) b) The geological cross- section of Nardın and Döskaya springs (modified by Aydın 2013)

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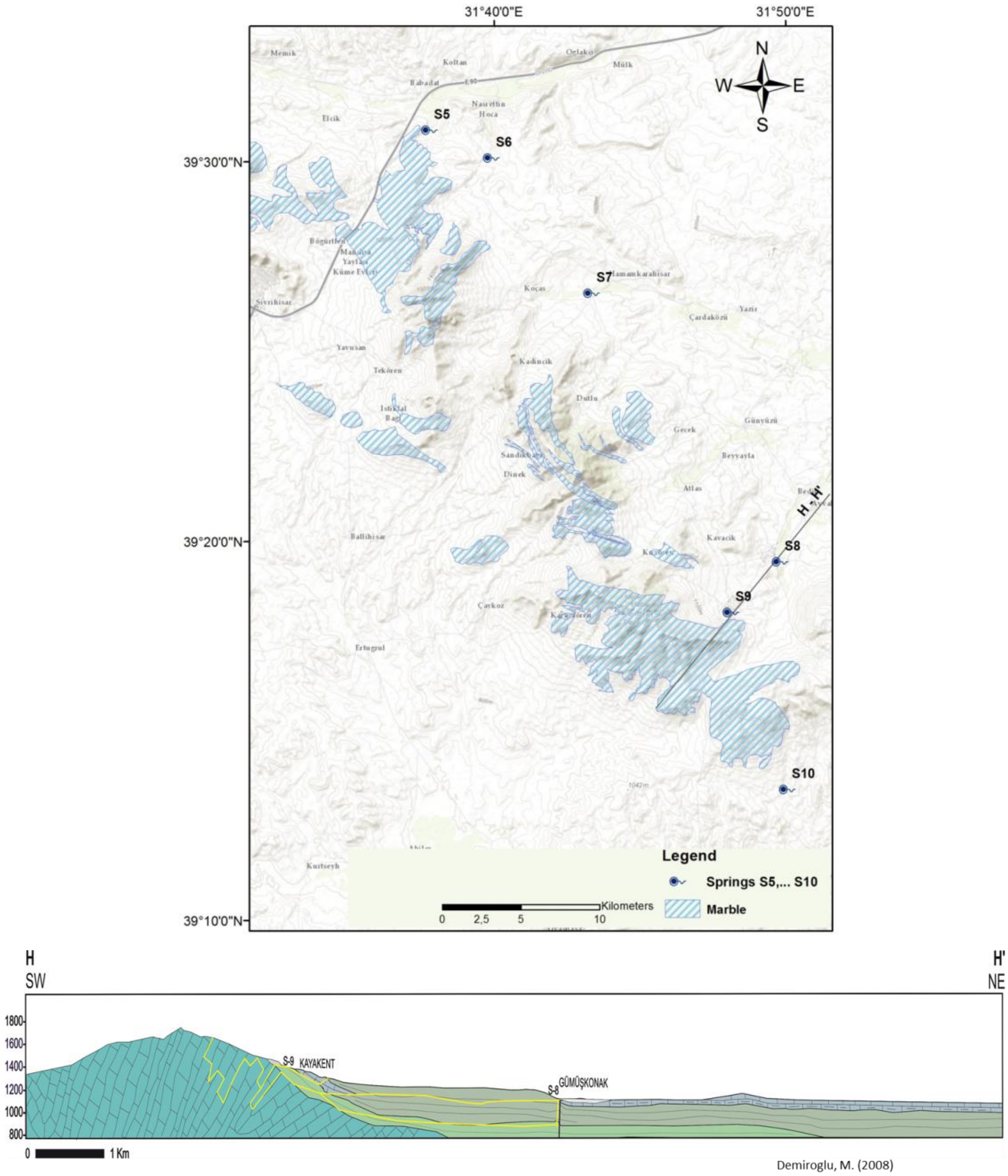

Figure 3 a) Gunyuzu marbles b) The geological cross- section of Gunyuzu springs (Demiroğlu 2008)

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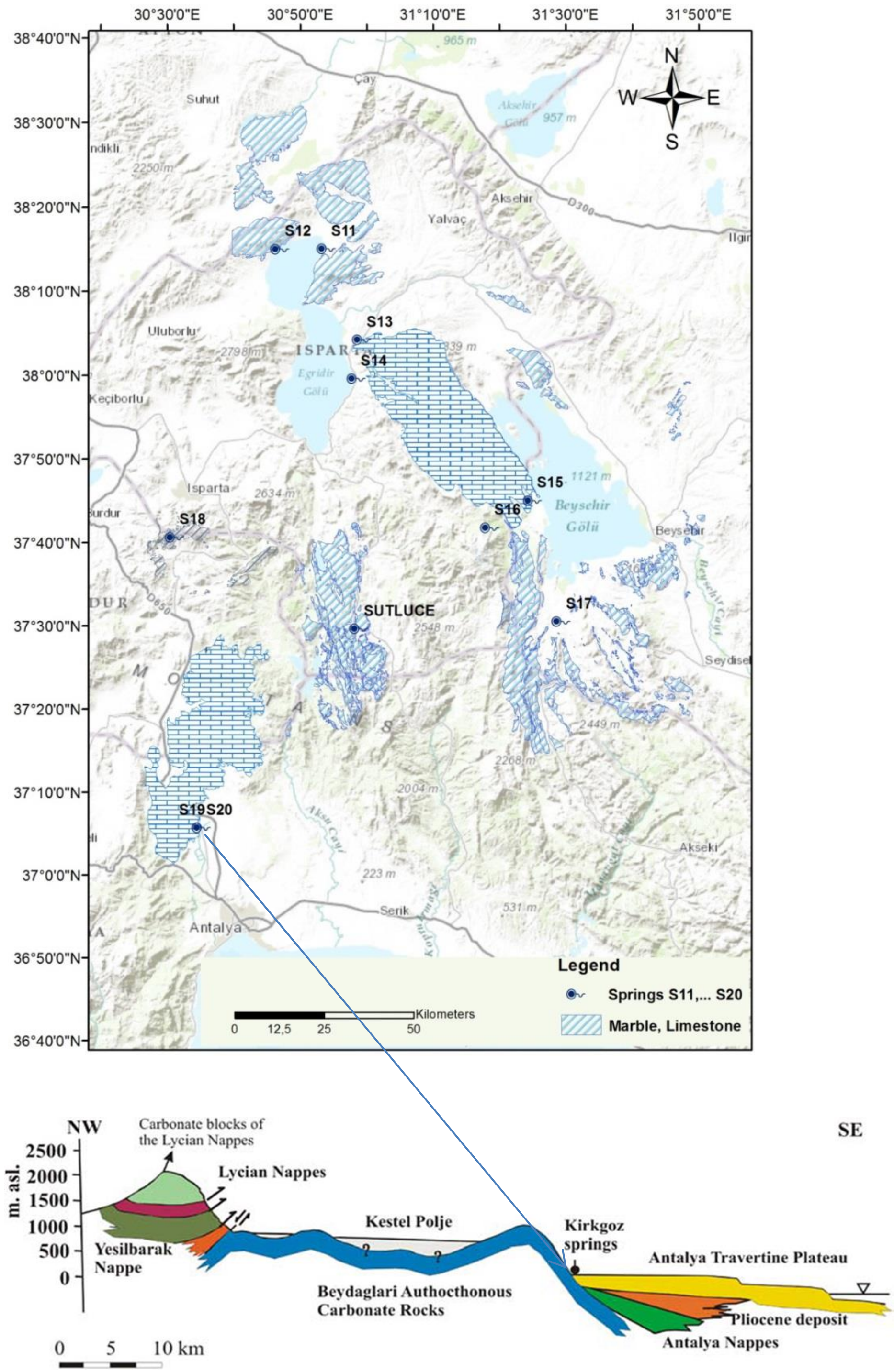

Figure 4 a) Lake district marble and limestones b) The geological cross- section of Kirkgoz karst springs, Southern Turkey (Ekmekci, 2005).

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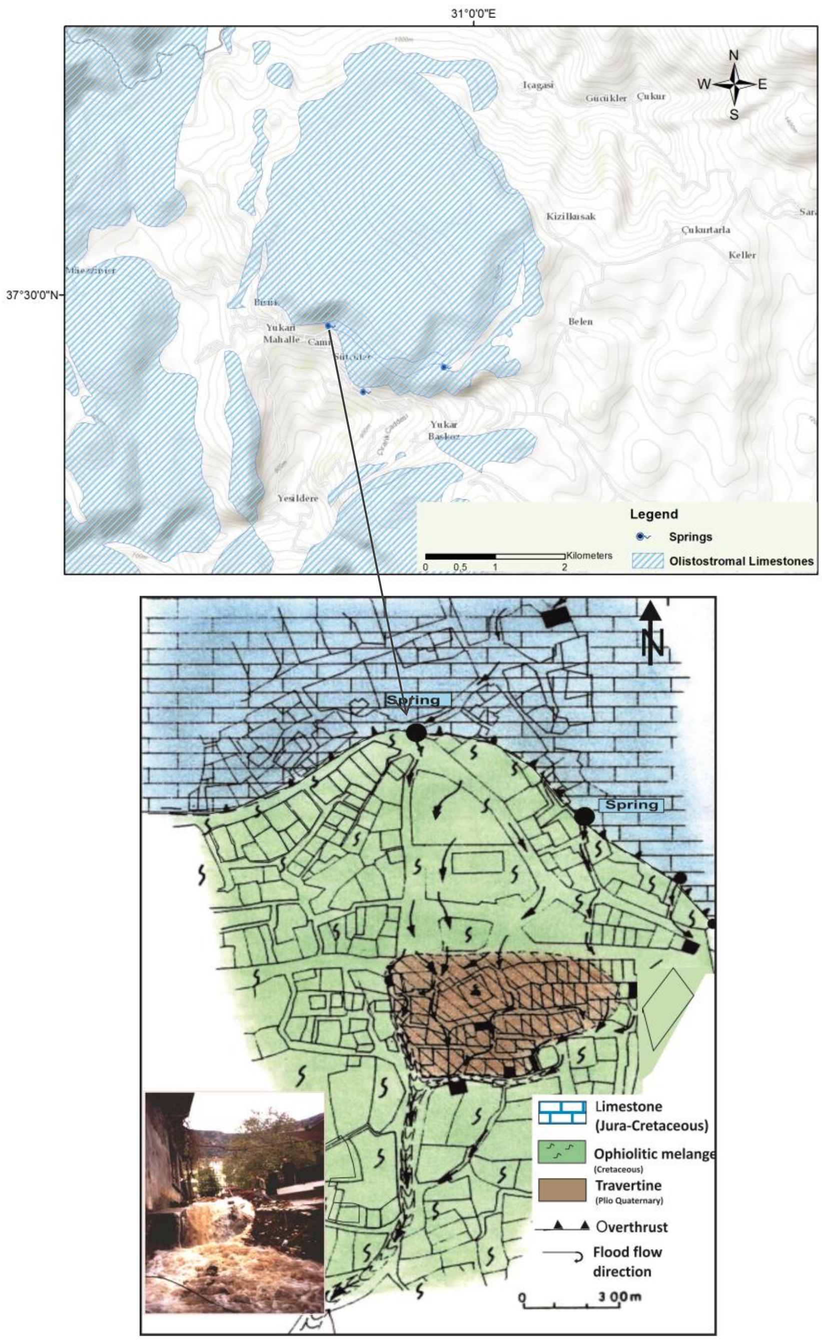

Figure 5. Map of flooding road in Sütcüler settlements (modified by Karagüzel 1998)

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

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

Table 2. Physicochemical data of S1 and S2 springs (Nardın and Döşkaya spring).

Dry season	T (^{o}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

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Table 3. Physicochemical data of Çifteler and Günyüzü springs

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	18	8,9	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	6,59	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	4,9	3,89

Table 4. Spring's yield, Qmax/Qmin and variation of the measurements.

No	Qmax. (l/s)	Qmin. (l/s)	Qmax/ Qmin	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	1447	2490	1,72	13,9		
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	0,001	103	ND	ND
S20	22000	10000	2,2	ND	0,3	0,31

Table 5. Physicochemical data of Lake District springs

Dry season	T(oC)	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	9,2	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