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ORIGINAL PAPER

Assessment of regional discharge and spring type using hydrograph and Maillet analyses in Kumalar Mountain region, Afyonkarahisar, Turkey

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Abstract

Kumalar Mountain and its surroundings have an important groundwater potential for Sandıklı and Şuhut districts, due to intense spring discharges. The springs discharged from limestones and volcanic units and are used for drinking, using, and irrigation purposes. Therefore, it is of great importance to determine the capacities and potentials of such springs in the rural areas. The aim of this study is to reveal the hydraulic properties, discharge mechanisms, and potential of the natural springs located around the Kumalar Mountain region. Monthly flow measurements were made between September 2017 and September 2018 in 19 springs in the study area. The annual flow rates of the springs in the study area vary between 0.01 and 2.10 l/s. Spring flow rates are increased in the rainy seasons. The annual base flow and average flow rates of springs were calculated by hydrography analysis and are 311.04–57,024 m^3/year and 0.01–1.81 l/s respectively. The coefficient of discharge (α) 8.77×10^{-4}–9.82×10^{-3} day^{-1}, flow variability (Q_d) 0.10–0.69 l/s, and average base flow (Q_b) 0.01–2.03 l/s values were calculated by Maillet equation. According to the coefficients of discharge and flow variation, springs were determined as "types 2 and 3". Torun spring in Yıprak which feed by limestone has the highest flow.

Keywords Natural springs · Flow · Discharge · Hydrography · Maillet · Kumalar

Introduction

Natural water springs are directly connected of the groundwater in the aquifers that feed them, and also affect the potential of the surface waters into which they discharge. Therefore, determining the potential of natural springs is very important in terms of both groundwaters and surface waters. Also, the spring waters are the most reliable sources used for all kinds of consumptive water supply. Main prerequisites for establishing a workable management plan must be determining recharge and discharge parameters of springs with hydrogeologic and hydrologic characterization of the spring type. As the demand for water increases, many techniques and methods are developed in spring waters to provide these conditions. At this point, in order to determine the supply and potential of natural springs, it comes to the fore to know the flow mechanism and regime of the springs. There are many international references about techniques and methods used for estimating the flow regime at natural springs in a region (Korkmaz 1990; Oztas 1993; Rani and Chen 2009; Kresic and Stevanovic 2010; Kresic and Bonacci 2010; Celik et al. 2015; Callı 2017; Giacopetti et al. 2017; Lorette et al. 2018). In these methods, they contain significant information about the hydrological and hydrogeological characteristics of such natural springs.

Many natural springs extend along the foothills and slopes of the Kumalar Mountain. This area is mostly supplied with water from the natural springs near Sandıklı and Şuhut districts (Fig. 1a). These natural springs are used generally for drinking, domestic, and

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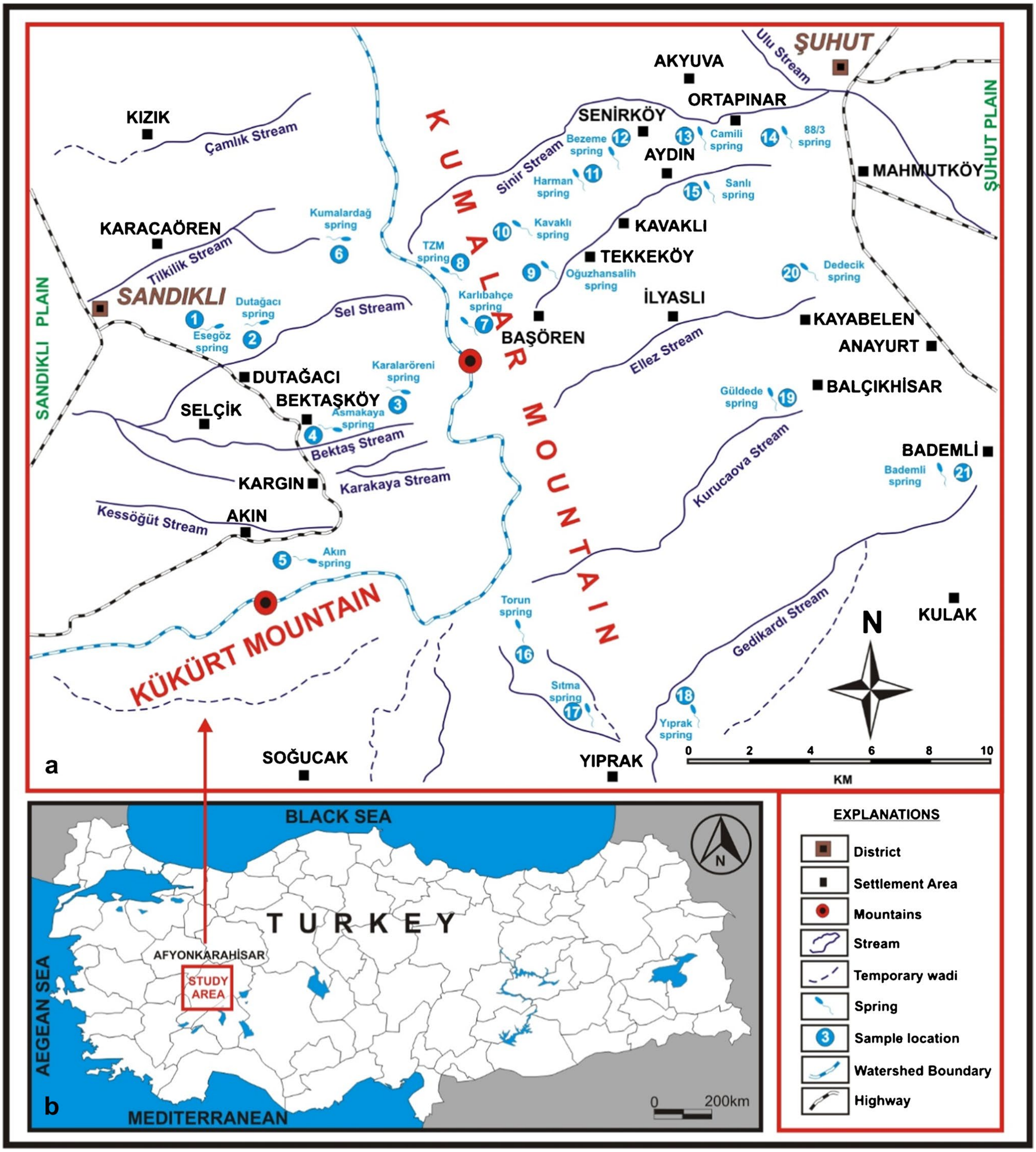


Fig. 1 Location map of the study area

irrigation purposes. This paper aimed to determine the potential flow of natural springs in the Kumalar Mountain area by using the hydrography analysis and the Maillet (1905) methods. The spring flow parameters have been achieved by calculating to analytical formula.

Study area

The study area covers an area of approximately 350 km^2, which extends along the SE of the Sandıklı basin and the SW of the Şuhut basin and includes the Kumalar and

Kükürt mountains (Afyonkarahisar) (Fig. 1a). Kumalar Mountain (2250 m) is the highest peak in the region. Kumalar Mountain extends in the Afyonkarahisar-Sandıklı-Dinar direction and separates the Sandıklı and Şuhut basins in the north–south direction. Sandıklı plain in the south of Afyonkarahisar province crops out to the west of the study area and Şuhut plain to the east. The largest settlements in the study area are Sandıklı and Şuhut districts of Afyonkarahisar province.

In the study area, there are a total of 24 settlement areas, in the Sandıklı district (Kızık, Karacaören, Dutağacı, Selçik, Bektaş, Kargın, Akın, and Soğucak) and in the Şuhut district (Akyuva, Senirköy, Ortapınar, Aydın, Kavaklı, Tekkeköy, Güneytepe, Mahmutköy, İlyaslı, Başören, Kayabelen, Anayurt, Balçıkhisar, Bademli, Kulak, and Yıprak) (Fig. 1a, 1b). These settlement areas provide most of their drinking, irrigation, and domestic needs from spring water.

Methodology

The average rainfall was computed by the isohyet method, using 42 annually (1975–2018) average rainfall data which belong to the area. Particularly, the flow rates of the springs are important due to the springs that are used as drinking, using, and irrigation water in settlement areas. For this reason, flow measurements of the springs selected as representative in the study area were monitored monthly and the flow potentials of the springs were determined. In order to determine the potential of springs in the study area, flow measurements were made during 1 year regularly every month in twenty-one (D1-D21) springs. Flow measurements were made in special containers with a known volume. The measurement period lasted from 01 September 2017 until 01 September 2018. A hydrological database has been created by obtaining the gauging flow data from natural springs during this period. During the flow measurements, some problems were encountered such as the spring being under the pond, the spring drying, and the spring road covered with snow. Therefore, flow measurements of the springs D1, D3, and D4 were recorded incompletely.

Generally, the springs are evaluated based on the minimum discharge recorded over a long period, typically longer than several hydrologic years (a hydrologic year is defined as spanning all wet and dry seasons within a full annual cycle) (Kresic 2010). When evaluating potential of spring flow in the study area, spring discharges were measured, which is based on periods of monthly in 1 hydrological year (2017–2018) due to climatic and physical conditions. In order to calculate the discharge rates of the springs in the study area, two different methods were used, namely "hydrography analysis" and "Maillet analysis". In these methods, springs must show a continuous flow. For this reason, the base flow calculations could not be made due to the lack of flow data in Esegöz (D1), Karalaröreni (D3), and Asmakaya (D4) springs. Monthly flow measurements obtained for 1 year (September 2017-September 2018) for a total of 19 water springs were used in the calculations. In the hydrograph analysis, monthly flow measurements and base flow curves were formed and the average base flow was calculated with the help of these curves.

In the Maillet analysis, the discharge (Q_t), the coefficient of discharge (α—day^{-1}), the flow variability (Q_d—l/s), and the average base flow above the spring discharge point of the aquifer (Q_b—l/s) were calculated using various exponential equations and formulas. The literature review shows that the Maillet (1905) formula, a widely used exponential equation, is an approach analytical solution for porous media (Dewandel et al. 2003). Maillet (1905) is described by the simple exponential equation as follows.

$$Q_t = Q_0 e^{-\alpha t} \tag{1}$$

where Q_t is the discharge at time t (m^3/s), Q_0 is the initial discharge (m^3/s), e is the Napierian logarithm base (exponential: 2.71828), α is the coefficient of discharge (day^{-1}), and t is the time (day).

The coefficient of discharge (α) is determined by formula (2)

$$\alpha = \log Q_{\max} - \log \mathrm{Q}_{\min}/t \log e \tag{2}$$

where α is the coefficient of discharge (day^{-1}), $Q_{\max}$ is the highest flow rate (l/s), $Q_{\min}$ is the lowest flow rate (l/s), t is the time difference between $Q_{\max}$ and $Q_{\min}$ (day), and log e: 0.4343.

The flow variability (Q_d) is determined by formula (3) (Sahinci 1991)

$$Q_d = \left(Q_{max} - Q_{min}\right)/Q_{max} \tag{3}$$

where Q_d is the flow variability (l/s), $Q_{\max}$ is the maximum flow (l/s), and $Q_{\min}$ is the minimum flow (l/s).

The average base flow above the spring discharge point of the aquifer (Q_b) is determined by formulas (4), (5), (6), and (7) (Mangin 1975; Sahinci 1991; Kresic and Bonacci 2010).

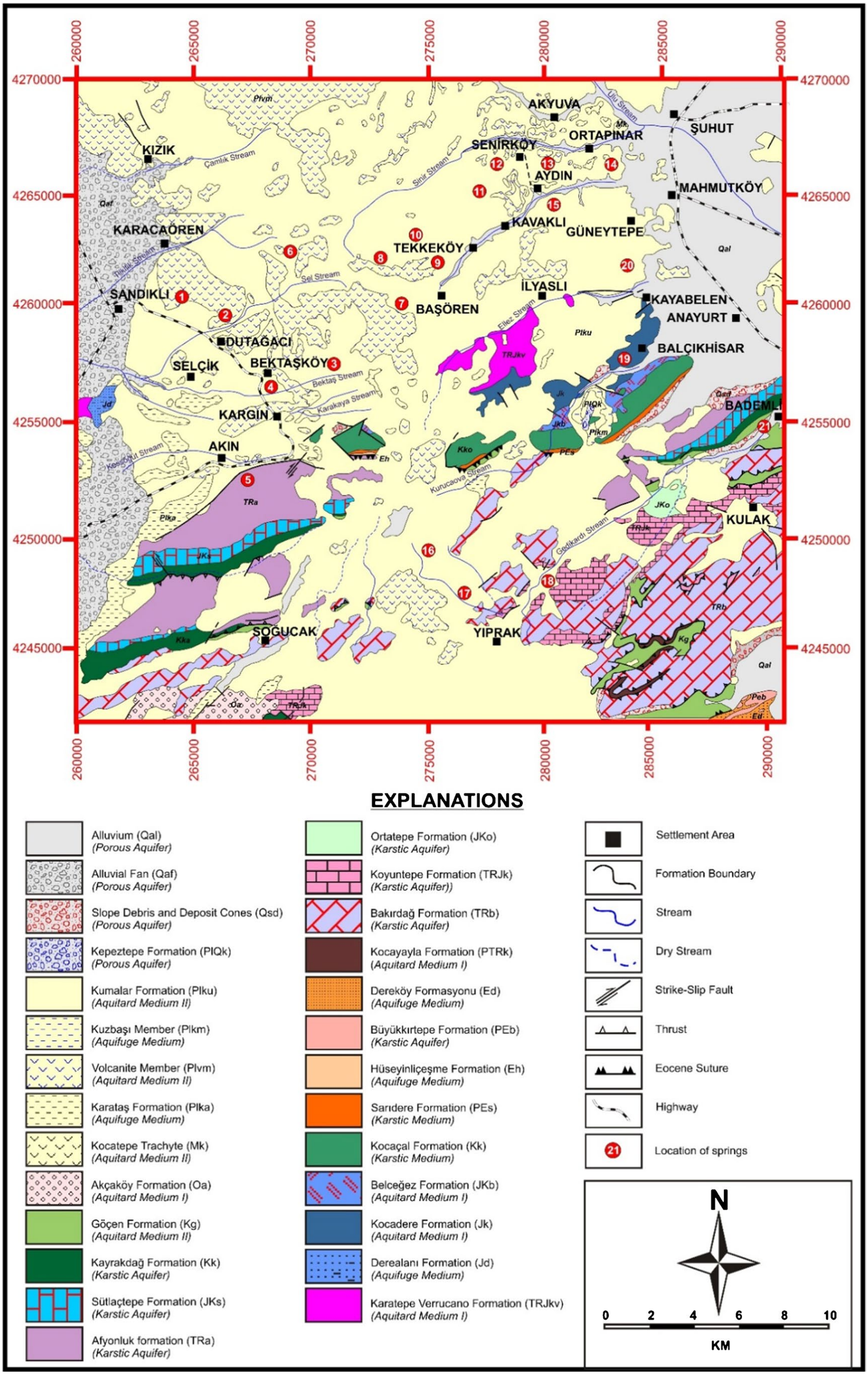
$$Q_b = \left(V_d/t\right) \tag{4}$$

$$V_d = V_{max} - V_{min} \tag{5}$$

$$V_{max} = \left(Q_{max}/\alpha\right) \tag{6}$$

$$V_{min} = \left(Q_{min}/\alpha\right) \tag{7}$$

where Q_b is the average base flow (l/s), V_d is the change in reservoir volume (l), $V_{\max}$ is the maximum reservoir volume (l), and $V_{\min}$ is the minimum reservoir volume (l).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BALÇIKHİSAR
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KARGIN
BADEMLİ
AKIN
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YIPRAK
Çamlık Stream
Sinir Stream
Sel Stream
Bektaş Stream
Karakaya Stream
Kurucaova Stream
Gedikardı Stream
Eflez Stream
EXPLANATIONS
Alluvium (Qal)
(Porous Aquifer)
Alluvial Fan (Qaf)
(Porous Aquifer)
Slope Debris and Deposit Cones (Qsd)
(Porous Aquifer)
Kepeztepe Formation (PlQk)
(Porous Aquifer)
Kumalar Formation (Plku)
(Aquitard Medium II)
Kuzbaşı Member (Plkm)
(Aquifuge Medium)
Volcanite Member (Plvm)
(Aquitard Medium II)
Karataş Formation (Plka)
(Aquifuge Medium)
Kocatepe Trachyte (Mk)
(Aquitard Medium II)
Akçaköy Formation (Oa)
(Aquitard Medium I)
Göçen Formation (Kg)
(Aquitard Medium II)
Kayrakdağ Formation (Kk)
(Karstic Aquifer)
Sütlaçtepe Formation (JKs)
(Karstic Aquifer)
Afyonluk formation (TRa)
(Karstic Aquifer)
Ortatepe Formation (JKo)
(Karstic Aquifer)
Koyuntepe Formation (TRJk)
(Karstic Aquifer))
Bakırdağ Formation (TRb)
(Karstic Aquifer)
Kocayayla Formation (PTRk)
(Aquitard Medium I)
Dereköy Formasyonu (Ed)
(Aquifuge Medium)
Büyükkırtepe Formation (PEb)
(Karstic Aquifer)
Hüseyinliçeşme Formation (Eh)
(Aquifuge Medium)
Sarıdere Formation (PEs)
(Karstic Medium)
Kocaçal Formation (Kk)
(Karstic Medium)
Belceğez Formation (JKb)
(Aquitard Medium I)
Kocadere Formation (Jk)
(Aquitard Medium I)
Derealanı Formation (Jd)
(Aquifuge Medium)
Karatepe Verrucano Formation (TRJkv)
(Aquitard Medium I)
Settlement Area
Formation Boundary
Stream
Dry Stream
Strike-Slip Fault
Thrust
Eocene Suture
Highway
Location of springs
N
0 2 4 6 8 10
KM

◂**Fig. 2** Geological and hydrogeological map of the study area (Balci 2011a, b; Ocal and Goktas 2011; Ocal et al. 2011)

As a result of the data obtained, springs were classified according to the coefficient of discharge and flow variability (Sahinci 1991) and the spring types were determined.

Geology

Autochthonous, allochthonous, and cover rocks are dominant in the study area (Fig. 2). In the study area, the Akdağ unit (Karatepe Verrucano and Derealanı formations), the Homa-Akdağ unit (Kocadere, Belceğez, Kocaçal, Sarıdere, and Hüseyinliçeşme formations), and the Kırdağ-Anamasdağ unit (Büyükkırtepe and Dereköy formations) belong to the Anamas-Akseki autochthonous. The autochthonous units have a narrow spread in the study area and the units are in the Middle Triassic-Middle Eocene age range. Generally, the Anamas-Akseki autochthonous is represented by carbonated rocks in the Middle Taurus. The Akdağ unit is composed of carbonate sandstone, siltstone, claystone, clayey limestone, conglomerate, sandstone, shale, and sandy-clayey limestone. The Homa-Akdağ unit is formed by limestone, mudstone, claystone, sandstone, siltstone, conglomerate, shale, marl, and spilitic pillow lava. The Kırdağ-Anamasdağ unit consists of limestone and flysch series.

The allochthonous rocks in the study area are represented by the Sazak group (Kocayayla, Bakırdağ, Koyuntepe, and Ortatepe formations) and the Kükürtdağ group (Afyonluk, Sütlaçtepe, Kayrakdağ, and Göçen formations) belonging to the Beyşehir-Hoyran-Hadim nappes. The allochthon units spread to the southwest and southeast of the study area. The units have Triassic-Cretaceous age range. The Sazak group is composed of sandstone, chert, limestone, and dolomitic and cherty limestone. The Kükürtdağ group consists of sandstone, pelagic limestone, serpentine-intercalated volcanite, and dolomitic and cherty limestone.

Cover rocks showed a very wide spread in the study area. The rocks are formed by the Akçaköy formation, the Şuhut group rocks (Kocatepe trachyte, Karataş formation, Kumalar formation, Kuzbaşı member, and volcanite member), and Plio-Quaternary terrestrial clastic rocks (Kepeztepe formation, slope debris and deposit cones, alluvium fan, and alluvium) in the study area. The Akçaköy formation is composed of conglomerate and the Şuhut group consists of claystone, siltstone, limestone, marl, and volcanic rocks (basalt, andesite, trachyte, etc.). Plio-Quaternary-aged Kepeztepe formation consists of old slope debris and fluvial deposits. Quaternary formations are represented to alluvium, alluvial fan, slope debris, and deposit cones. The formations are composed of loose, interlayered clay, silt, sand, gravel, and mud deposit materials (Balci 2011a, b; Ocal and Goktas 2011; Ocal et al. 2011; Fig. 2). The stratigraphic structure and lithological characteristics of the study area are shown in Table 1.

Hydrogeology

Lithologic properties of the geological units in the study area have been investigated to define the extent of the aquifer system and regional hydrogeological characteristics. The lithological units of the study area range in age from Triassic to Quaternary and have different aquifer systems. The lithological units were classified as porous aquifer, karstic aquifer, aquitard, and aquifuge mediums (Table 1). The Quaternary deposits and Kepeztepe formation are mainly characterized by silty, muddy, and sandy layers alternating with sandy and gravel deposit materials. The units are represented as porous aquifer system with high permeability in the study area. The porous aquifer is located in Sandıklı and Şuhut plains and numerous wells have been drilled on the aquifer. The units are important groundwater reservoirs and are the main drinking, domestic, and irrigation resources for the region. Kocaçal, Sarıdere, Büyükkırtepe, Bakırdağ, Koyuntepe, Ortatepe, Afyonluk, Sütlaçtepe, and Kayrakdağ formations are composed of limestone. These formations have the characteristics of a karstic aquifer due to their secondary porosity that develops with melting gaps, faulted structure, intersecting cracks, and discontinuities. The flow rates of the wells drilled on the karstic aquifer are between 15 and 30.27 l/s. Karatepe Verrucano, Kocadere, Belceğez, Kocayayla, and Akçaköy formations consist of conglomerate, sandstone, shale, and sandy-clayey limestone and have semi-permeable properties. While fractured and faulted structures within the units increase the permeability, shale and clayey layers cause impermeability. The semi-permeable units are described as Aquitard Medium I in the study area. Kocatepe trachyte, volcanite member, Göçen, and Kumalar formations are slightly permeable and defined as Aquitard Medium II. Deralanı, Hüseyinliçeşme, Dereköy, and Karataş formations and Kuzbaşı member do not contain groundwater due to their lithological properties. The units are impermeable and they show the characteristics of an aquifuge medium (Fig. 2; Table 1).

Hydrology

Precipitation and temperature

In general, the most important recharge component of groundwater is rainfall. In order to determine the average rainfall on the study area, annual total precipitation data were used. There are 6 observation stations located in Afyonkarahisar, Sandıklı, Şuhut, Dinar, Sincanlı (Sinanpaşa), and Çay settlements in the vicinity of the study area. Annual

Table 1 Stratigraphic structure and lithological and hydrogeological characteristics of study area

Group		Formation	Symbol	System/series/epoch	Lithology	Hydrogeological properties	Aquifer systems
Cover rocks	Plio-Quaternary aged Clastic rocks	Alluvium	Qal	Quaternary	Loose clay, silt, sand, gravel, and mud deposits	Permeable	Porous aquifer
		Alluvial fan	Qaf	Quaternary	Clayey, sandy, gravelly material	Permeable	Porous aquifer
		Slope debris and deposit cones	Qsd	Quaternary	Loose, gravel, and block deposits	Permeable	Porous aquifer
		Kepeztepe	PlQk	Plio-Quaternary	Old slope debris and fluvial deposits	Permeable	Porous aquifer
	Şuhut group	Volcanite member	Plvm	Late Pliocene-Pliocene	Basalt, andesite, trachyte, etc	Slightly permeable	Aquitard medium II
		Kuzbaşı member	Plkm	Late Pliocene-Pliocene	Coal-level marl, claystone, siltstone, limestone	Slightly permeable	Aquifuge medium
		Kumalar	Plku	Late Pliocene-Pliocene	Volcanic origin rock and clastic limestone	Semi-permeable	Aquitard medium II
		Karataş	Plka	Late Pliocene-Pliocene	Gravel and sand lensed claystone, marl, limestone	Slightly permeable	Aquifuge medium
		Kocatepe trachyte	Mk	Middle Miocene	Dominantly trachytic lava	Semi-permeable	Aquitard medium II
		Akçaköy	Oa	Middle-Early Oligocene	Pebble	Semi-permeable	Aquitard medium I
Beyşehir-Hoyran-Hadim nappes	Kükürtdağ group	Göçen	Kg	Late Cretaceous	Sandstone, serpentinite-intercalated volcanite	Semi-permeable	Aquitard medium II
		Kayrakdağ	Kka	Late Cretaceous	Locally dolomitic and cherty limestone	Permeable	Karstic aquifer
		Sütlaçtepe	JKs	Early Jurassic-Early Cretaceous	Pelagic limestone	Permeable	Karstic aquifer
		Afyonluk	TRa	Late-Middle Triassic	Dolomite, chert-banded limestone	Permeable	Karstic aquifer
	Sazak group	Ortatepe	JKo	Late Jurassic-Cretaceous	Limestone, cherty limestone	Permeable	Karstic aquifer
		Koyuntepe	TRJk	Late Triassic-Early Jurassic	Limestone, chert	Permeable	Karstic aquifer
		Bakırdağ	TRb	Late-Middle Triassic	Limestone, dolomitic limestone	Permeable	Karstic aquifer
		Kocayayla	PTRk	Permo(?)-Triassic	Sandstone	Semi-permeable	Aquitard medium I

Table 1 (continued)

Group		Formation	Symbol	System/series/epoch	Lithology	Hydrogeological properties	Aquifer systems
Anamas-Akseki autochthonous	Kırdağ-Anamasdağ unit	Dereköy	Ed	Middle Eocene	Flysch series	Impermeable	Aquifuge medium
		Büyükkırtepe	PEb	Paleocene-Early Eocene	Limestone	Permeable	Karstic aquifer
	Homa-Akdağ unit	Hüseyinliçeşme	Eh	Early Eocene	Mudstone, claystone, sandstone, shale, marl	Impermeable	Aquifuge medium
		Sarıdere	PEs	Paleocene-Early Eocene	Limestone	Permeable	Karstic aquifer
		Kocaçal	Kko	Cretaceous	Cherty biomicrite, limestone	Permeable	Karstic aquifer
		Belceğez	JKb	Late Jurassic-Early Cretaceous	Spilitic pillow lava, sandstone, limestone	Semi-permeable	Aquitard medium I
		Kocadere	Jk	Early–Late Jurassic	Sandstone, siltstone, claystone, limestone, conglomerate	Semi-permeable	Aquitard medium I
	Akdağ unit	Derealanı	Jd	Early Jurassic	Carbonate sandstone, siltstone, claystone, clayey limestone	Impermeable	Aquifuge medium
		Karatepe Verrucano	TRJkv	Middle Triassic-Early Jurassic	Pebble stone, sandstone, shale, sandy-clayey limestone	Semi-permeable	Aquitard medium I

total precipitation data of these observation stations were obtained from the Turkish State Meteorological Service. Average annual precipitation values for 1975–2018 years were determined as Afyonkarahisar (426.41 mm), Sandıklı (470.25 mm), Şuhut (417.32 mm), Dinar (448.67 mm), Sincanlı (533.78 mm), and Çay (446.08 mm). It is seen that the total average annual precipitation data at these stations are parallel (Fig. 3). The average rainfall was computed by the isohyetal method, using annually average rainfall data which belong to the area. The annual average rainfall was determined by the isohyetal method as 407.315 mm for a period of 43 years (1975–2018) and isohyetal map of the study area was prepared (Fig. 4).

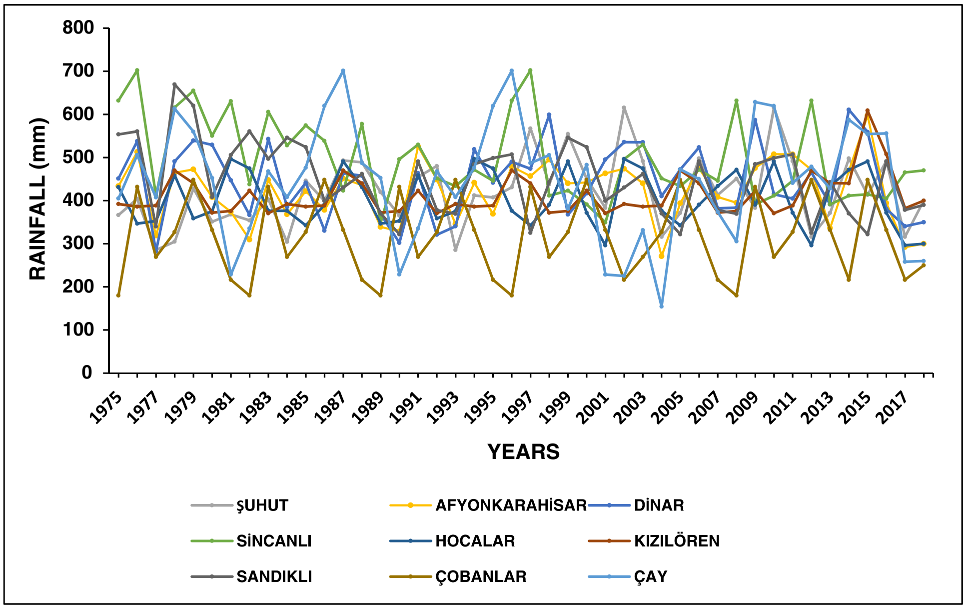
Temperature of the study area generally rises to 24.2 °C in the summer (August), and decreases to – 2.1 °C in the winter (January). Average temperature values are measured as Afyonkarahisar (12.4 °C), Dinar (13.9 °C), Şuhut (12.6 °C), Hocalar (12.1 °C), Kızılören (13.4 °C), Çoban (12.3 °C), and Çay (12.8 °C) for 1975–2018 years.

Discharge mechanism of the springs

The springs show distribution in Dutağacı, Bektaş, Akın, Başören, Kavaklı, Aydın, Yıprak, Balçıkhisar, Kayabelen, and Bademli locations in the study area. These springs are Esegöz, Dutağacı, Karalaröreni, Asmakaya, Akın, Kumalardağ, Karlıbahçe, TZM, Oğuzhansalih, Kavaklı, Harman, Bezeme, Camili, 88/3, Sanlı, Torun, Sıtma, Yıprak, Güldede, Dedecik, and Bademli springs (Fig. 1a).

Karalaröreni (D3) and Asmakaya (D4) springs located in Bektaş village and Torun (D16) spring (2.10 l/s) in Yıprak village are productive springs. Karalaröreni (D3) spring feeds the Bektaş ponds. Except for Esegöz (D1), Karalaröreni (D3), and Asmakaya (D4) springs, 19 springs flow continuously during 1 year (2017–2018). It has been observed that the increases in the rainfall are effective in the spring flows. The fact that the feeding areas of the springs are not very large causes the flow rates of the springs to be small. Most of the springs in the study area are feed by volcanic rocks (Fig. 5). Argillisation due to alteration in

Fig. 3 The monthly average rainfall data in the study area



volcanics and semi-depth rocks in the feeding areas of the springs delays rainfall waters reaching the aquifer (Okan et al. 2018). The effect of climate and lithological conditions in the recharge areas of the investigated springs is directly related to the discharge mechanism of the spring.

The annual discharge of the springs in the study area varies between 0.01 and 2.10 l/s (Table 2). Esegöz (D1), Dutağacı (D2), Kavaklı (D10), Camili (D13), 88/3 (D14), and Dedecik (D20) springs discharge from the rocks containing high alkali, which are the dacite, rhyolite, andesite, basalt, and etc. (Volkanit member). The average discharge of Esegöz spring could not be determined because it is dry for 4 months of the year. The annual average discharge of the other springs are 0.05, 0.02, 0.01, 0.86, and 0.03 l/s, respectively. Karalaröreni (D3), Asmakaya (D4), Kumalardağ (D6), Karlıbahçe (D7), TZM (D8), Oğuzhansalih (D9), Harman (D11), Bezeme (D12), and Sanlı (D15) springs discharge from volcanic origin rocks and clastic limestones, which belong to Kumalar formation. The average annual flow rates of other springs except Karalaröreni and Asmakaya springs are respectively 0.09, 0.16, 0.18, 0.09, 0.07, 0.03, and 0.23 l/s. The Akın spring discharges from the Afyonluk formation consisting of limestones with dolomite lentils and chert bands and the annual average flow rate of the spring is 0.30 l/s. Torun (D16) and Sıtma (D17) springs discharge from the Kumalar formation and are feed from the limestones of the Bakırdağ formation. The annual average flow rates of the springs are 2.10 and 0.48 l/s. The Yıprak (D18) spring discharges from the Kumalar formation and Koyuntepe formation contact and the Güldede (D19) spring is discharged from the Kocadere formation, which consists of sandstone, claystone, siltstone, limestone alternation, and reefal limestone. Annual average flow rates of the springs are 0.02 and 0.23 l/s. The Bademli (D21) spring discharges from the Alluvium contact with the Göçen formation, which consists of sandstone with volcanic intercalations with olistoliths and serpentinite, and its annual average flow rate was measured as 0.13 l/s (Table 2; Fig. 5).

It is observed that there are many springs discharging from the Kumalar formation, which is made up of volcanic origin rocks and clastic limestones, presenting a wide distribution in the study area. However, the flow rates of these springs are very low. An increase in flow is observed in the springs that are feed from the limestone levels in this formation. The highest flow rate is Torun (D16) spring, which is also feed from the Bakırdağ formation limestones.

Relation between flow rates and precipitation

The monthly precipitation data in the study area and monthly discharges of the springs are shown in Fig. 6. The discharge graph of the springs shows that while the spring flows decrease in the dry period, it increases in the rainy season. The flow of springs begins to decrease when recharge processes decrease as a consequence of temperature increase and rainfall decrease. The increase in spring flow rates with precipitation in the rainy period can be explained by the fullness of the aquifer reserve located in the recharge zone of the spring and the excess amount of precipitation. This result indicates that the springs and groundwater system in the area respond quickly to precipitation and drought conditions. Especially the flow rate change in the springs increases between December and May in the rainy period depending on the climatic

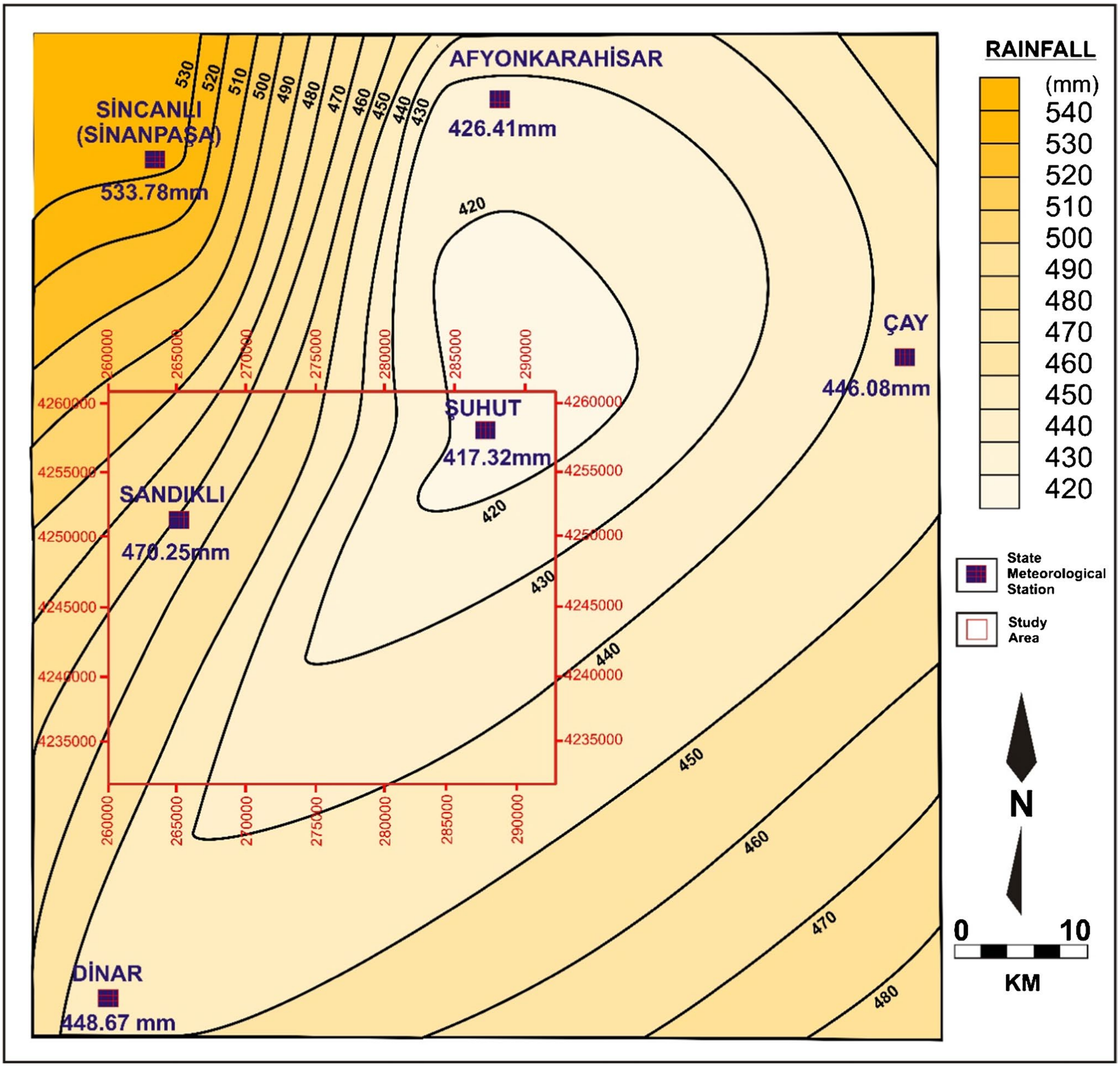


Fig. 4 Isohyetal map of the study area

changes. With the increase in temperatures in the dry period between June and November, the flow values of the springs in the study area are decreased. Especially, in some springs (D5 and D14), when there is a decrease in the flow rate in the dry period, the flow rate is increased in these springs by artificial feeding due to the need in the settlements. Although there are seasonal fluctuations in all springs, the same flow rates were measured in between September 2017 and September 2018, which is considered the beginning of the water year. This shows that the nutritional conditions did not change (Fig. 6).

Discharge regime of the springs

Various analysis and methods are used for identifying the regime of the springs. Selection of proper investigative techniques characterizing discharge regime properties of a spring is important in terms of the flow components of springs. Hydrological methods are used to characterize flow rate and properties of spring in the water resources applications. Discharge of spring changes in time, due to the recharge and emptying of its natural reservoir. Systematic measurements of discharge should be performed at least for one complete hydrological cycle where both regular major

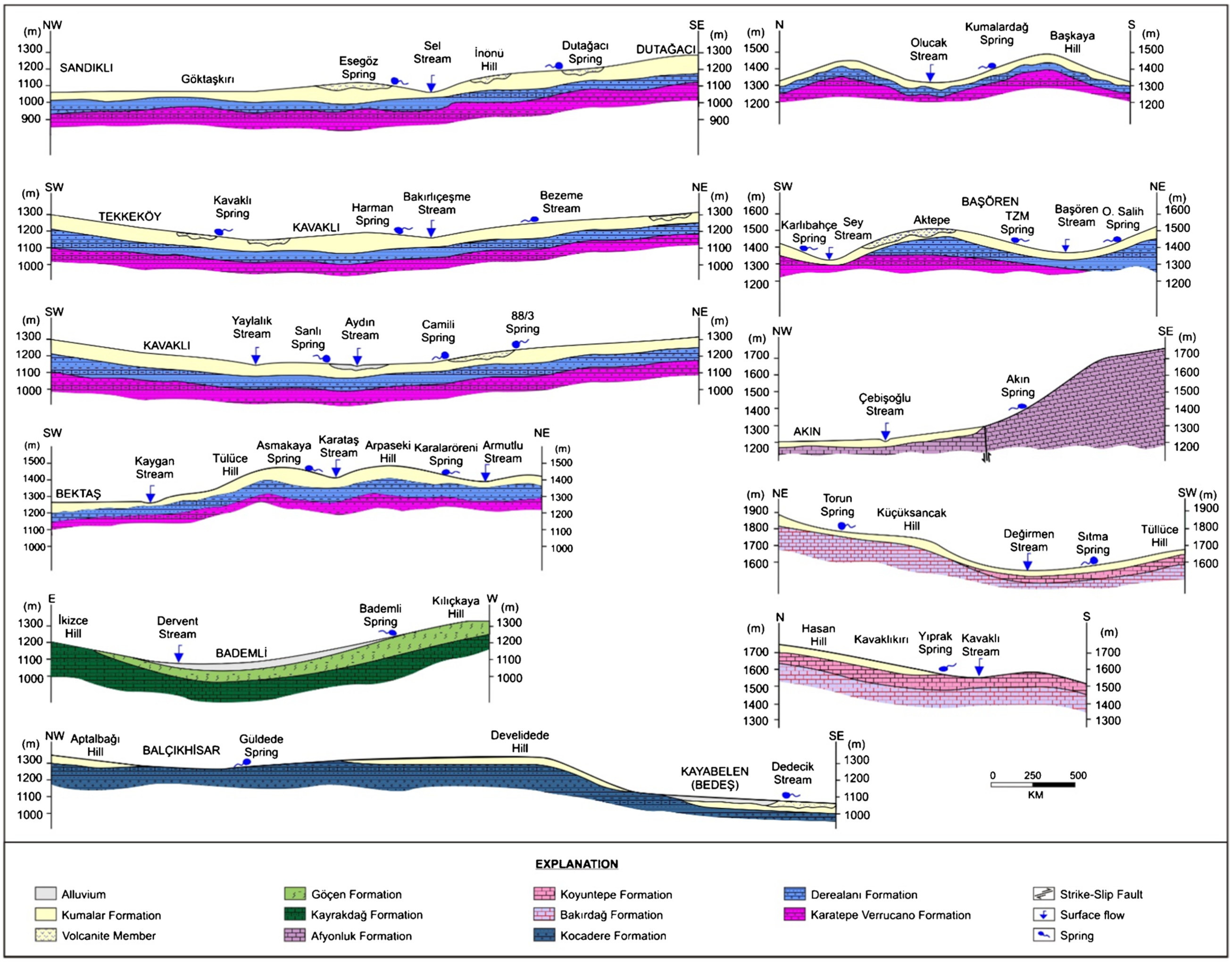


Fig. 5 Geological sections of springs in the study area

recharge events and recession are observed (Malík 2015). "Hydrography analysis" and "Maillet analysis" were used in order to determine the discharge regime of the springs in the study area.

Hydrography analysis method

Hydrography of springs represents clearly all physical processes that control groundwater flows inside the aquifer (Kuhta et al. 2012). The spring discharge hydrograph is the final result of various processes that govern the transformation of precipitation and other water inputs in the spring's drainage area into the single output at the spring. In many cases, the discharge hydrograph of a spring closely resembles hydrographs of surface streams, particularly if the aquifer is unconfined and reacts relatively quickly to water input. The shape of a discharge hydrograph depends on the size and shape of the drainage area, as well as the precipitation intensity. Analysis of spring hydrographs always includes determination of the general statistical parameters of the time series, such as average, minimum, and maximum flows for the period of record; standard deviation of the flows; coefficient of variation; flow duration curves; and frequency of characteristic flows at the minimum (Kresic and Bonacci 2010).

Flow rate monitoring is important to determine the continuity of the spring flows. Continuity in flow rates characterizes the relationship between the amount and frequency of flow in a given time interval. Thus, the springs have a continuous and regular discharge regime. The term "discharge regime" means the regular, expected discharge of flowing water within a year (Malík 2015). In the hydrograph analysis, monthly flow rate measurements of the springs were taken periodically for 1 year (2017–2018) in the study area. Base flow curves were formed with the obtained flow measurements and average base flow was calculated with the help of these curves. The annual base flow and average flow rate of the springs were calculated as 311.04–57,024 m^3/year

Table 2 Measured discharge values of springs in the study area

No	Location	Spring	Universal Transverse Mercator (UTM) System			Flow (l/s)													
			X	*Y*	*Z*	2017				2018									Annual Average
			(E)	(N)	(m)	September	October	November	December	January	February	March	April	May	June	July	August	September	
D1	Sandıklı	Esegöz	36S265216	4,259,681	1215	0.98	0.65	Dry	Dry	Dry	Dry	3.53	3.38	1.11	0.99	1.29	1.26	1.51	-
D2	Dutağacı	Dutağacı	36S265566	4,259,638	1275	0.04	0.04	0.04	0.05	0.07	0.06	0.03	0.03	0.03	0.10	0.05	0.05	0.05	0.05
D3	Bektaş	Karalarören i	36S269655	4,258,005	1334	2.50	2.58	After the completion of the Bektaş Pond, Karalaröreni spring was flooded											-
D4	Bektaş	Asmakaya	36S268919	4,257,632	1302	3.33	3.45	3.33	3.14	1.22	1.18	1.29	4.38	Asmakaya spring is remained under the water channel					-
D5	Akın	Akın	36S265786	4,253,522	1243	0.44	0.35	0.05	0.13	0.19	0.37	0.38	0.43	0.41	0.52	0.39	0.40	0.09	0.3
D6	Sandıklı-Şuhut	Kumalardağ	36S269809	4,261,203	1668	0.08	0.07	0.11	0.08	0.07	0.09	0.12	0.11	0.09	0.12	0.09	0.08	0.08	0.09
D7	Başören	Karlıbahçe	36S274677	4,260,675	1571	0.20	0.17	0.21	0.22	0.19	0.20	0.19	0.24	0.22	0.21	0.17	0.07	0.08	0.16
D8	Başören	TZM	36S276041	4,261,451	1366	0.11	0.08	0.12	0.20	0.21	0.20	0.55	0.10	0.10	0.44	0.11	0.11	0.10	0.18
D9	Başören	Oğuzhansalih	36S276265	4,261,627	1244	0.05	0.04	0.01	0.13	0.10	0.07	0.14	0.23	0.05	0.14	0.07	0.07	0.06	0.09
D10	Kavaklı	Kavaklı	37S279001	4,264,003	1247	0.01	0.01	0.02	0.04	0.04	0.02	0.02	0.01	0.01	0.01	0.02	0.03	0.03	0.02
D11	Aydın	Harman	36S280061	4,265,461	1215	0.05	0.04	0.06	0.06	0.06	0.07	0.11	0.09	0.11	0.12	0.06	0.06	0.06	0.07
D12	Aydın	Bezeme	36S281404	4,265,466	1181	0.01	0.01	0.04	0.04	0.04	0.04	0.07	0.04	0.01	0.02	0.01	0.01	0.01	0.03
D13	Aydın	Camili	36S280738	4,265,388	1189	0.01	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.01	0.03	0.01	0.01	0.01	0.01
D14	Aydın	88/3	36S282604	4,265,881	1178	0.46	0.76	0.91	0.90	0.86	0.84	0.90	0.84	0.84	0.96	0.93	0.93	0.97	0.86
D15	Aydın	Sanlı	36S280208	4,264,942	1205	0.19	0.19	0.22	0.22	-	0.20	0.20	0.21	0.22	0.25	0.27	0.26	0.29	0.23
D16	Yıprak	Torun	36S275867	4,249,538	1745	1.30	1.55	1.84	2.52	-	3.00	2.77	2.50	2.22	1.99	1.98	1.96	1.85	2.1
D17	Yıprak	Sıtma	36S276409	4,247,310	1457	0.55	0.54	0.53	0.50	0.51	0.49	0.51	0.51	0.48	0.46	0.44	0.43	0.42	0.48
D18	Yıprak	Yıprak	36S280495	4,248,555	1447	0.01	0.01	0.03	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
D19	Balçıkhisar	Güldede	36S283609	4,257,443	1214	0.16	0.16	0.20	0.20	0.21	0.16	0.47	0.45	0.29	0.35	0.18	0.15	0.12	0.23
D20	Kayabelen	Dedecik	36S284751	4,260,537	1178	0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03
D21	Bademli	Bademli	36S291243	4,254,590	1228	0.06	0.14	0.16	0.18	0.14	0.14	0.15	0.14	0.06	0.17	0.17	0.16	0.05	0.13

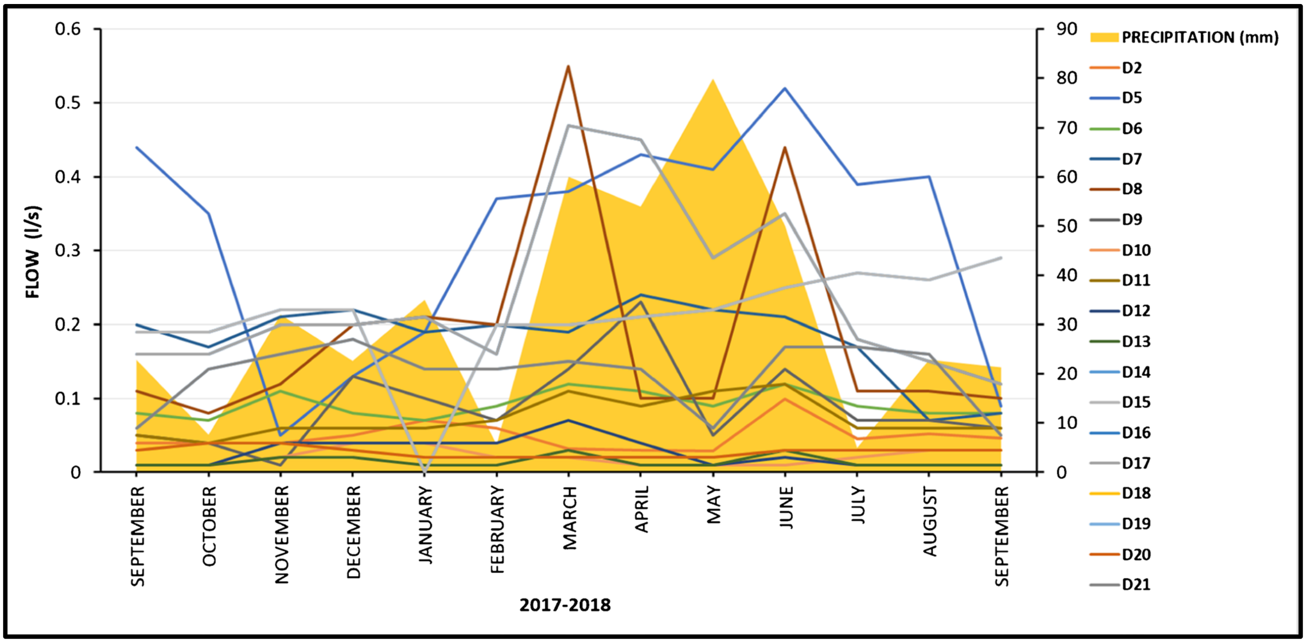


Fig. 6 The graphs of discharge of the springs in the study area

and 0.01–1.81 l/s respectively from the spring hydrography analysis (Table 3). In most springs, significant decreases are observed in the summer season. It has been observed that the increases in monthly rainfall in the region directly affect the monthly average flow values of the springs. Especially during the rainy period in December-January–February-March–April-May, significant increases are observed in spring flow data (Fig. 6). In the summer months, while there is a decrease in some of the spring flows, some of them have not been affected at all. The most efficient spring discharged from aquifers in the study area is Torun spring, located in Yıprak, with a base flow of 57,024 m^3/year. Located at an altitude of 1745 m, the spring drains from the Kumalar formation and is feed from the limestones of the Bakırdağ formation. The flow rate of the spring, whose amount increases in the rainy seasons, reaches its peak and is most efficient in February.

Maillet analysis method

Maillet (1905) suggested that the discharge of a spring is a function of the water volume held in storage (Milanovic 1981; Ford and Williams 2007). Although Maillet (1905) developed Eq. (1) from catchments with aquifers consisting of granulated media, it has been very widely used for karst media, i.e. non-homogeneous and anisotropic media with fissures (Bonacci 1993).

Maillet (1905) introduced an analytical expression into hydrotechnical theory and practice for defining a hydrograph recession curve in a long-lasting dry period (with no precipitation) (Bonacci 1993). According to the concept of Maillet (1905), the discharge (Q) of each reservoir is a function of time (t) and the coefficient of discharge (α). Maillet (1905) also defined the coefficient of discharge (α) as the recession coefficient. The coefficient of discharge is one of the most important parameters that reflect the aquifer characteristics. The coefficient of discharge (α) depends on storage, permeability, geometric properties of a reservoir, and the geological, morphological structure of the catchment analyzed. Numerous equations were used to calculate this parameter (Boussinesq 1877; Maillet 1905; Bonacci 1993; Dewandel et al. 2003; Kovács et al. 2005). The coefficient of discharge (α—day^{-1}), flow variability (Q_d—l/s), and average base flow (Q_b – l/s) of the springs were calculated with Maillet (1905) equation which defines the discharge curves of the springs in the dry period without rain (Table 3). The coefficient of discharge (α), flow variability (Q_d), and average base flow (Q_b) of the springs in the study area were calculated respectively $\alpha = 8.7799 \times 10^{-4}$–$9.8220 \times 10^{-3}$ day^{-1}, $Q_d = 0.10$–0.69 l/s, and $Q_b = 0.01$–2.03 l/s. While the flow variability (Q_d) was determined, it was calculated as maximum flow (Q_{max}) 0.012–2.22 l/s and minimum flow (Q_{min}) 0.01–1.85 l/s. Changes in reservoir volume ($V_d = 1.32$–243.53 l), maximum reservoir volume ($V_{max} = 3.28$–1461.17 l), and minimum reservoir volume ($V_{min} = 1.09$–1217.64 l) were calculated for the average base flow above the spring discharge point of the aquifer (Q_b) (Table 3). In the calculations, data of May, June, July, and August were used as the least flow rate variation and the dry period. The coefficient of discharge (α) is a

Table 3 Calculated flow values of the spring in the study area

No	Location	Spring	Measured	Hydrography analysis		Maillet (1905) analysis								According to the flow variation
			Annual average flow	Average flow	Base flow						Base flow	Coefficient of discharge	Flow variability	Spring type
						Q_{max}	Q_{min}	V_{max}	V_{min}	V_d	Q_b	α	Q_d	Sahinci 1991
			l/s	l/s	m^3/year	l/s	l/s	l	l	l	l/s	(10^{-3}) day^{-1}	l/s	
D2	Dutağacı	Dutağacı	0.05	0.04	1140.48	0.075	0.04	14.32	7.64	6.68	0.06	5.24	0.47	High
D5	Akın	Akın	0.30	0.11	3576.96	0.48	0.4	315.93	263.27	52.65	0.44	1.52	0.17	Medium
D6	Sandıklı-Şuhut	Kumalardağ	0.09	0.08	2436.48	0.1	0.08	53.78	43.02	10.76	0.09	1.56	0.20	Medium
D7	Başören	Karlıbahçe	0.16	0.10	3162.24	0.26	0.08	26.47	8.14	18.33	0.15	9.82	0.69	High
D8	Başören	TZM	0.18	0.09	2851.2	0.14	0.09	38.02	24.44	13.58	0.11	3.68	0.36	High
D9	Başören	Oğuzhansalih	0.09	0.05	1451.52	0.068	0.053	32.74	25.52	7.22	0.06	1.74	0.22	Medium
D10	Kavaklı	Kavaklı	0.02	0.01	311.04	0.03	0.01	3.28	1.09	2.18	0.02	9.16	0.67	High
D11	Aydın	Harman	0.07	0.05	1710.72	0.11	0.055	19.04	9.52	9.52	0.08	5.78	0.50	High
D12	Aydın	Bezeme	0.03	0.01	311.04	0.012	0.01	7.90	6.58	1.32	0.01	1.52	0.17	Medium
D13	Aydın	Camili	0.01	0.01	311.04	0.013	0.01	5.95	4.57	1.37	0.01	1.72	0.23	Medium
D14	Aydın	88/3	0.86	0.17	5391.36	0.1	0.09	113.90	102.51	11.39	0.09	1.45	0.10	Medium
D15	Aydın	Sanlı	0.23	0.11	3421.44	0.27	0.22	158.21	128.91	29.30	0.24	1.71	0.19	Medium
D16	Yıprak	Torun	2.10	1.81	57,024	2.22	1.85	1461.17	1217.64	243.53	2.03	1.52	0.17	Medium
D17	Yıprak	Sıtma	0.48	0.14	4302.72	0.48	0.42	431.36	377.44	53.92	0.45	1.11	0.13	Medium
D18	Yıprak	Yıprak	0.02	0.01	311.04	0.02	0.01	3.46	1.73	1.73	0.01	5.78	0.50	High
D19	Balçıkhisar	Güldede	0.23	0.10	3265.92	0.032	0.013	4.26	1.73	2.53	0.02	7.51	0.59	High
D20	Kayabelen	Dedecik	0.03	0.02	622.08	0.03	0.025	19.75	16.45	3.29	0.03	1.52	0.17	Medium
D21	Bademli	Bademli	0.13	0.09	2851.2	0.12	0.1	78.98	65.82	13.16	0.11	1.52	0.17	Medium

Table 4 Classification of springs according to the coefficient of discharge and flow variability (Sahinci 1991)

Spring type	According to the flow variability (Q_d)		According to the coefficient of discharge (α)	Type of rainfall affected by springs
	(%)		day^{-1}	
Type 1	Springs with little flow variation	<6	$\alpha < 3.5 \times 10^{-4}$	Dependent on long and regular cumulative departure values
Type 2	Springs with medium flow variation	6–27	$3.5 \times 10^{-4} < \alpha < 1.75 \times 10^{-3}$	Separately related to with the cumulative departure values in dry and rainy periods
Type 3	Spring with high flow variation	27–92	$1.75 \times 10^{-3} < \alpha < 1.26 \times 10^{-2}$	Dependent on annual rainfall
Type 4	Spring with very high flow variation	>92	$\alpha \geq 1.26 \times 10^{-2}$	Dependent on monthly rainfall

very important parameter that determines the type of aquifer in base flow analysis. Springs are divided into four groups according to certain limit values of discharge coefficients (Sahinci 1991; Table 4). Each spring group has approximately the same storage and flow variability characteristics.

Classification of springs

There are several classifications of springs made in accordance with criterions of springs in Table 4. According to the obtained data with Maillet analysis, the classification made by Sahinci (1991) was used to determine the spring type (Table 4). According to this classification, Akın (D5), Kumalardağ (D6), Oğuzhansalih (D9), Bezeme (D12), Camili (D13), 88/3 (D14), Sanlı (D15), Torun (D16), Sıtma (D17), Dedecik (D20), and Bademli (D21) springs are “type 2”. The type is springs with medium flow variation. The flow rates of these springs and the annual discharged water amounts show parallelism with dry and rainy period values that are the annual cumulative departure from the long years’ precipitation average (Sahinci 1991, Table 4). Other springs such as Dutağacı (D2), Karlıbahçe (D7), TZM (D8), Kavaklı (D10), Harman (D11), Yıprak (D18), and Güldede (D19) are “type 3”. The type is springs with high flow variation. The flow rates and annual discharge of these springs vary depending on the annual rainfall and distribution (Sahinci 1991, Table 4).

The coefficient of discharge (α) depends on the hydrogeological characteristics of the spring area (aquifer) such as geology, geomorphology, effective porosity, and conductivity. Also, this coefficient represents the water transmission capacity of the aquifer. D5, D12, D15, D16, D17, D20, and D21 springs have small discharge coefficient values and D2, D6, D7, D8, D9, D10, D11, D13, D14, D18, and D19 have spring large discharge coefficient values. Small values of α indicate as the slow drainage of aquifers with large storage capacity, the spring is drained more slowly, the low hydraulic conductivity and the conductivity coefficient higher. The large values of α indicate as the rapid drainage of the flow channels of the aquifer, small storage underground, faster discharge of the spring, high hydraulic conductivity, and lower conductivity coefficient (Meinzer 1942; Schoeller 1967; Hall 1968; Karanjac 1977; Milanovic 1981; Ford and Williams 1989; Kiraly 2003).

Conclusion

The relationship between spring recharge and discharge is one of the most important aspects in the efficiency of the springs. The aim of the study is to evaluate the sustainable use of natural water resources discharged from the Kumalar Mountain region. In accordance with this purpose, potentials of the springs were determined using hydrographic analysis and Maillet analysis techniques, and the spring type and discharge mechanism were also determined. The annual flow rates of the springs were measured as 0.01–2.10 l/s. Spring flow rates increase in the rainy seasons. The annual base flow 311.04–57,024 m^3/year and average flow rates of springs 0.01–1.81 l/s are calculated by hydrography analysis. Also, according to the Maillet analysis in springs, the coefficient of discharge 8.77×10^{-4}–9.82×10^{-3} day^{-1}, flow variability 0.10–0.69 l/s, and average base flow 0.01–2.03 l/s are calculated. According to the coefficient of discharge and flow variation, springs in the area were determined as “types 2 and 3”. As a result of both methods, it has been observed that the springs feed with limestone are efficient. Torun spring in Yıprak which is feed by limestone has the highest flow. The fact that the feeding areas of springs are karstic media increases their quantities and productivity. This study has shown that it will be possible to ensure sustainability by making base flow calculations for efficient use of natural springs in rural areas.

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Declarations

Conflict of interest The authors declare no competing interests.

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