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THEMATIC ISSUE

Groundwater recharge estımatıon ın the Alaşehir sub-basın usıng hydro-geochemical data; Alaşehir case study

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Abstract

The issue of groundwater recharge has gained importance in countries where there is not enough water supply to the aquifer. However, groundwater recharge is a difficult parameter to determine. This difficulty stems from factors such as the location of the area to be studied, time, cost, and hydrological data. Numerical, isotope, and chemical approaches are used in groundwater recharge investigations. Numerical and chemical approaches are more costly and time-consuming than chemical approaches. This study aims to ascertain alluvial aquifer recharge in Alaşehir (Manisa) sub-basin using chemical approaches (Chloride Mass Balance Method) and its applicability. For this purpose, research wells were drilled at 25 different points in the alluvial aquifer, water sampling was done in wet and dry periods, and rainwater water samples were collected. Groundwater recharge was calculated by using chemical approaches from the chloride concentrations of the water samples collected. An annual average of 74.84 mm of recharge was found in the Alaşehir sub-basin. This value corresponds to 16.38% of annual rainfall. At the same time, it was examined the groundwater and geothermal mixing mechanism to demonstrate the applicability of the Chloride Mass Balance Method. It was concluded that geothermal fluid in Alaşehir sub-basin mixed with groundwater at a rate of 17%.

Keywords Groundwater recharge · Alaşehir sub-basin · Gediz basin · Chloride mass balance method (CMB)

Introduction

Groundwater recharge is important in understanding the water potential of the basins. In recent years, dramatic drops in water levels have been recorded in semi-arid climatic regions, where groundwater withdrawal increases. These decreases in groundwater levels are controlled by factors such as precipitation, temperature, and evaporation in basins (Scanlon and Cook 2002). Lithological conditions in basins are another factor affecting groundwater recharge. To illustrate, in areas with high humidity and high temperatures in the world, significant groundwater recharge occurs in underground cavities and karstic systems (Herczeg et al. 1997).

In Europe, where more than 30% of the surface of the terrain is found in karstic systems, most of the drinking water is produced from karst aquifers (Hartmann et al. 2013). Many researchers agree that groundwater recharge approaches should differ depending on the application since groundwater recharge approaches include many variables such as water quality, ecology, and socio-economic factors on a temporal and spatial scale (Sophocleous 1997; FAO 2003; Alley and Leake 2004; Maimone 2004). However, only a few methods can be applied in regional, long-term average recharge estimates. Some of these methods are the Chloride Mass Balance Method and isotope tracers (Scanlon et al. 2002). Recharge estimates associated with isotope tracers are based on stable and radioactive isotopes. While stable isotopes ($\delta^{18}O$, $\delta^{2}H$) give information about the location of the recharge area and how the groundwater moves during the

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recharge process, radioactive isotopes (δ^3H, δ^3He, δ^{14}C) provide important information in predicting recharge by aging the groundwater (De Vries and Simmers 2002; Scanlon et al. 2002). However, recharge estimation using isotope tracers has some disadvantages. Even in developing countries, some scientists have difficulty reaching the laboratories where isotope analysis can be done, and this leads to the loss of data. Therefore, recharge estimation using chemical methods instead of isotope tracers was more favored by researchers. The chloride mass balance method (CMB) determines recharge based on the increase in chloride originating from precipitation in the groundwater (Dettinger 1989; Sami and Hughes 1996; Bazuhair and Wood 1996; De Vries et al. 2000). For the application of this method, there should be no salt-containing units in the aquifer material. At the same time, the aquifer should not interact with the seawater intrusion or with surface contaminants that increase salinity (De Vries and Simmers 2002; Scanlon and Cook 2002). Some researchers have carried out some studies to increase water quality in groundwater recharge studies in basins affected by surface contaminants (Solangi et al. 2019; Bhatti et al. 2020; Fazelabdolabadi and Golestan 2020; Hussain and Al-Fatlawi 2020). In the CMB, if there is no sampling point representing deep aquifer systems, deep and lateral recharge amounts cannot be calculated. Therefore, the recharge is evaluated based on the chloride concentration entering the aquifer system from precipitation (Leaney et al. 2009). While the CMB is applied to basins, groundwater should be recharged only by precipitation and not be under the influence of pollutants. This study was aimed to examine aquifer recharge using the CMB, and the validity of the results obtained was clarified by the mixing mechanism of groundwater and geothermal waters in the Alaşehir sub-basin where geothermal power plants are concentrated.

Description of the study area

The Gediz basin is one of the most important groundwater basins of western Turkey, occupying an area of about 17.000 km^2 and having a population of approximately 200.000 (Fig. 1). Groundwater is the main source of water, with agricultural usage about 86.5% of total water use. Groundwater wells unawares opened in the Alaşehir sub-basin, and water famine restrict socio-economic development, especially in agriculture. Excessive use of groundwater in this semi-arid basin has caused groundwater levels to drop in the last few years. The alluvium aquifer appears to have an annual average drop of 57 cm. One of the main reasons that the water level in the basin tends to drop so steadily is water withdrawal. The Alaşehir sub-basin is also one of the most important basins in terms of geothermal activities. Many geothermal wells have been opened in the Alaşehir sub-basin for electricity production. In the sub-basin, water famine and environmental problems increasingly threaten the local groundwater sustainability of the region.

Geology of the study area

The Menderes Massif, which includes green, yellow, and brown chlorite-schist and mica-schist units, forms the basement of the study area (Fig. 2). The Menderes Massif is observed in the high parts of the study area and extends to

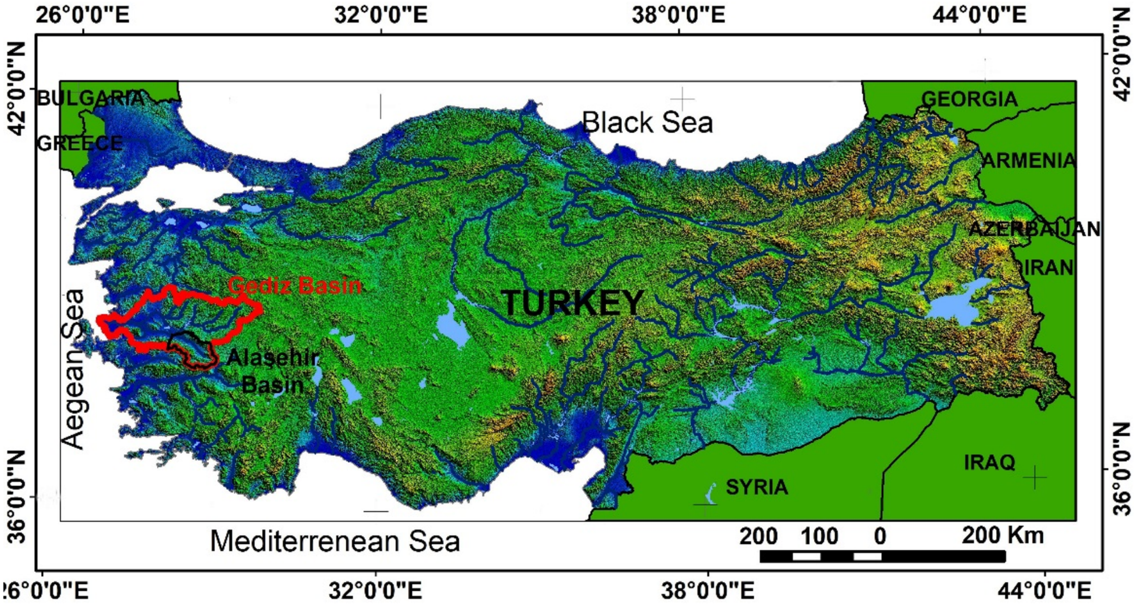


Fig. 1 Location map of the study area

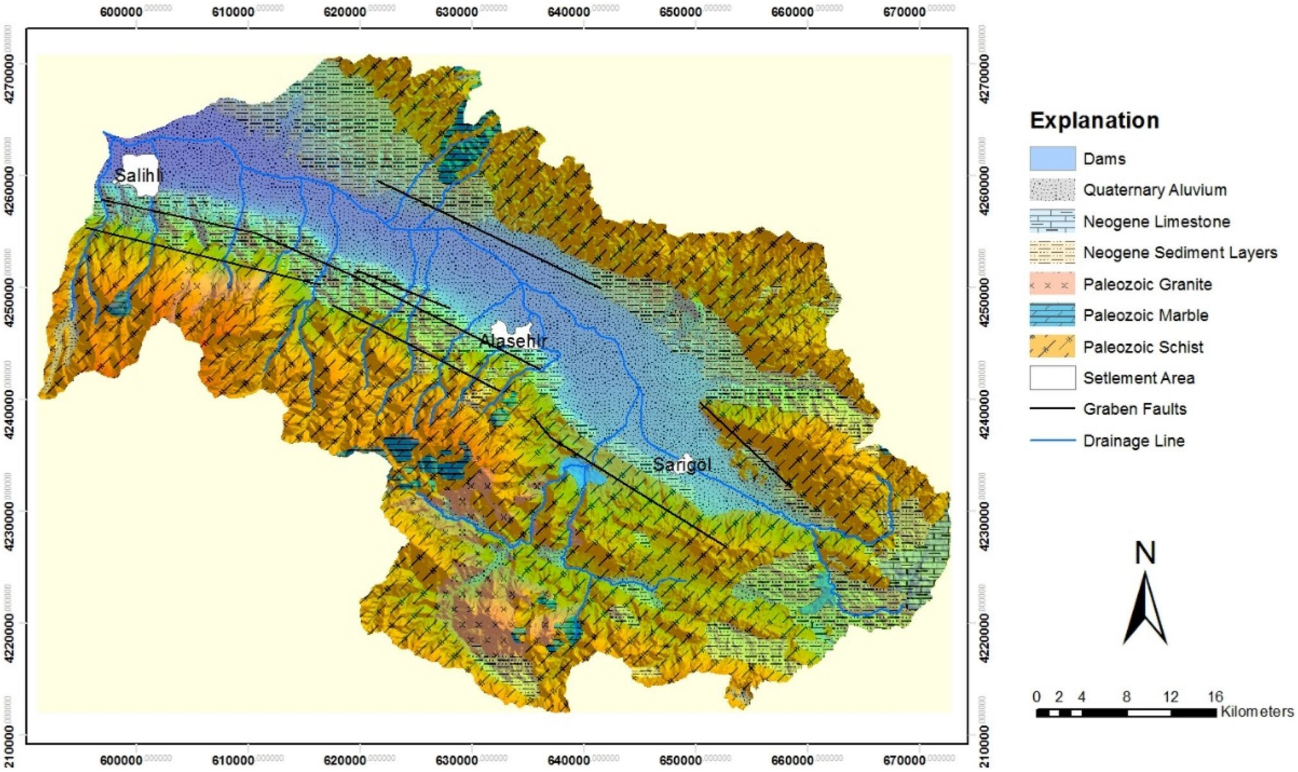


Fig. 2 Geology map of the study area

the Bozdağ site in the NE–SW direction. Musadağı marbles outcrop on top of the mica-schist units. Musadağı marbles are composed of recrystallized marbles with gray, white, and karstic cavities that form the top part of Paleozoic basement rocks. Musadağı marbles are observed in small areas in different parts of the study area and are widespread especially in the Bozdağ site in high areas. Şimşek et al. (2015) revealed that Musadağı marbles can reach a thickness of 250 m. Within these basement units, Salihli granodiorites are intrusive rocks. The oldest sedimentary units outcropping in the southern part of the Gediz graben is the Alaşehir formation. The Alaşehir formation is structurally located on the Gediz Detachment Fault, which is considered the most important fault of the region (Çiftçi 2007). The Çaltılık formation, which is located on the Alaşehir formation with conformity, consists of limestone and conglomerate (Yilmaz et al. 2000). The Gediz formation, which stretches on the edge of the graben along the line bounded by NW–SE-trending normal faults, is located on the Çaltılık formation with conformity (İztan and Yazman 1990). The Gediz formation was also named the Gediz and Salihli formation in some studies conducted in the region. The Gediz formation has been exposed to sediment erosion due to the lithological unit separation along the Gediz graben fault zone. Hence, it outcrops in the lower parts of the study area. The Bintepe formation, generally represented by gray carbonate rocks and marls, overlies the Gediz formation and outcrops on the northern edge of the Gediz graben. The thickness of Quartenary aged alluvium, which forms the youngest units of the Gediz Graben, varies between 50 and 250 m. Quaternary alluvium contains most of the groundwater potential in the region.

Methodology

To examine the groundwater hydrochemistry and chloride concentration, 25 core sampling wells were drilled in the represented area of the aquifer, and sampling campaigns were conducted within the drilled wells, as seen in Fig. 3. Some of these wells could not be sampled in some periods due to weather and land conditions. It has been noted that research wells should be far from the pollutant effect in the choice of location. Therefore, the locations of the research wells in the study area have been chosen away from the regions where geothermal wells are located. In addition to the drilled wells, rainwater was also sampled from Hacıaliler (YM1), Alaşehir (YM2), and Alhan (YM3) regions. Some basic physicochemical parameters such as pH, electrical conductivity, water temperature, and salinity were measured in-situ with portable multi-parameter probes. Collected water samples were analyzed by ion chromatography (IC) in Dokuz Eylül University laboratories. For the groundwater

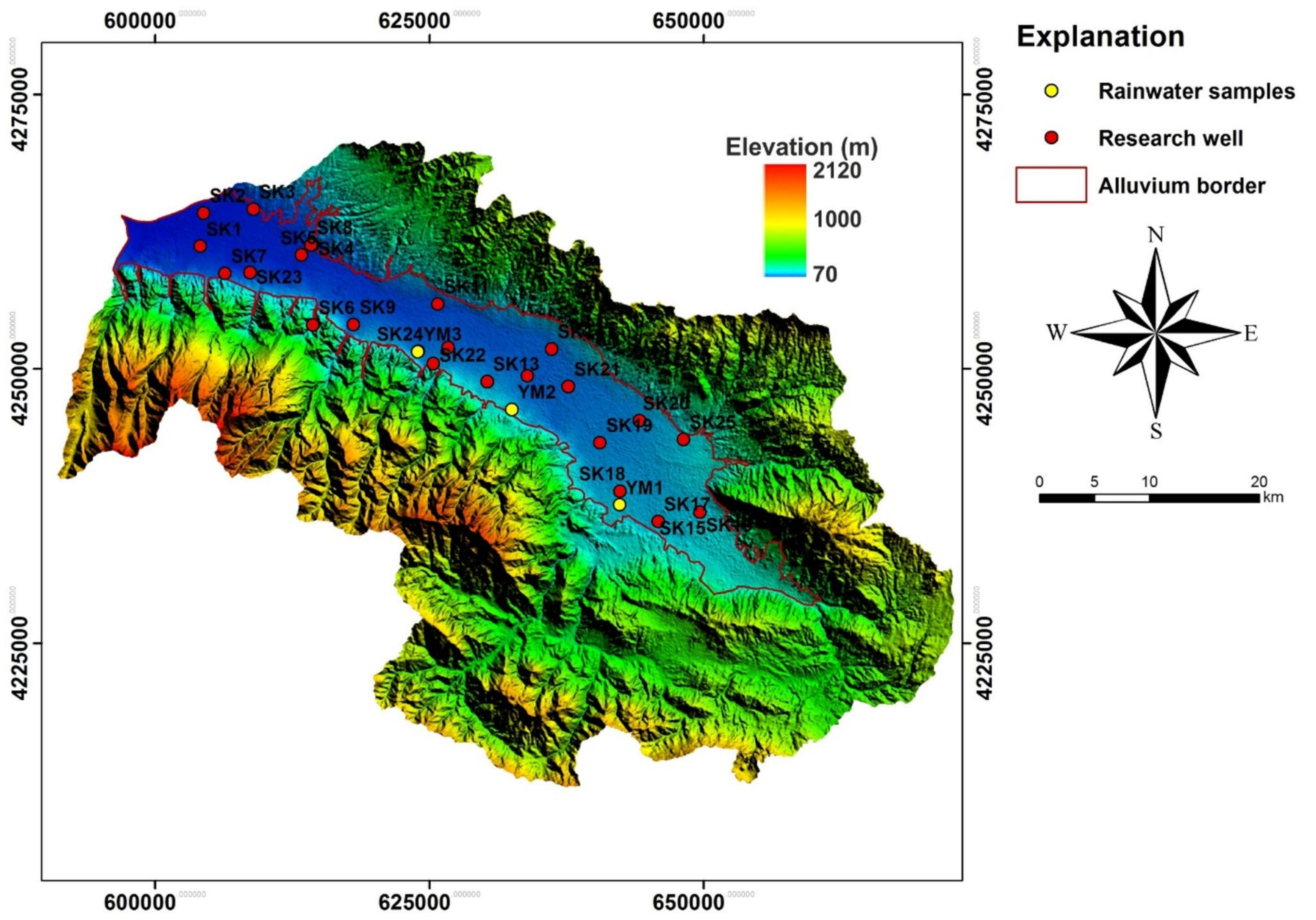


Fig. 3 Sampling location map of the study area

chloride concentration used in the calculation of aquifer recharge and included in Eq. 1, the chloride values of the water samples taken during the wet and dry periods were averaged. The average value was also taken for rainwater chloride concentrations in Eq. 1.

Meteorology stations have been placed at three different points in the study area to evaluate the precipitation data (Fig. 4). Rainfall and air temperature values are measured from these stations. The MT1 meteorology station was established in Yeşilova Village located in the northern part of the Alaşehir sub-basin. The MT2 meteorology station was located in Alhan (Caglayan) Village in the central part of the sub-basin. The MT3 meteorology station was located in the Çavuşlar Village in the south of the sub-basin. In the location selections of the stations, the State Hydraulic Works (DSİ) and Meteorology General Directorate stations in the sub-basin were taken into consideration. Meteorological monitoring was performed for one year from these meteorology stations, and the general meteorological and climatic characteristics of the study area were evaluated according to the long-term average values. Monthly precipitation and temperature data were obtained from three meteorology stations, and the total annual precipitation value of the basin was used in calculating aquifer recharge. The flow chart for the research methodology is given in Fig. 5.

Chloride mass balance method (CMB)

The CMB is the most commonly used, simple, and low-cost chemical method for predicting groundwater recharge in water budget studies. The CMB is usually applied in areas where the groundwater table is close to the surface. The chloride in the pore water begins to condense in the unsaturated region by evaporation and transpiration and finally reaches the groundwater through horizontal conduction. If vegetation uses the water source, chloride may continue to evaporate, so the method gives accurate results for groundwater recharge estimation.

The CMB is a method that can be applied to both the vadose zone and the saturated zone in the long-term average annual recharge estimates (Walker et al. 1991; Wood and Sanford 1995).

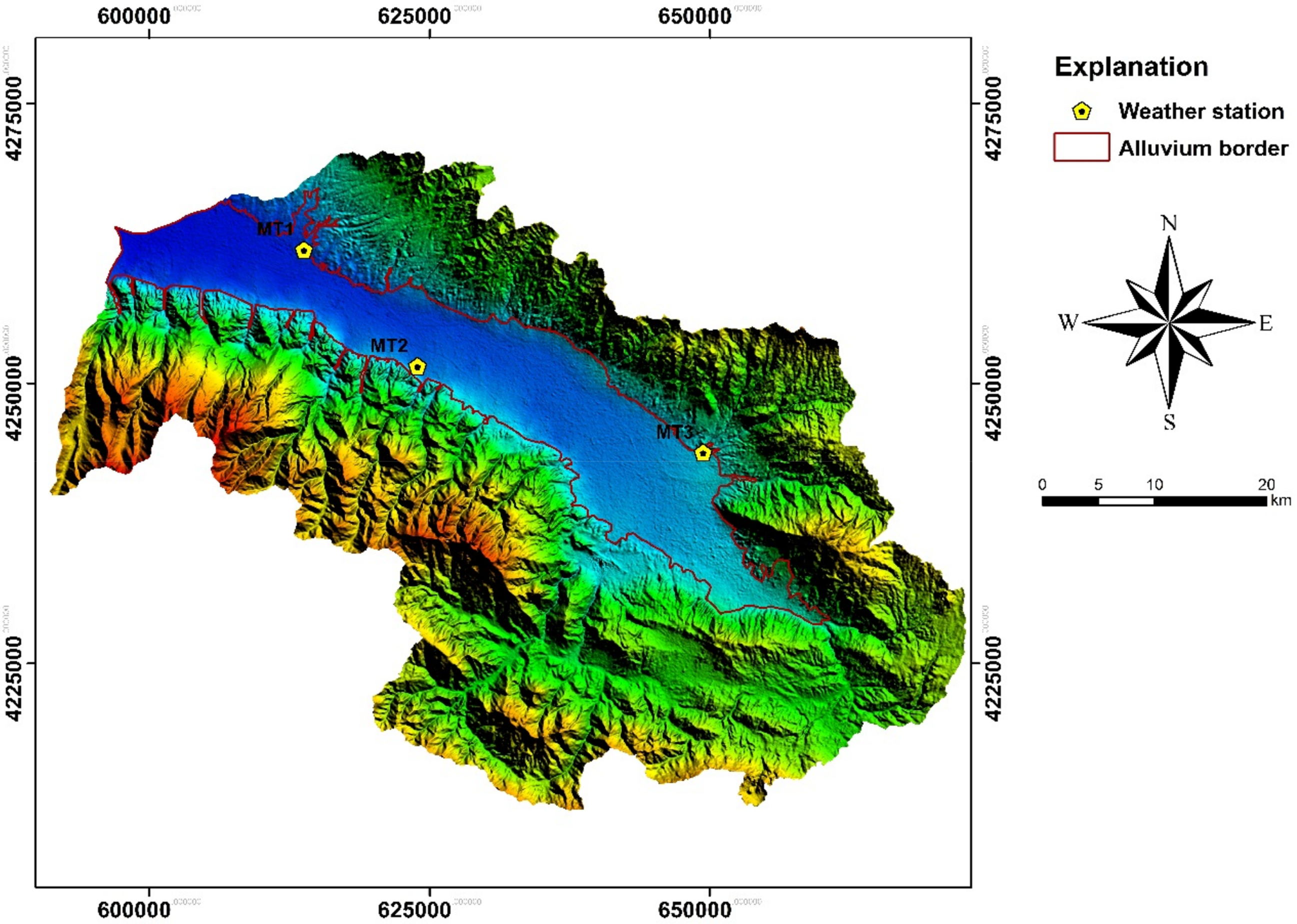


Fig. 4 Location of weather stations

The CMB can be used to estimate the chloride recharge relationship of groundwater. However, this method has some disadvantages. When using the CMB, it is recommended that the source of chloride is completely from rainfall and the groundwater is not under the influence of any pollutants (Wood 2014). The storage of chloride in the system should not change over a long period. Considering these limitations, it appears as a suitable method for alluvium and karstic aquifers in Turkey. In general, it seems suitable to be used in this type of aquifers since the karstic and alluvial aquifers have unconfined aquifer feature that reacts quickly to rainwater and they do not contain saline rock material in general (Hartmann et al. 2013). There are different approaches in equations related to CMB in the literature. The most common equation used in CMB is expressed in the following equation (Scanlon et al. 2002).

$$R = \frac{P \times C_{p+D}}{C_g} \quad (1)$$

where R is the recharge (mm/y), $C_{\text{p+D}}$ is the chloride concentrations in rainwater (mg/l), C_{g} is in equilibrium with unsaturated zone groundwater chloride concentration (mg/l).

Result and discussion

Meteorological properties

In the study area, there are meteorological stations ranging from 75 to 1150 m elevations and operated by the State Hydraulic Works (DSİ). The annual precipitation totals observed in these meteorological stations vary between 435.1 mm and 1240 mm, and the average precipitation is 574.3 mm (Table 1). Long-term average temperature values range from 13.5 °C to 17.0 °C, and the average temperature value is 15.4 °C (DSİ 2014). According to long-term meteorological data, the highest temperature is 29 °C in July, while the lowest temperature is 5.8 °C in January (DSİ 2014).

The spatial distribution of the averages of the long-term annual precipitation is given in Fig. 6. As can be seen in

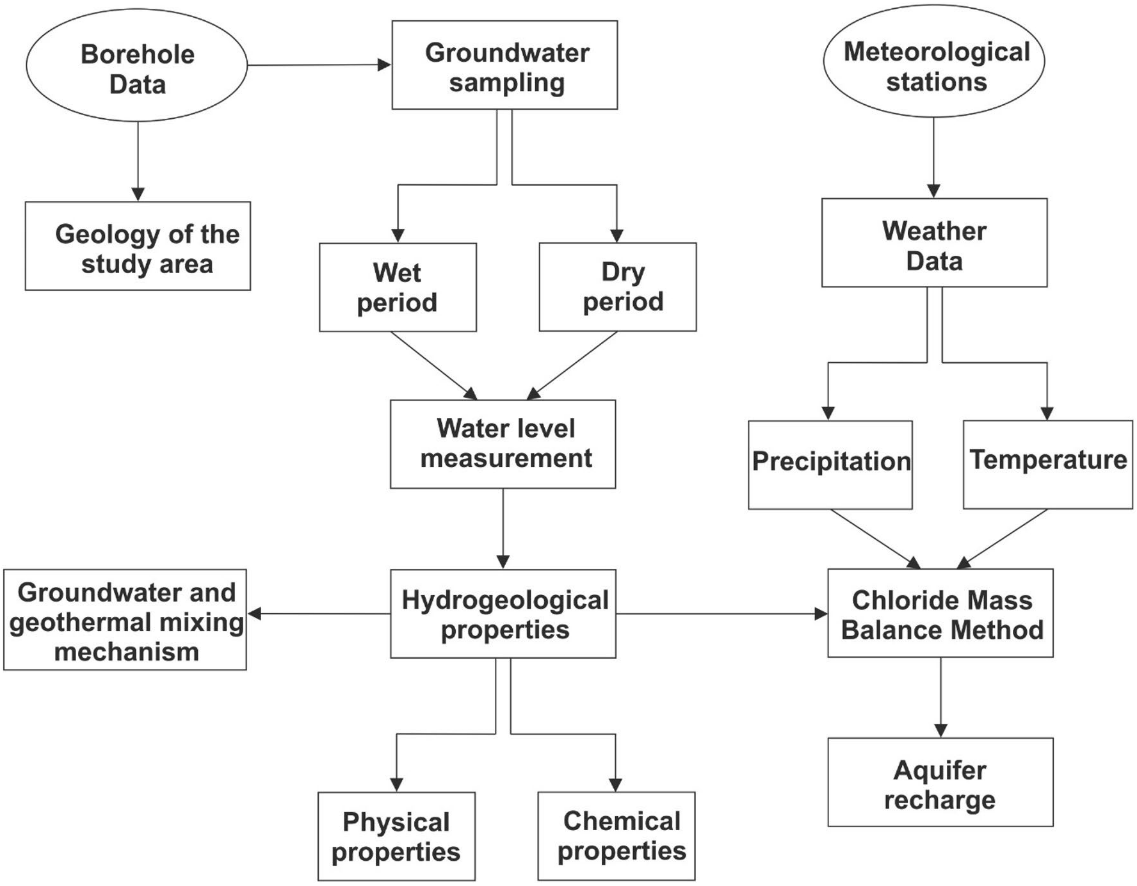


Fig. 5 Flow chart for the research methodology

Table 1 Statistical information of the long-term meteorology data in the Alaşehir sub-basin (DSİ 2014)

	Annual total rainfall (mm)	Annual average temperature (°C)	Annual total PET (mm)	Annual total actual ET (mm)	Annual total surface evaporation (mm)
Min	435.14	13.52	767.46	320.97	1167.33
Max	1239.76	17.03	929.11	358.65	1800.05
Average	574.31	15.39	851.79	342.63	1434.19
SD	187.65	1.34	60.35	10.59	205.63

Fig. 6, long term precipitation values in the basin vary between 440.3 mm and 1240 mm. When the distribution of precipitation in the basin is analysed, it is seen that it has high values in Salihli and Bozdağlar. There is a decrease in precipitation towards the plain (Fig. 6). Figure 7 shows that the total rainfall of 2017 belonging to the meteorology stations established within the scope of the study is below the long-term annual precipitation average of the Alaşehir sub-basin.

The monthly average temperatures measured in the meteorological stations established in the study area reveal that the hottest month was August 2017. The lowest temperatures were measured in December 2016 (Figs. 8a, 9a and 10a). In 2017, the highest rainfall was 116.8 mm in Alhan, 98.2 mm in Yeşilova, and 78.8 mm in Çavuşlar. The least amount of precipitation occurred in July, August, and September (Figs. 8b, 9b and 10b).

Within the scope of the study, the average precipitation of the basin obtained from the meteorological stations installed in the study area is 457 mm per year. The annual potential evapotranspiration is 902.92 mm/year in the sub-basin (Tonkul et al. 2019). The daily temperature graphs of the Alaşehir sub-basin show that the sub-basin has higher average temperatures than the long-term annual average temperature of 15.4 °C. Therefore, the precipitation in the Alaşehir sub-basin is less than the long-term average precipitation. In addition, the fact that the temperature average is higher than the long-term temperature means that the basin had an arid

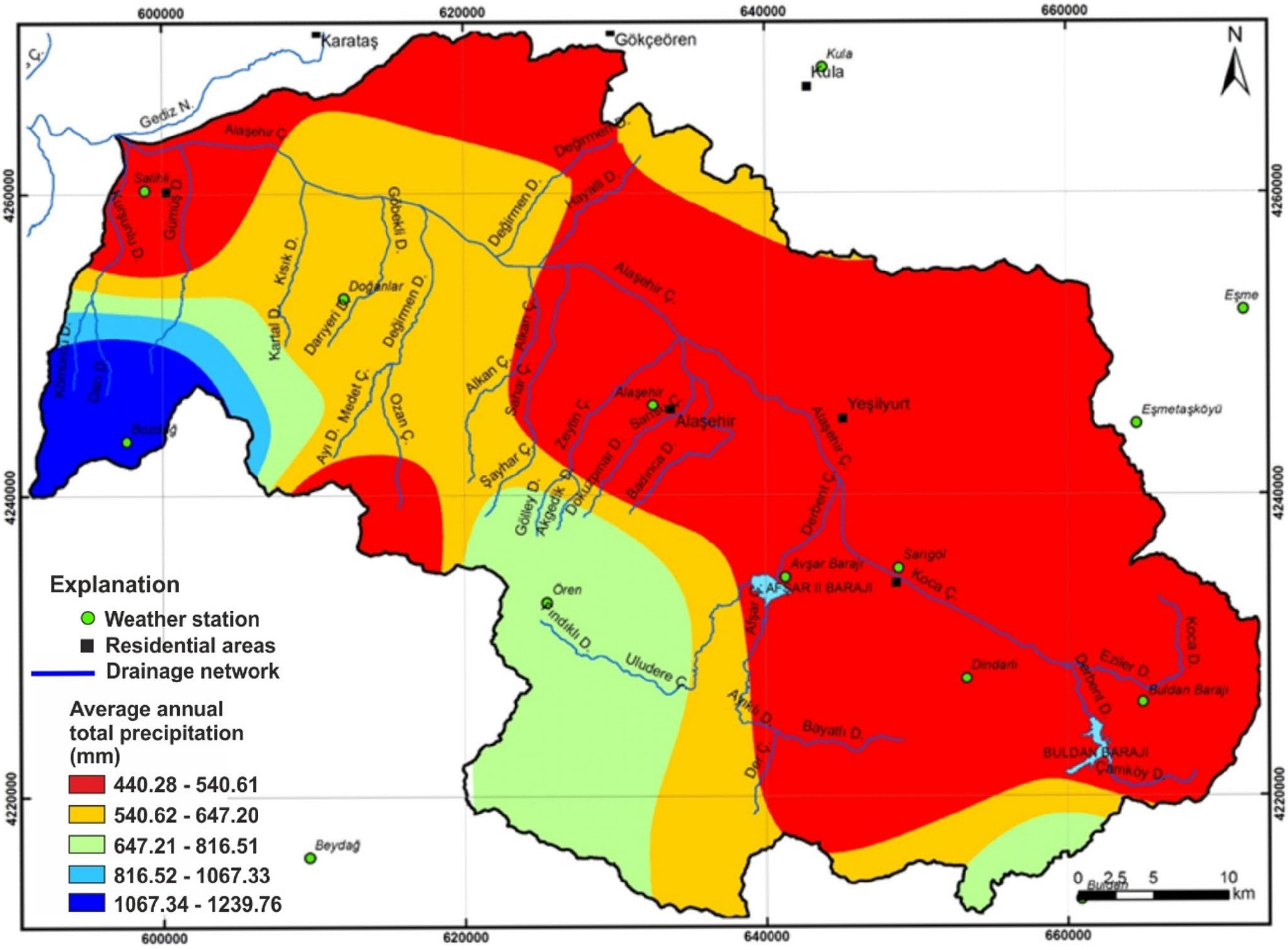
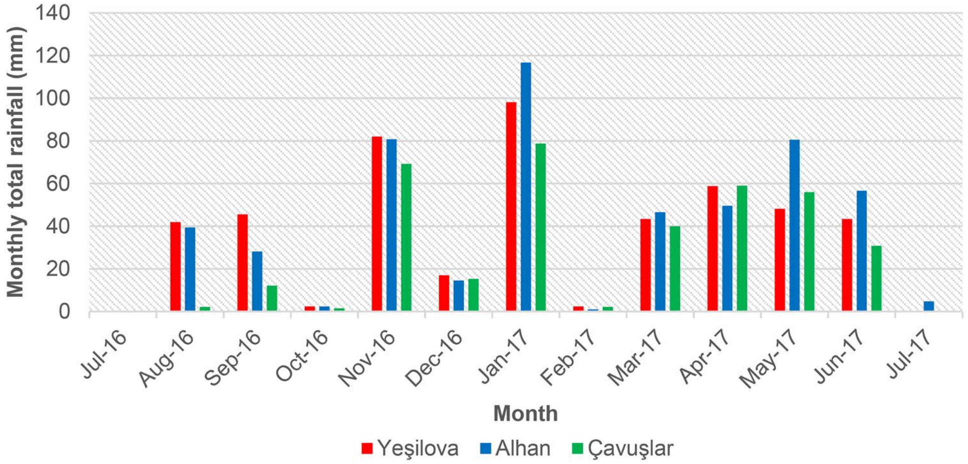


Fig. 6 The spatial distribution of the long-term annual precipitation (DSİ 2014)

Fig. 7 Monthly total rainfall graph measured for the Alaşehir sub-basin



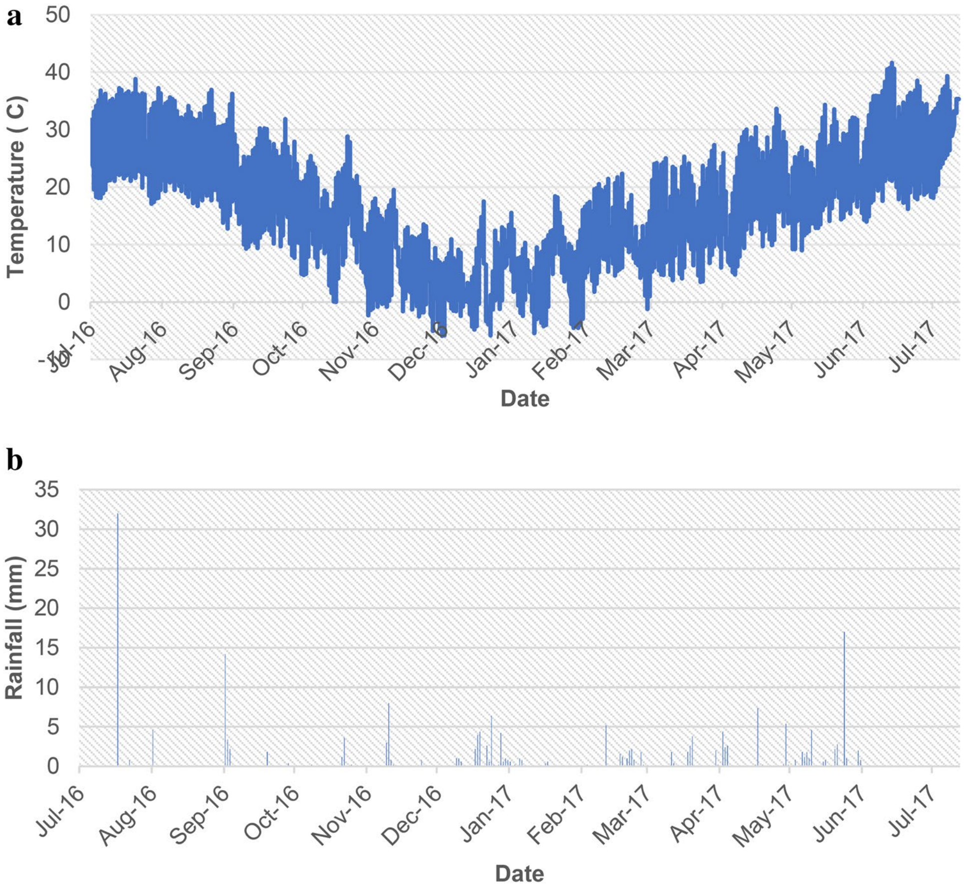


Fig. 8 Yeşilova (MT-1) weather station meteorological data **a** Daily temperature, **b** Rainfall change

year between 2016 and 2017. The importance of the concept of drought has increased due to the decreases in rainfall in recent years in the Alaşehir sub-basin. As can be seen from the meteorological data, it is highly probable that the study area is at risk of drought and a resulting decrease in both surface and groundwater amounts.

Groundwater level

Here, it was aimed to understand the effect of rainfall on the alluvium aquifer, as well as the effect of the irrigation attraction, which started in the basin in spring, on the aquifer. Groundwater level changes obtained manually from research wells are given in Table 2. Manually measured groundwater level monitoring results for the study area coincide with the measured decrease in rainfall (Table 2). The decrease in rainfall is reflected in the groundwater level as a lack of recharge. Moreover, the presence of an arid climate in the region causes an increase in demand for groundwater. This situation increases the withdrawal in the basin. The decrease in occupancy rates in the Avşar Dam, which is the most important dam in the region, can be considered as a result of the lack of precipitation in the region in recent years. The shortage of precipitation, which is the main source of recharge for both surface water and groundwater, is directly reflected in groundwater recharge in the study area. In addition, the low level of occupancy rates in the dams in the region is likely due to a lack of precipitation in the Aegean region. As can be seen from the groundwater level measurements, this downward trend is continuing.

Hydrochemical properties of water samples

To determine the chemical parameters, it was collected water samples from the research wells in May 2017 and September 2016 to represent the wet and dry periods, respectively. In addition, rainwater was taken from the villages of Hacıaliler (YM-1), Alaşehir (YM-2), and Alhan (YM-3). It was ensured that the sampling was done correctly so that the water samples would accurately reflect the quality conditions at the points where they were taken.

As can be seen in Tables 3 and 4, the electrical conductivity (EC) and boron (B) values of some wells in the study area presented higher values than other wells. Electrical conductivity values of some water wells (SK-6 and SK-12) are much higher, especially those located in old lake sediments and near graben fault zones affected by geothermal systems. It was observed gas outlets opening near the fault zone in

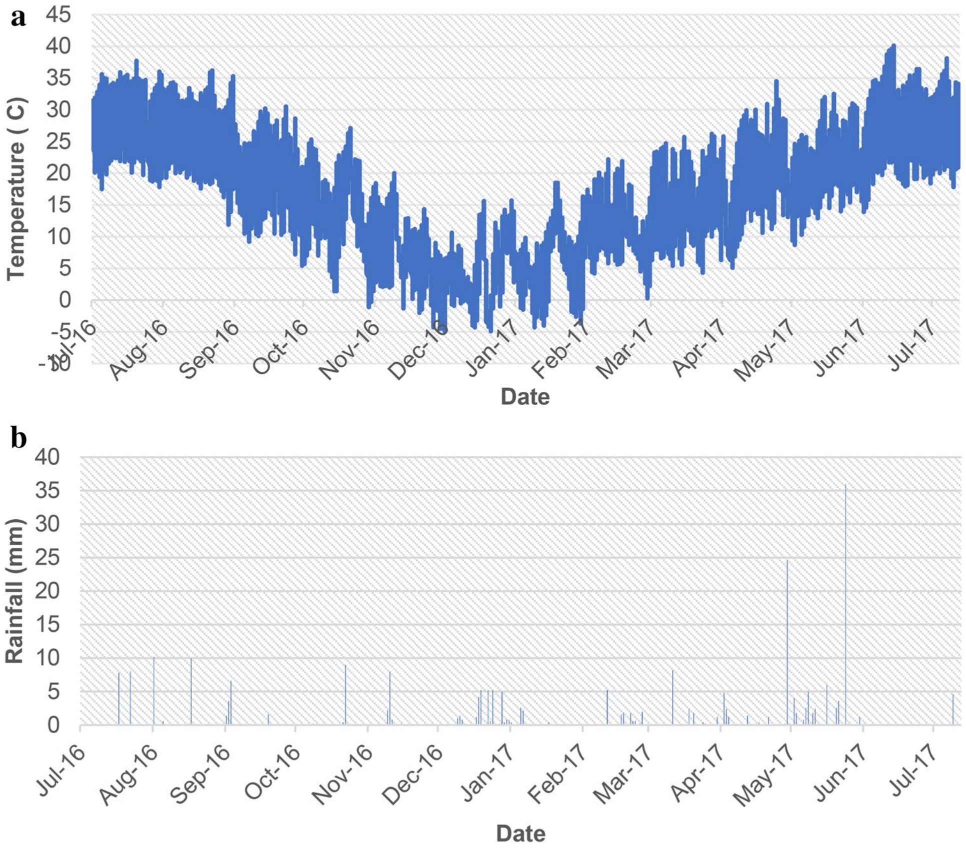


Fig. 9 Alhan (MT-2) weather station meteorological data **a** Daily temperature, **b** Rainfall change

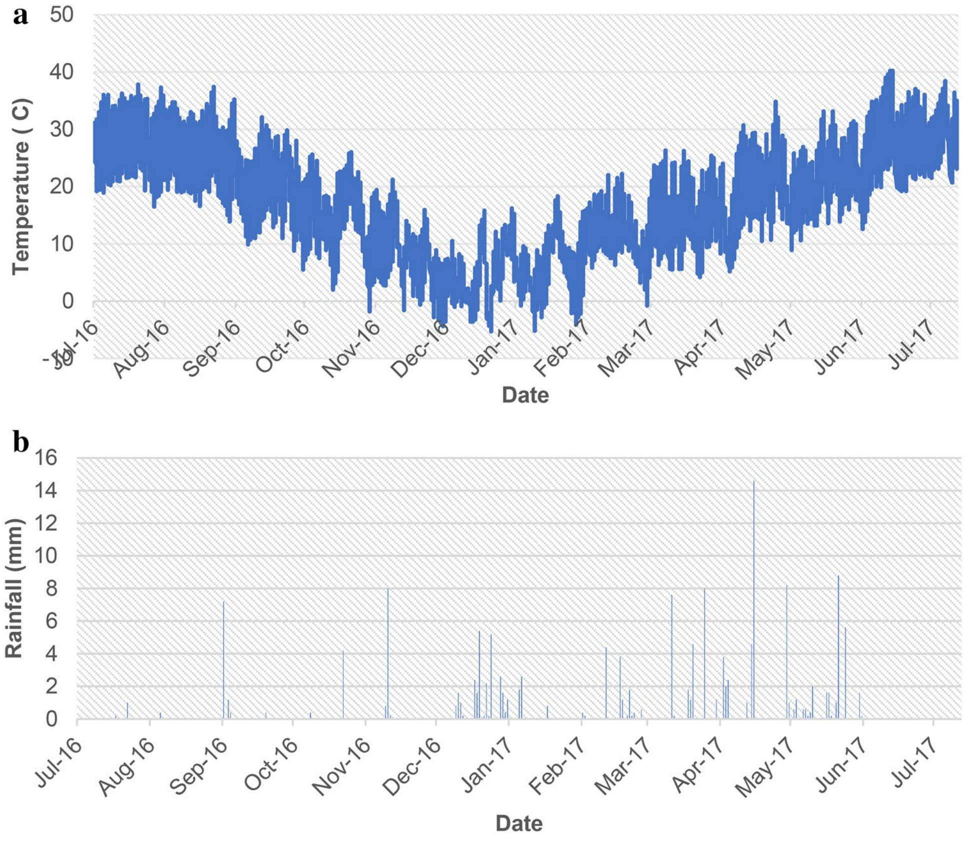


Fig. 10 Çavuşlar (MT-3) weather station meteorological data **a** Daily temperature, **b** Rainfall change

Table 2 Groundwater level measurements in the study area

Well ID	Water level (m)											
	January	February	March	April	May	June	July	August	September	October	November	December
SK-1	4.14	4.08	3.95	6.05	4.00	4.10	3.90	3.95	4.28	6.10	5.93	5.74
SK-2	2.23	2.09	2.06	2.24	2.23	2.57	2.70	2.57	2.58	2.57	2.55	2.38
SK-3	4.30	4.09	4.24	4.36	4.48	4.72	5.00	4.12	4.40	4.68	4.71	4.64
SK-4	35.12	34.89	38.58	33.74	31.40	41.99	35.43	36.23	36.35	36.28	36.04	40.99
SK-5	3.25	3.17	2.93	3.30	3.10	3.14	3.84	3.57	3.94	4.05	4.13	3.24
SK-6	2.81	2.80	2.78	2.75	2.80	2.74	2.66	2.80	2.83	2.91	2.97	2.85
SK-7	25.80	25.50	24.80	29.97	29.70	29.33	31.37	32.12	32.17	32.05	32.09	32.09
SK-8	3.78	3.76	3.73	3.70	3.37	3.57	4.20	4.42	4.54	4.40	4.28	4.28
SK-9	21.50	21.60	21.29	21.50	21.90	21.74	22.87	24.00	23.60	23.49	23.20	22.74
SK-10	27.52	26.45	23.50	19.15	27.90	29.57	32.78	32.40	31.67	31.04	30.46	29.38
SK-11	10.26	9.82	10.07	11.68	10.40	10.44	16.90	14.33	13.53	12.39	11.80	11.24
SK-12	10.34	9.60	9.17	9.15	10.50	9.70	10.23	10.61	10.60	10.58	10.39	10.27
SK-13	23.80	23.10	22.95	23.18	23.54	23.52	24.44	25.00	25.22	25.17	24.97	24.59
SK-14	25.80	25.52	25.29	25.80	26.79	26.22	28.60	28.09	28.18	28.10	27.85	25.36
SK-17	16.56	15.85	15.88	16.93	16.90	23.70	25.94	22.58	22.79	21.56	20.48	18.36
SK-18	37.85	37.79	37.83	37.88	34.48	32.75	33.47	33.58	33.64	33.69	33.01	32.47
SK-19	16.44	15.12	17.85	17.99	18.86	19.00	19.16	19.30	19.15	19.10	18.99	18.90
SK-20	19.82	19.01	18.90	18.78	18.40	18.42	18.87	19.00	19.11	19.05	19.14	19.04
SK-21	25.87	25.79	25.74	26.00	26.04	26.87	26.95	26.91	26.98	26.21	25.94	25.15
SK-22	32.44	31.89	31.84	32.10	32.14	32.70	32.78	32.81	32.88	31.04	30.91	30.55
SK-23	11.20	11.15	10.53	10.51	10.01	10.00	10.36	10.41	10.57	10.51	10.48	10.32

some wells (SK-6) that show different chemical characteristics in the alluvial aquifer. The boron content in groundwater is one of the most important pollutant markers originating from geothermal wells. For this purpose, boron distribution maps have been produced in the study area for wet and dry periods.

Alluvium aquifer recharge

The CMB was applied to calculate the recharge value in the alluvium aquifer. Groundwater recharging from rainfall occurs in different time periods depending on aquifer characterization. For this reason, it was determined the average chloride values of groundwater samples taken during the wet period and the groundwater recharge ratio. In the study area, 5 mg/l was used for rainwater chloride concentrations, which is the average of three rainwater samples taken during the wet period. According to this, for the rainfall rate of 457 mm/year measured from weather stations, the infiltration rate was 16.38%. The annual amount of recharge obtained for the study area is 74.84 mm.

The spatial distribution of chloride is presented in Figs. 11 and 12. High chloride values are mainly concentrated in the central and northern parts of the alluvial aquifer. As seen in the distribution map, this situation is also attributed to the recharge zone in the alluvial aquifer that is a permeable zone. When we look at the periodic concentration of chloride, the dry period average is higher than the wet period, as seen in Table 5. This is explained by the water–rock interaction. In addition, rainwater reaches the aquifer after a certain period of time. Therefore, the effect of recharge appears in the dry period (Fig. 13). There is a noticeable decrease in water levels with the start of irrigation in March and August.

It was created a chloride recharge distribution map to better interpret the amount of chloride recharge in the Alaşehir sub-basin (Fig. 14). In general, groundwater recharge is high in the southern part of the aquifer where the surface

Table 3 Chemical analysis results of groundwater and in the wet period

Well ID	pH	T (°C)	EC (µS/cm)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	SO_4^{2-} (mg/l)	HCO_3^-(mg/l)	CO_3^- (mg/l)	Cl^- (mg/l)	As (mg/l)	B (mg/l)	Br (mg/l)
SK1	7.5	19.30	329.00	56.7	10.71	13.91	3.8	36	115.9	*	10	0.007	0.023	0.02
SK2	6.6	19.40	1138.00	56.12	47.91	116.52	140.81	165	501.6	*	35	0.4376	0.884	0.117
SK3	7.0	19.00	1086.00	44.33	54.77	188.61	4.22	135	396.6	*	142	0.0573	0.751	0.664
SK4	7.5	19.30	1525.00	68.65	74.56	257.06	6.59	185	396.6	55.21	209	0.013	0.946	0.778
SK5	7.1	19.50	1961.00	73.84	47.09	543.43	14.05	41	1687	*	53	0.0448	6.43	0.27
SK6	6.5	22.20	4340.00	175.2	99	1231	154	4	4228	*	54.1	<3	21.948	*
SK7	7.5	24.00	571.00	49.75	18.83	78.02	2.62	41	184.3	56.41	17	0.011	0.114	0.068
SK8	7.2	22.30	1198.00	109.16	54.59	140.97	11.08	121	610.2	*	74	0.0156	4.776	0.165
SK9	6.9	24.80	770.00	77.35	54.14	54.38	7.22	68	293.5	40.21	15	0.0005	0.197	0.051
SK10	7.5	23.20	964.00	144.84	38.81	93.58	17.23	77	619.9	*	25	0.0024	3.104	0.086
SK11	6.5	21.50	1727.00	206.05	125.57	195.17	10.01	346	1022	*	105	0.0056	1.905	0.334
SK12	6.8	21.90	7910.00	581.8	1805	871	33	378	1233	*	250	<3	0.88	*
SK13	7.1	21.30	884.00	142.11	77.75	27.98	13.44	90	593.7	*	15	0.0021	0.054	0.031
SK14	7.9	21.60	972.00	66.46	62.3	109.52	7.87	222	247.1	37.21	92	0.0077	0.207	0.381
SK19	7.5	20.40	965.00	154.79	55.89	27.3	11.2	302	450.9	*	18	0.1565	0.04	0.047
SK20	7.0	23.10	881.00	44.28	82.38	85.53	16.67	149	330.1	55.81	33	0.0098	0.396	0.099

* equal to zero

Table 4 Chemical analysis results of groundwater and in the dry period

Well ID	pH	T (°C)	EC (µS/cm)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	SO_4^{2-} (mg/l)	HCO_3^- (mg/l)	CO_3^- (mg/l)	Cl^- (mg/l)	As (mg/l)	B (mg/l)	Br (mg/l)
SK1	7.6	21.10	672	92.92	21.34	35.73	18.93	114	320.9	*	25	0.0139	0.098	0.083
SK2	7.6	21.80	1265	67.17	53.5	125.87	163.95	202	435	42.01	43	0.4906	1.188	0.136
SK3	7.8	21.80	989	38.89	48.37	176.89	2.93	148	259.9	58.21	52	0.0567	0.679	0.159
SK4	7.7	26.40	1087	59.17	51.88	167.3	6.3	88	375.2	21	123	0.0053	0.576	0.497
SK5	7.4	21.50	1135	116.01	52.36	151	8.04	111	746.8	*	39	0.0077	1.788	0.234
SK6	7.2	25.10	4480	193.4	98	1226	154	3	4213	*	30	<3	22.529	*
SK7	7.8	22.90	517	56.14	17.02	74.51	2.52	37	295.3	18	12	0.0008	0.116	0.055
SK8	7.8	23.70	1063	100.17	51.55	139.95	10.49	134	413.7	55.81	54	0.0063	4.471	0.231
SK10	7.9	21.90	708	94.27	53.7	52.51	6.22	90	378.9	13.2	21	0.0022	0.262	0.062
SK11	7.3	21.40	2030	221.66	142.15	255.74	7.44	26	1732	*	58	0.0022	2.216	0.279
SK13	7.4	22.70	898	116.75	74.16	19.76	9.25	80	615	*	15	0.001	0.058	0.057
SK14	7.6	210	962	86.1	69.5	111.86	8.32	194	346.6	*	95	0.0114	0.234	0.391
SK19	7.6	21.20	951	192.66	60.59	27.82	11.4	306	439.3	*	16	0.8807	0.044	0.046
SK20	7.7	21.30	874	42	83.03	77.98	15.82	148	421	24	29	0.0075	0.412	0.093

* equal to zero

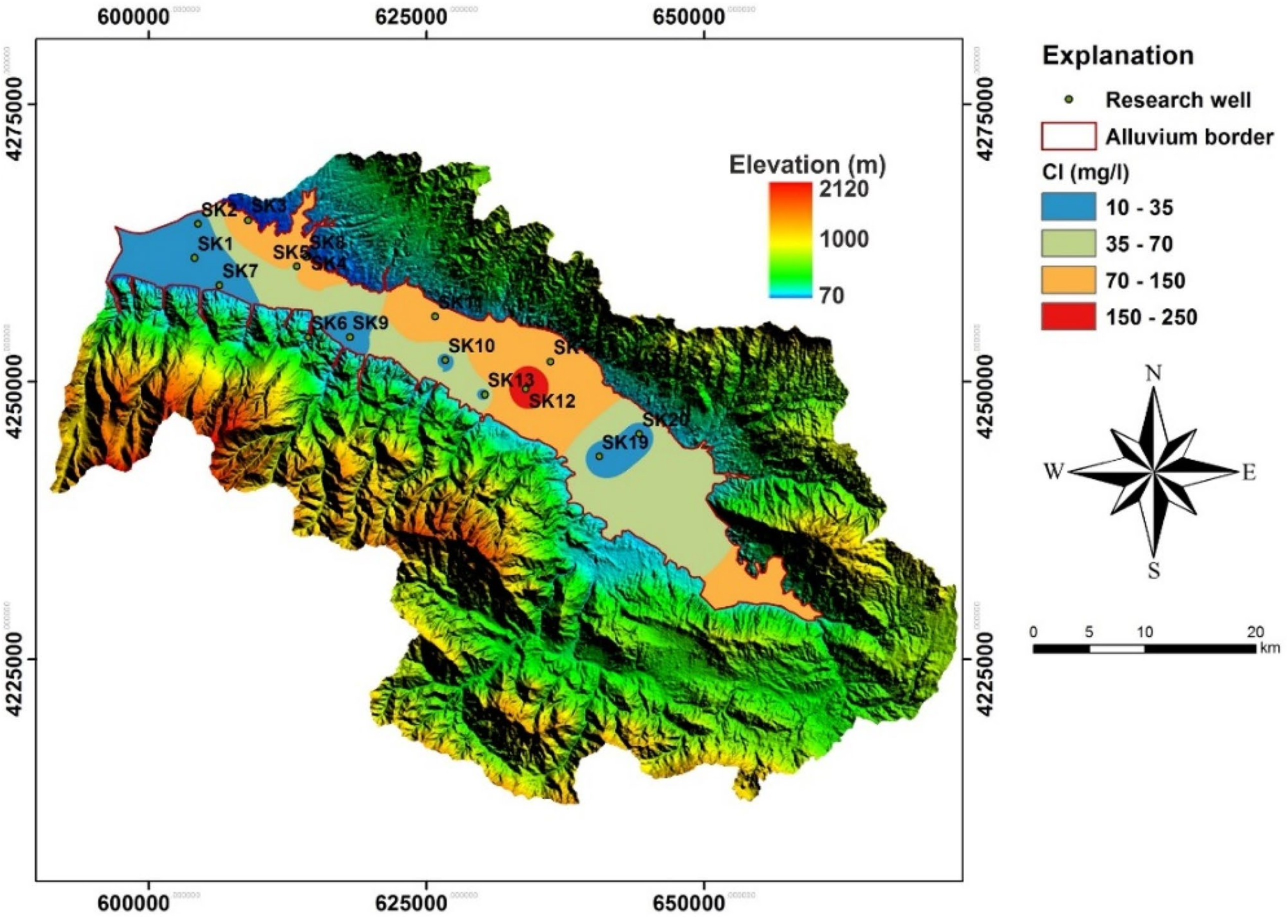


Fig. 11 Cl^- concentration map of wet period

drainage network is very dense. As seen in the chloride distribution map, recharge has increased in areas where chloride concentrations decrease. This implies that groundwater is recharged from the surface water coming from rainfall. Especially when some parts of the aquifer are covered by impermeable clays, the areas with stream beds constitute important recharge areas.

Groundwater and geothermal mixing mechanism

The distribution map of groundwater and geothermal wells available in the basin was established to interpret the mixing mechanism of groundwater and geothermal fluid in the study area. To determine the mixing mechanism of groundwater and geothermal fluid in the study area, we took the KLM-2 geothermal well in the same region as a reference well (Fig. 15).

The physical and chemical property of the KLM-2 geothermal well is presented in Table 6.

Boron is an important indicator and gives significant information about the mixing mechanism of geothermal fluid and groundwater. The Boron distribution maps show that SK6 has a high concentration in both periods (Figs. 16 and 17).

KLM-2, SK-1, SK-13, and SK-19 wells were mixed at 10%, 20%, 30%, 40%, and 50% in the AquaChem program to determine the mixing mechanism of the research wells and the geothermal system in the study area. We chose the SK-1, SK-13, and SK-19 wells because their low EC, temperature, and boron values during wet and dry periods meant that they were unlikely to be affected by the geothermal fluid in the area. The results of the obtained geothermal mixture ratio are presented in Fig. 18.

According to the results, the boron values of the SK6 well affected by the geothermal fluid in the study area overlap in

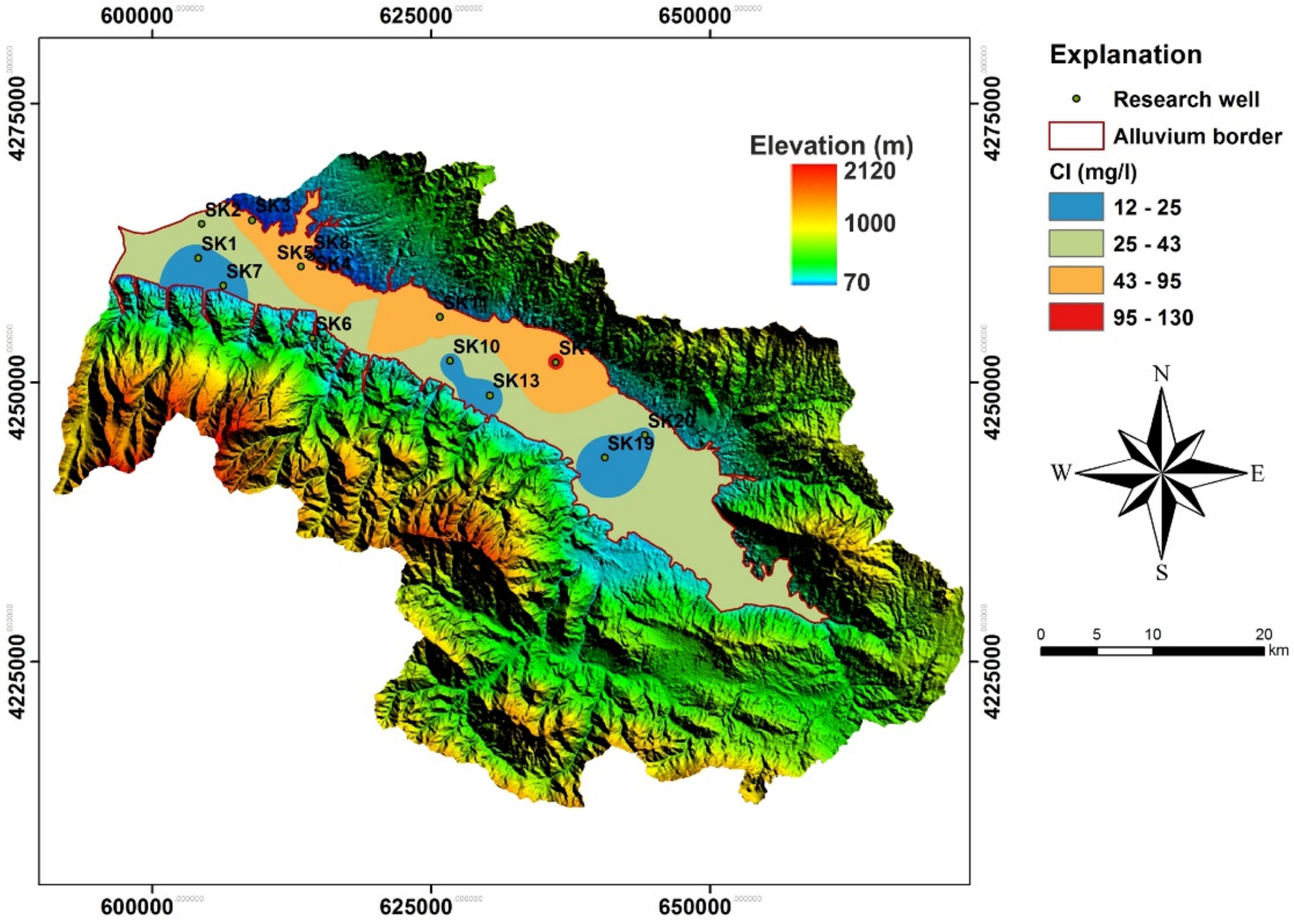


Fig. 12 Cl^- concentration map of dry period

the boron graphs for mixture ratios. High boron values in SK-6 in the wet and the dry periods suggest that the geothermal system affected this well. When calculating mixing ratios, we considered the water chemistry of the SK-1 and SK-6, SK-13, and SK-19 wells during the wet period since there is a lot of water circulation in this period.

According to Fig. 18, a mixture was found as 17% depending on the Boron in the SK-6 well.

Rapid methods are needed to determine the groundwater recharge rates for decreasing groundwater potential in semi-arid climatic zones. For alluvium aquifers in typical graben areas in the Aegean Region, 16.38% of the precipitation was obtained according to the chloride mass equation with the wells data drilled for this purpose. Based on the results of this application, the CMB was found to be fairly good and most suitable for short time groundwater recharge estimation for the unconfined aquifer. However, since the chloride concentration can be exposed to pollutants as in the Alaşehir sub-basin, special attention should be given to its natural origin. It should be taken into account that the monitoring wells should be drilled to the points away from the pollutants in the area to be studied, and the recharge rate will give more accurate results. The results obtained were compared with the results of some researchers who applied the CMB in basins under pollutant effect as in the Alaşehir sub-basin, and similar relations were obtained (Wu et al. 2016; Huang et al. 2017; Al-Tamimi 2018; Crosbie et al. 2018; Gebru and Tesfahunegn 2019).

Table 5 Chloride concentration results of groundwater and rainwater in wet and dry period

Well ID	Coordinate			Chloride concentration (mg/l)					
	x	y	z	Wet period	Dry period	Wet period recharge (mm/year)	Dry period recharge (mm/year)	Mean Cl⁻ concentration (mg/l)	Aquifer recharge (mm/year)
SK-1	604,121	4,261,160	88	10	25	228.50	91.40	17.50	130.57
SK-2	604,422	4,264,194	101	35	43	65.29	53.14	39.00	58.59
SK-3	608,939	4,264,553	97	142	52	16.09	43.94	97.00	23.56
SK-4	614,316	4,261,311	121	209	123	10.93	18.58	166.00	13.77
SK-5	613,324	4,260,377	105	53	39	43.11	58.59	46.00	49.67
SK-6	614,345	4,253,994	211	54.1	30	42.24	76.17	42.05	54.34
SK-7	606,376	4,258,683	131	17	12	134.41	190.42	14.50	157.59
SK-8	614,192	4,261,269	115	74	54	30.88	42.31	64.00	35.70
SK-9	618,086	4,254,018	143	15	*	152.33	–	15.00	152.33
SK-10	626,711	4,251,955	148	25	21	91.40	108.81	23.00	99.35
SK-11	625,770	4,255,886	125	105	58	21.76	39.40	81.50	28.04
SK-12	633,947	4,249,342	143	250	*	9.14	–	250.00	9.14
SK-13	630,254	4,248,858	101	15	15	152.33	152.33	15.00	152.33
SK-14	636,158	4,251,807	148	92	95	24.84	24.05	93.50	24.44
SK-19	640,552	4,243,264	170	18	16	126.94	142.81	17.00	134.41
SK-20	644,149	4,245,284	170	33	29	69.24	78.79	31.00	73.71
YM-1	642,329	4,237,596	211	3					
YM-2	632,502	4,246,286	170	5					
YM-3	623,921	4,251,566	166	6					
		Mean		71.69	43.71	76.22	80.05		74.84

* equal to zero

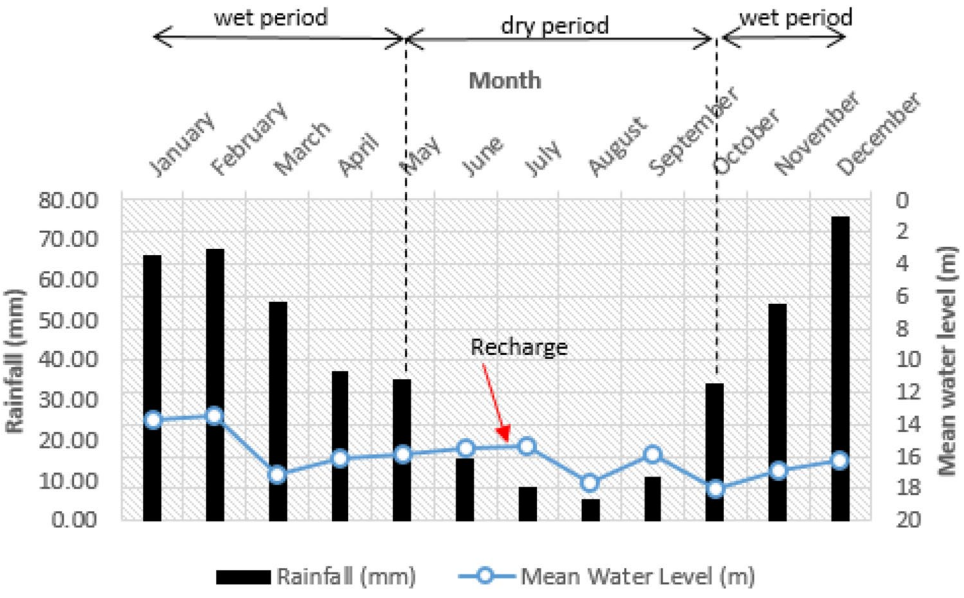


Fig. 13 Seasonal mean water levels due to rainfall

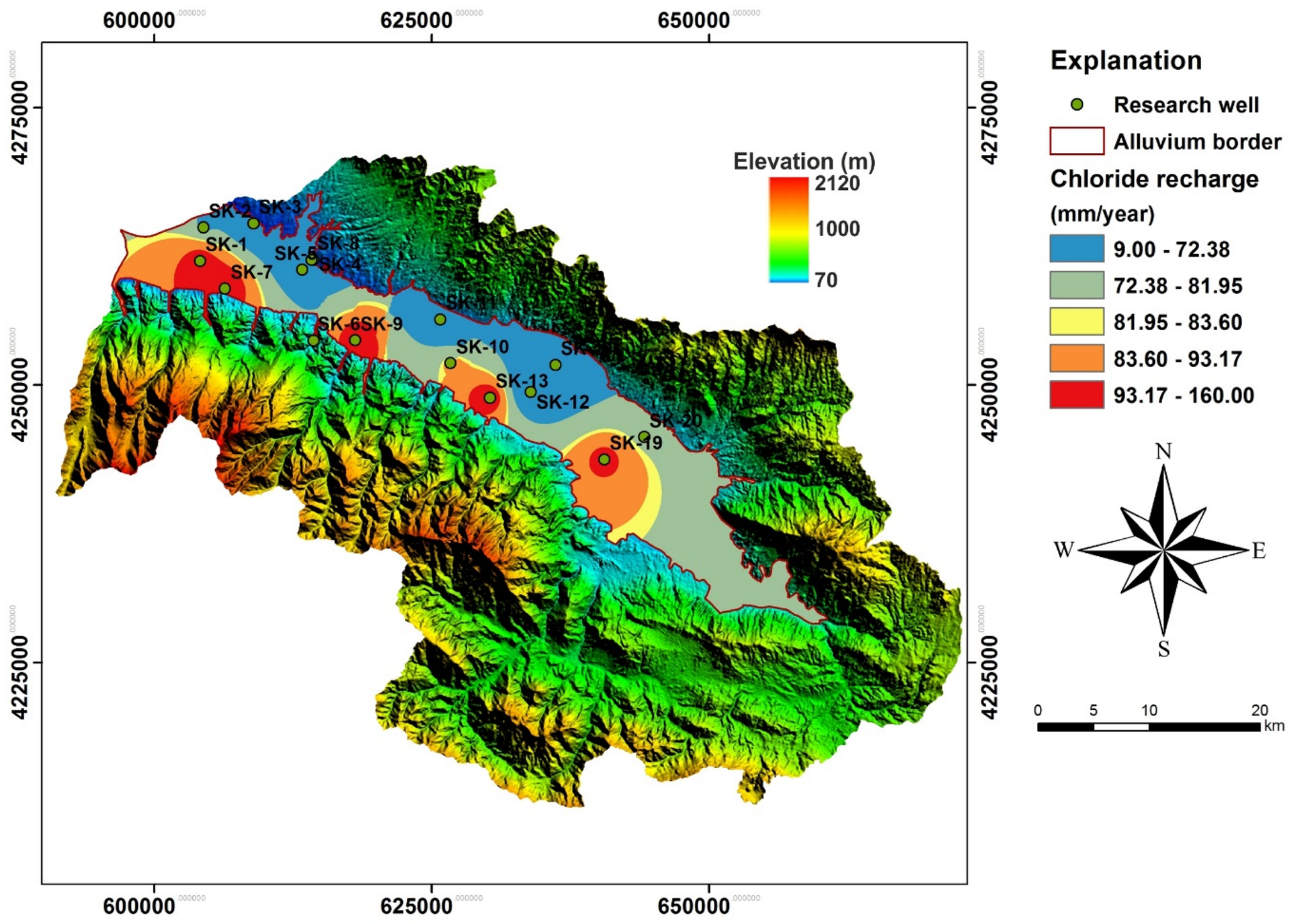


Fig. 14 Chloride recharge distribution map for the Alaşehir sub-basin

Conclusions

Increasing climate change and global warming have become important problems in groundwater basins in recent years. Therefore, the importance of groundwater recharge and its applicability in basins are important for the protection of water resources. This study presents a detailed hydrogeochemical characterization and determination of groundwater recharge estimation using the CMB for the alluvial aquifer in the Alasehir sub-basin, which is an important groundwater supply in the Aegean region. The CMB is applied quickly and economically in groundwater recharge studies. This method is suitable for studying alluvium and karstic aquifers since they are unconfined aquifers that react quickly to precipitation. The CMB is a very applicable tool to determine groundwater recharge from precipitation. It is found that the CMB is very easy and economically toll to determine the groundwater recharge in the semi-arid region from the precipitation. Several monitoring wells were drilled in the basin to determine the hydrogeochemical properties of the groundwater resources and groundwater recharge estimation using the chemical data. Based on the hydrogeochemical investigations, it is found that deep water circulation originating due to geothermal waters flow out along the fault zone. According to the CMB, groundwater recharge for the alluvial aquifer ranged between 13.77 mm and 157.59 mm

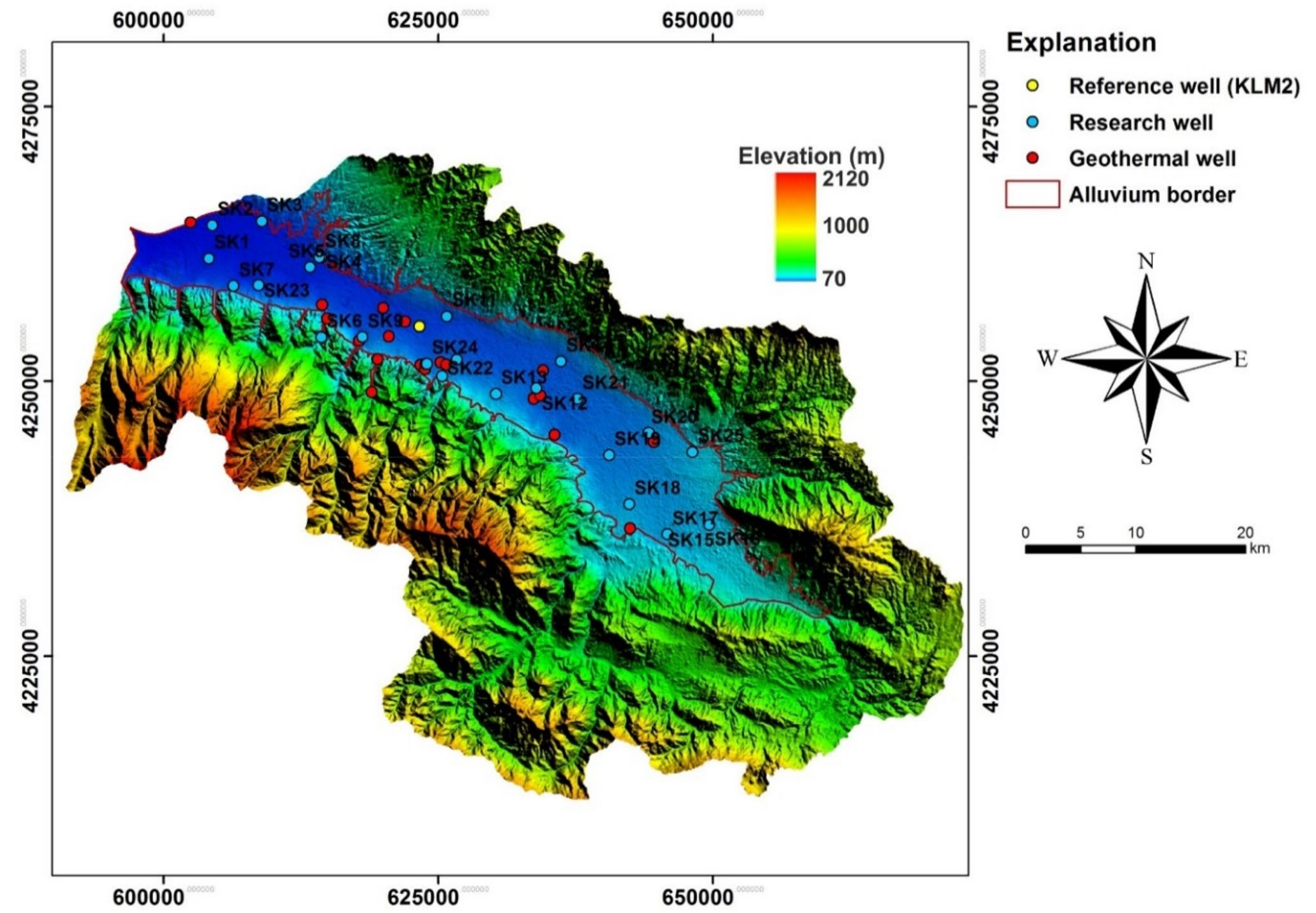


Fig. 15 Research wells, geothermal wells belonging to private companies in the Alaşehir sub-basin and location map of reference geothermal well

Table 6 The physical and chemical properties of KLM2 geothermal well (Rabet et al. 2017)

Parameter	Value
pH	8.72
T (°C)	100
EC (μS/cm)	2860
Ca^{2+} (mg/l)	7.2
Mg^{2+} (mg/l)	1
Na^{+} (mg/l)	1006
K^{+} (mg/l)	53
SO_4^{2-} (mg/l)	52
HCO_3^{-} (mg/l)	1450.46
CO_3^{-}(mg/l)	54.12
Cl^{-} (mg/l)	1747.82
B (mg/l)	127.62

with a mean value of 74.84 mm. For annual precipitation of 457 mm, the groundwater recharged from rainfall was 16.38%. However, the CMB gives more reliable aquifers in which recharge are entirely from precipitation, without pollutant. For this purpose, it was determined whether the groundwater-geothermal mixing has a pollutant effect on the alluvial aquifer in the Alaşehir sub-basin. The boron concentration is used to determine the mixing condition in the west of the study area along the fault zone. Boron is an important indicator and gives significant information about the mixing mechanism of geothermal fluid and groundwater. The boron concentration in geothermal water is 127 mg/L and the highest concentration in the Alaşehir sub-basin. The geothermal well KLM-2 boron concentration was mixed with SK-1, SK-13, and SK-19 sampling water at 10%, 20%,

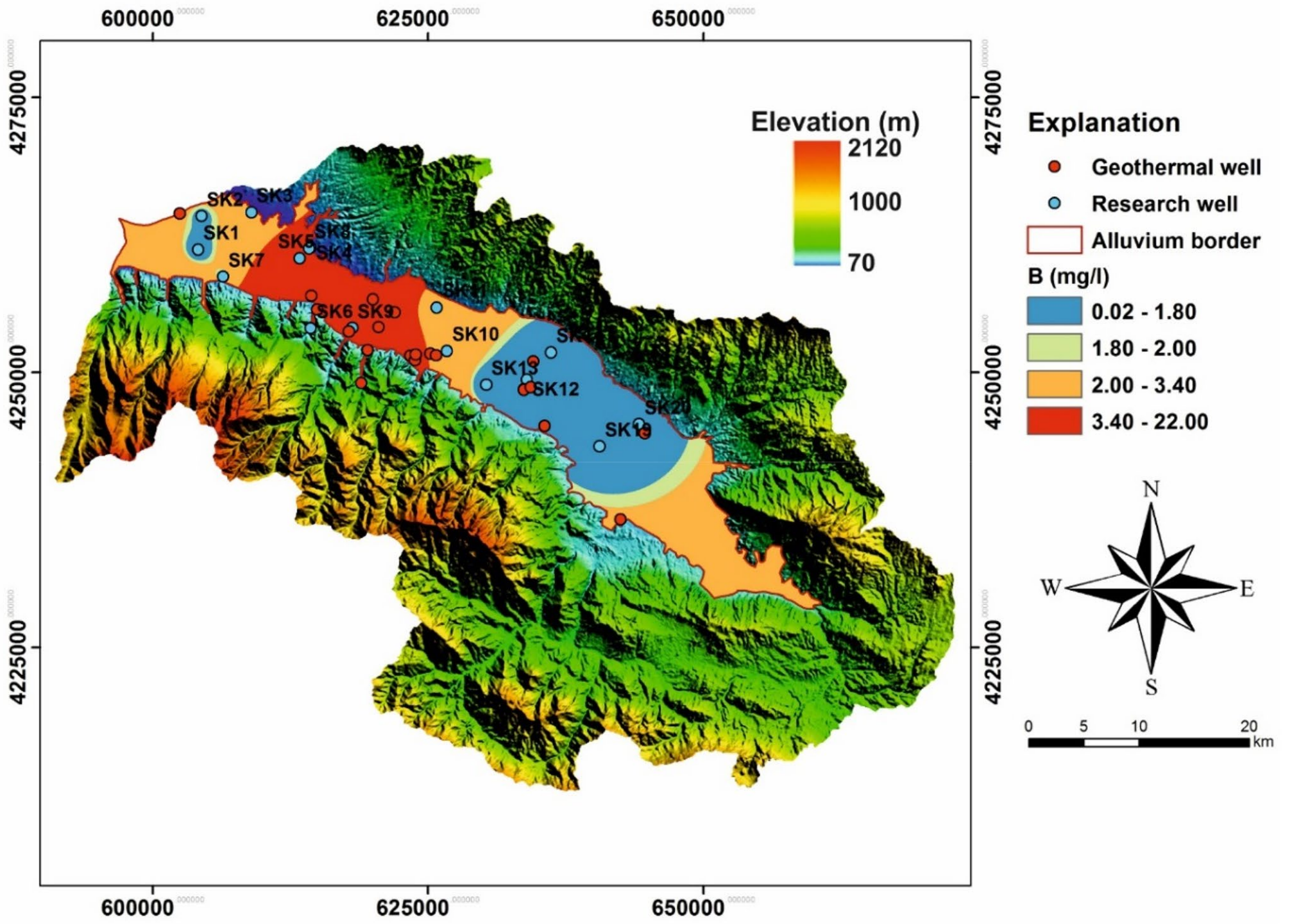


Fig. 16 Boron distribution map for wet period

30%, 40% and 50% in the AquaChem program to determine the mixing mechanism of the research wells and the geothermal system in the study area. We found that geothermal fluid in the Alaşehir sub-basin mixed with groundwater at a rate of 17%. This means that deep geothermal water mixed the groundwater along the fault zone that causes both groundwater recharge and thermal pollution in the Alasehir plain. Based on the results of this application, the CMB was found to be fairly good and mostly suitable for short time groundwater recharge estimation for the unconfined aquifer. However, since the chloride concentration can be exposed to pollutants, special attention should be given to its natural origin. It should be taken into account that the monitoring wells should be drilled to the points away from the pollutants in the area to be studied, and the recharge rate will give more accurate results. Thereof, according to the groundwater and geothermal mixing mechanism, we concluded that the CMB

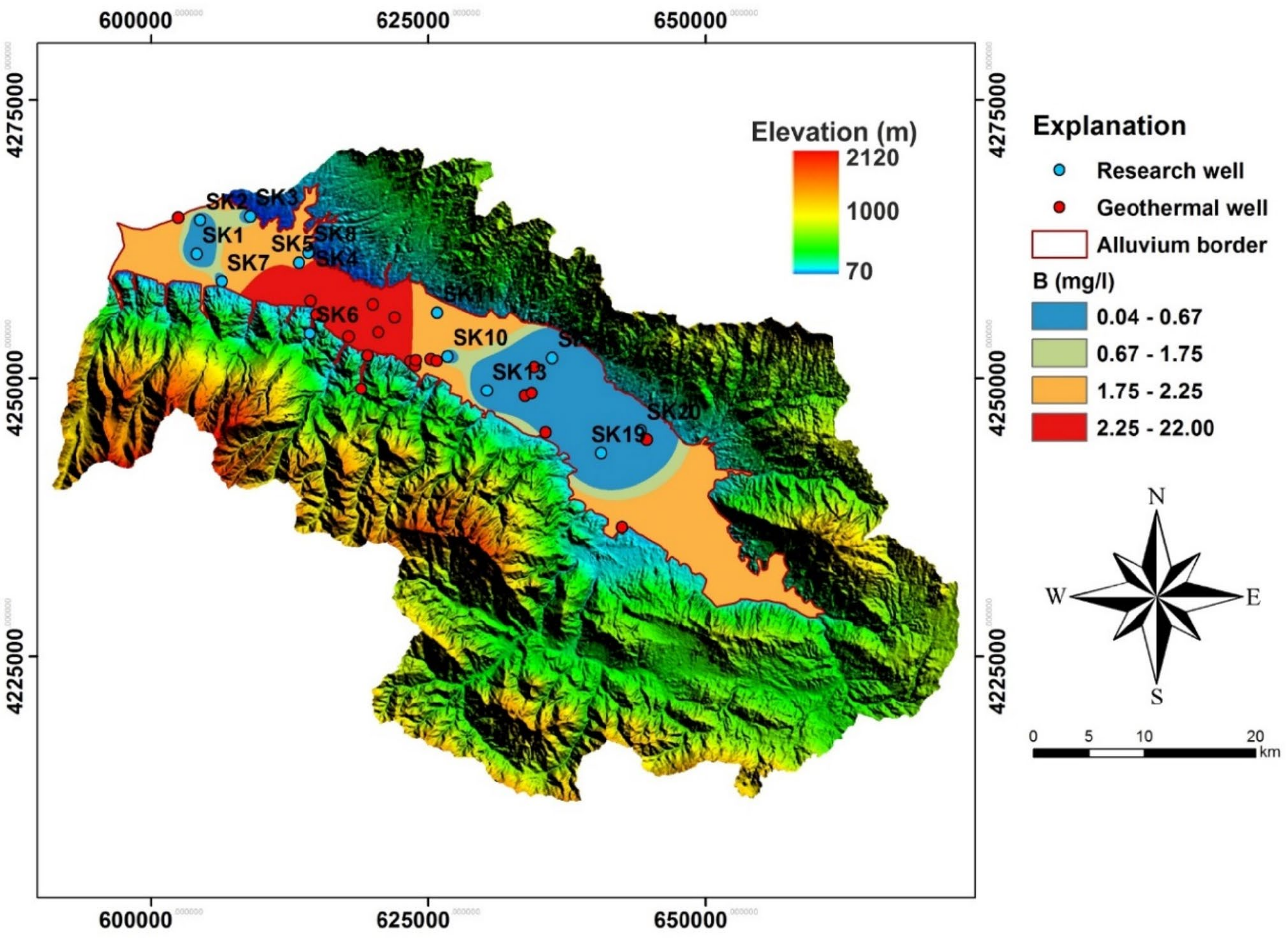


Fig. 17 Boron distribution map for dry period

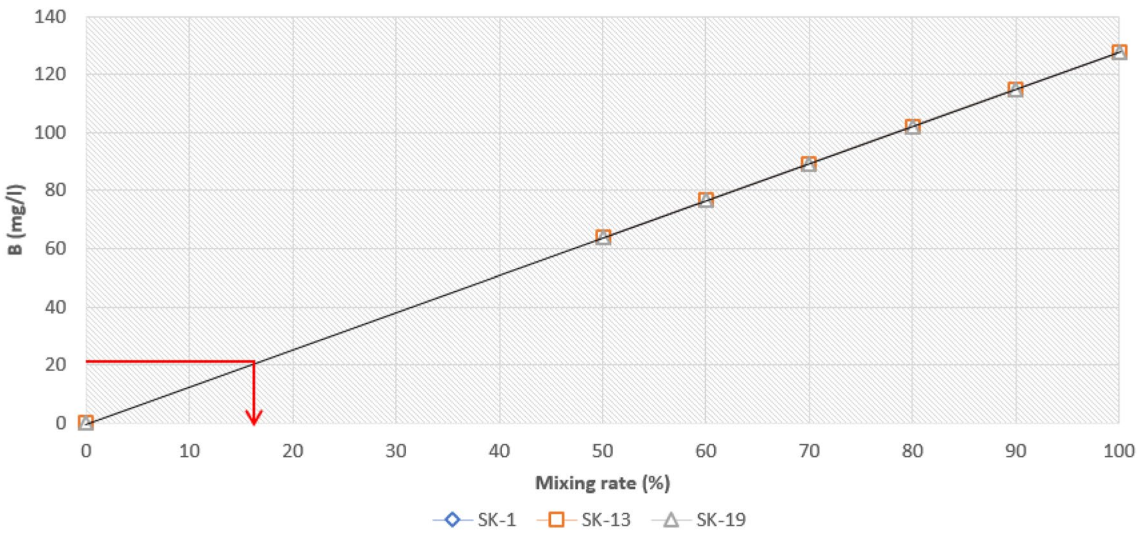


Fig. 18 Geothermal well mix ratio according to Boron in SK6 well

applied to groundwater recharge prediction in the Alaşehir basin did not yield reliable results.

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