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REVIEW PAPER

Estimation groundwater total recharge and discharge using GIS-integrated water level fluctuation method: a case study from the Alaşehir alluvial aquifer Western Anatolia, Turkey

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Abstract
The estimation of groundwater recharge is an essential process for hydrogeological study. Realistic determination approach is crucial for assessing groundwater potential in an aquifer system and estimating of groundwater levels and/or changes in dry periods. Based on these matters, we employ a GIS-integrated groundwater level fluctuation method to determine the groundwater recharge for a hydrological period in the Alaşehir alluvial aquifer (W. Anatolia). The method basically takes into account both increasing and decreasing of the groundwater levels due to the recharge and discharge mechanisms in the aquifer. In this study, 16 pumping and monitoring wells were drilled with a total depth of 1300 m, and water level data loggers were installed into the monitoring wells to determine the groundwater level changes. The spatial distribution of the monthly groundwater level change map was multiplied by the aquifer storage distribution map and then the accurate water volume is calculated by using the 3-D spatial analysis. According to our evaluation in the aquifer, positive volume change of the groundwater is 187 hm^3 in a year, which is considered as a recharge value of groundwater. It is concluded that the GIS-integrated water table fluctuation method gave rise to estimate the total recharge amount of the groundwater in the Alaşehir aquifer. The total groundwater recharge indicates that total inflow in the aquifer from precipitation, leakage from surface water and irrigation waters. It can be stated that the recharge estimation of groundwater in a surficial aquifer, like the Alaşehir aquifer, is fairly easy using the GIS-integrated water table fluctuation method.

Keywords Groundwater recharge · Groundwater level fluctuation method · Alluvial aquifer · Groundwater budget

Introduction

The climate change affects the water resources in the whole world. Therefore, the groundwater has become the most important in the semiarid regions (Holman 2006). It is a vital source of global water demand and provides drinking water usage (Milhalm et al. 2009; Raneesh and Santosh 2013). In many regions of the Western Anatolia (Turkey), the groundwater levels' decrease with its potential issues become an important challenge due to overexploitation of the aquifers and as well as the climate change (Gündüz and Şimşek 2011). In the last decade, the detailed hydrogeological and water management projects were conducted to protect the groundwater potential in large river basins in Turkey (GDWM 2017). One of the main phenomena of the hydrogeological study is to determine the groundwater recharge and discharge ratio for the estimation of groundwater budget in the related regions. The indirect groundwater

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recharge methods are most likely preferred instead of detailed reachable sources for the estimation of the groundwater budget (GDHW 2014). Groundwater levels along the Western Anatolia indicate relevant risks in quantity and quality due to the use of the indirect recharge estimation methods or by the use of the global recharge ratio. In order to accurately estimate the groundwater budget, the aquifer-based groundwater recharge studies are needed to be established. Especially, in alluvial aquifers, where big amount of the groundwater discharges from the aquifer systems, it is crucial to evaluate the accurate amount of the recharge rates in the supplying aquifers.

The groundwater recharge is generally described as the infiltration of water (rainfall, surface water, snow, etc.) from ground surface to groundwater table in an aquifer system. The recharge mechanism depends on various geological and hydrogeological parameters, and therefore, determining the groundwater recharge is one of the robust processes in hydrological studies. To groundwater potential in an aquifer system, the groundwater recharge ratio is an important parameter for the hydrogeological analysis. In general, many of recharge estimation methods are used to estimate the recharge ratio, such as the groundwater level fluctuating, the water balance, the groundwater chloride mass balance, the soil moisture, and the tracing methods based on available hydrological and aquifer characteristic data (Lerner et al. 1990; Scanlon et al. 2002; Leaney et al. 2011).

There are several methods reported in the literature for estimation of natural and artificial recharge in an aquifer. The available data can eventually be correlated to the groundwater level data collected from a surface aquifer in an alluvial plain for the water budget estimations. It is known that precipitation is directly influential in groundwater levels for surficial alluvial systems. While this is a direct hydrological consequence of infiltration, it may likely be affected by external stimuli such as groundwater production from wells drilled in the surface aquifer (Fıstıkoğlu et al. 2016). The groundwater level fluctuating method (GWLFM) is commonly used to estimate the groundwater recharge in the aquifers (Healy, 2010; Healy and Cook 2002). The GWLFM is only applicable to the unconfined aquifers, since the recharge water arrives at the water table and raises the water level. In order to apply this method, monitoring of water levels in one or more wells and estimation of specific yield are required (Şimşek et al. 2019).

Alluvial aquifers, as a geological unit, are widely observed in most of the groundwater sites in Turkey. In general, major aquifer sites are located in the grabens of the Western Anatolia (Fig. 1), where tectonic activity is commonly observed. Generally, the most important aquifers are located in the graben areas in the Aegean region due to the deposition of alluvial units. An alluvial aquifer comprises significant amount of groundwater as well as bearing a rapid responding to the groundwater recharge from the precipitation. The relationship between recharge and discharge mechanism in alluvial aquifers is quite dynamic, and water level fluctuations in these systems demonstrate cycles not longer than one season (Gündüz and Şimşek 2011). Based on these fundamentals, this study focuses on the Alaşehir alluvial aquifer that is located in Gediz River Basin in the Western part of İzmir, Turkey.

At spatial scales of catchments affected with tectonic activity, it cannot be ruled out that the potential influence of regional groundwater flows across adjacent watersheds on recharge. This influence has been conceptualized and documented recently by Pacheco (2015). This long-term groundwater transference across catchment boundaries, usually related with flows in large-scale tectonic structures, can greatly influence water budgets.

It is commonly accepted that the groundwater recharge estimation depends on numerous factors including the aquifer parameters, such as specific yield and the number of monitoring wells representing the area of the aquifer. For an effective and sustainable water potential estimate in an aquifer, spatial interpolation technique is needed to obtain high-resolution estimates of spatially variable data collected at discrete locations with a traceable accuracy. Based on these parameters mentioned above, a GIS-integrated technique by using the monthly groundwater level fluctuation method is selected to estimate the groundwater recharge and discharge ratio in the Alaşehir alluvial aquifer. The groundwater level data were collected from 16 pumping and monitoring wells. In this study, the data collected from 16 pumping and monitoring wells with a total depth of 1300 m and water level data loggers were presented in the following sections. All the collected data with the integration of the GIS platform for the estimation of the groundwater budget concluded with the groundwater recharge maps. In addition to that, the details of the methodology were linked for the ease of the total discharge and recharge analyses, and they were interpreted for future researches.

The main objectives of this study are: (1) to estimate total groundwater recharge and discharge in an aquifer by using the GIS platform; (2) to provide spatial distributions of changes of the groundwater levels on maps as 3-D raster models; and (3) to interpret the resultant hydro-geological maps and models to obtain geo-information about the study area.

Study area

This case study subjecting the estimation of the groundwater recharge by using the GIS-integrated water level fluctuation

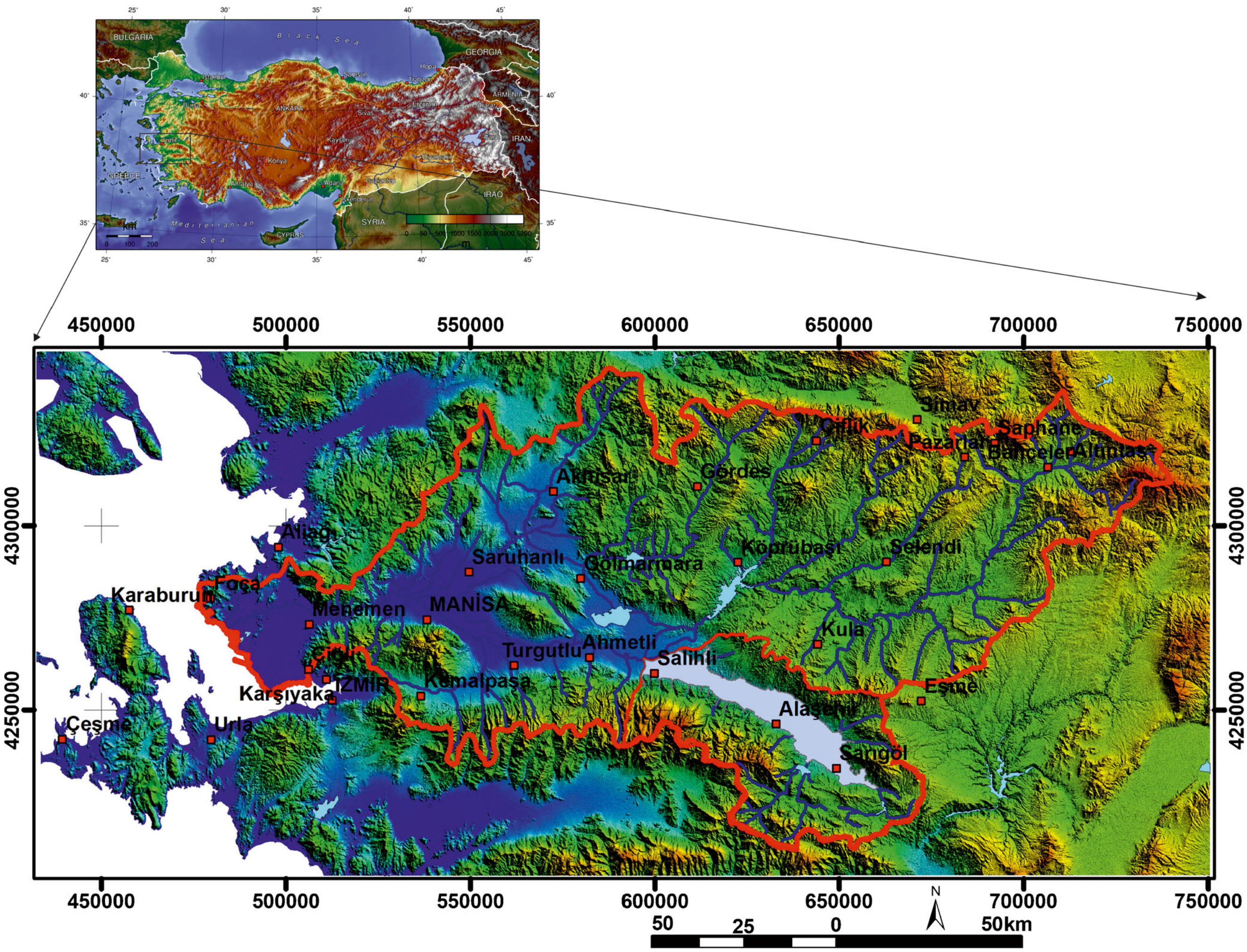

Fig. 1 Location map of the study area

method took place in the Alaşehir Basin at the Southwest of Gediz River Basin in the Western Anatolia (Fig. 1). In the study area, meteorological data set concludes that watershed receives an average total precipitation of 439 mm annually, and the highest monthly precipitation is an average of 249 mm in January. In addition to that, average maximum and minimum temperature values are 28 °C in July and 6.1 °C in January (Rabet et al. 2017). These data indicate that the climate of the study area is characterized by a typical Mediterranean climate with hot/dry summers and warm/rainy winters. However, it is also noted that the Aegean region in Turkey is likely affected by the global climate change trends associated with increases in the frequency and intensity of droughts and hot weather conditions (Lelieveld et al. 2012). Therefore, annual precipitation is expected to decrease in Western Turkey according to the previous research (Kukul et al. 2007). The study area presents clear precipitation decreasing trend during the research time, based on the three meteorological stations installed. In the study area, it was noted that especially the rainfall rate of the year 2016 was higher than in the year 2017 (Fig. 2). The continuation of the rainfall over the research area was reported during March–July 2017, and the heaviest rainfalls occurred in January 2017.

Geological and hydrogeological properties of the Alaşehir Basin

The Alaşehir Basin was located in the Menderes Massif, which was geologically well-reported. The detailed geology of the Alaşehir Basin is widely subjected and researched in terms of stratigraphy, tectonic evolution, and geochronology (Seyitoğlu et al., 2002). The Alaşehir Basin is mainly made up of metamorphic rocks named as the Menderes Massif. From bottom to the top: (i) Paleozoic gneiss, schists, and marble associations,

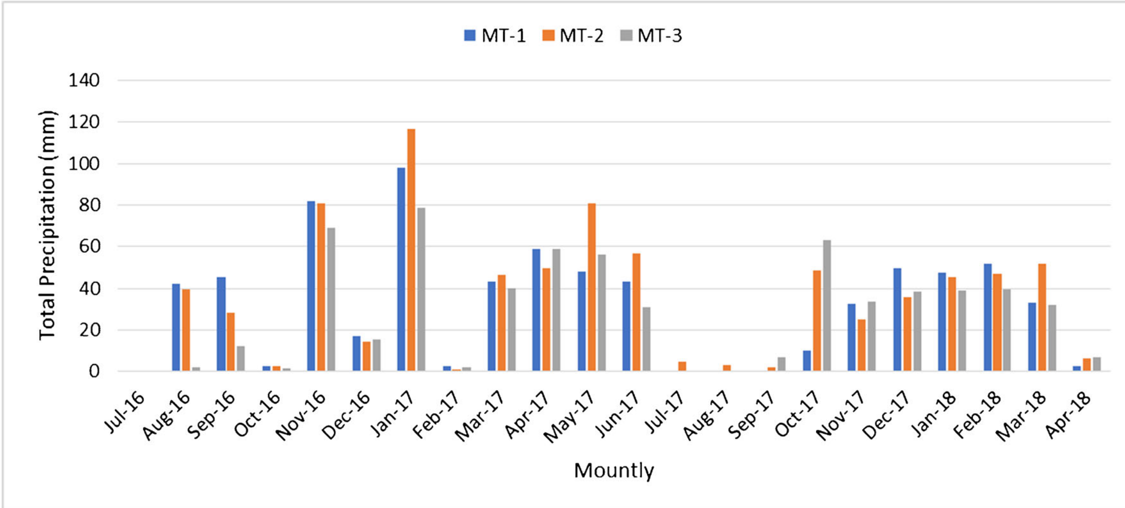

Fig. 2 Monthly total precipitation in the study area

(ii) Neogene terrestrial sediments, and (iii) Quaternary deposits (Fig. 3). General consensus of the Menderes Massif evolution is based on the core complex model, where footwall is made up of high-grade metamorphic rocks (gneiss, schist, and marble) and hanging wall is defined as Miocene to Quaternary units with syntectonic Miocene-aged granites (Baba and Sözbilir 2012, and references therein). The Neogene associations are mainly composed of sandstone, conglomerate, claystone, limestone, and volcanic intercalations (Erdoğan Rabet et al. 2017). At the upper parts of the succession, Quaternary-aged unconsolidated sediments cover the basement units with unconformity along the Alaşehir Basin (Fig. 3). This alluvial material consists of mostly clayey sands with gravel, and the thickness of these unconsolidated sediments reaches up to 250 m in the study area.

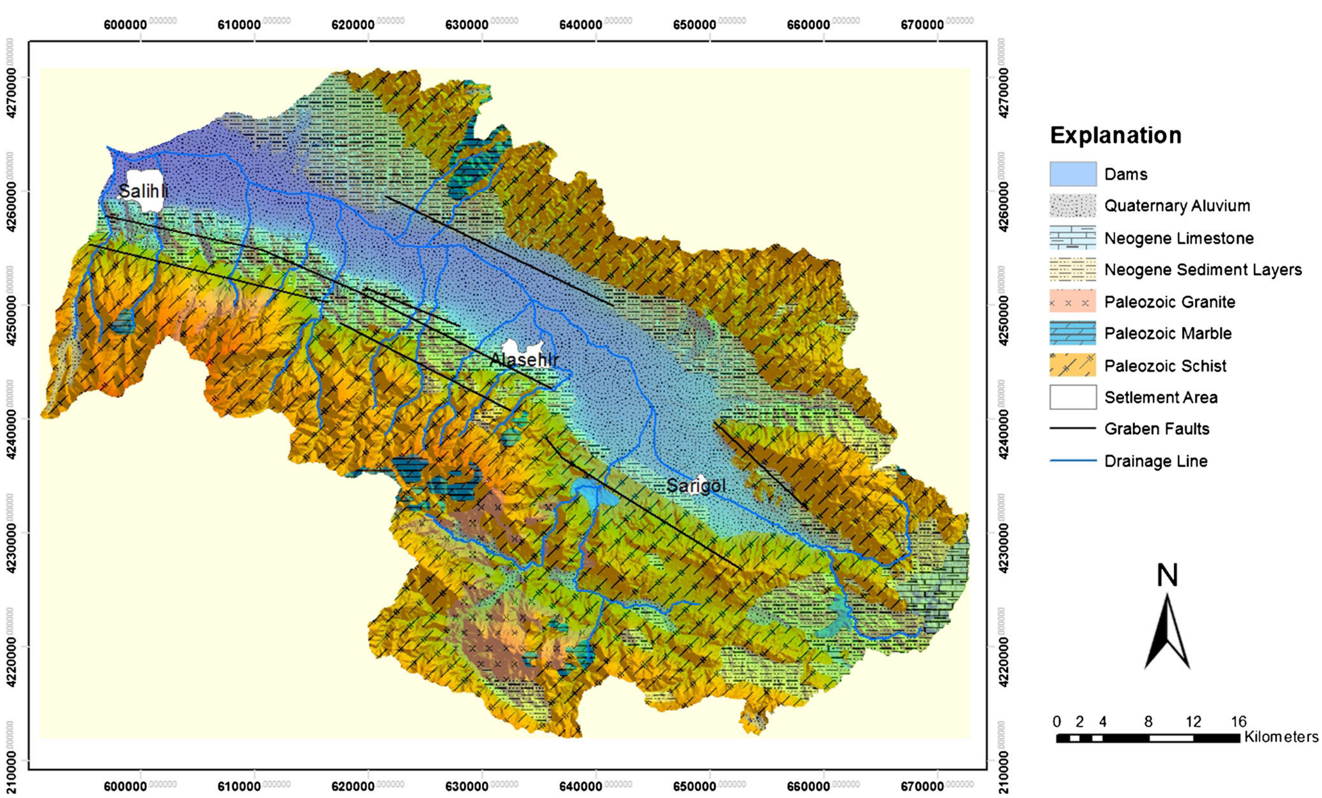

Fig. 3 Geological map of the Alaşehir Basin

The aquifer characteristics observed in the Alaşehir Basin is mainly heterogenic in terms of sediment ingredients. Sub-consolidated parts are mainly basement rock fragments from the basement rocks. Unconsolidated parts are composed of granular grains such as sands and silt. The aquifer nature of the Alaşehir Basin displays semi-confined to unconfined features in places. The Neogene sediments reported in the basin consists of sandy clayey beddings with low permeability. The alluvial succession, where the main aquifer is linked here, displays 120 to 250 m in depth according to the deep wells in the study area. The discharge rate of the groundwater produced in these wells ranges from 5.0 to 30 L/s (Özen et al. 2010). The general flow direction in the alluvial aquifer system is from the Southeast to the Northwest in the study area.

In this paper, the long-term water level data from the Badinca well, which has been monitored by The State Hydraulics Works (DSI) since 2013 in the Alaşehir alluvial aquifer, is used to understand the general features of the water level in the aquifer system. According to that, the groundwater level displays a negative trend from 2013 and fluctuates seasonally. Moreover, the level of the groundwater annually drops about 1 m due to the overexploiting from the aquifer system. The data from the Badinca well also indicates that water temperature decreases during the discharging period, whereas it increases in the recharging period and remains stable at 22 °C (Fig. 4). All the data, mentioned above, gave rise to monitor that the fluctuation in the groundwater level is quite dynamic, and rapid response to the precipitation in the water level fluctuations is recorded in the alluvial aquifer system.

Methodology

The groundwater recharge and discharge ratio were estimated for the Alaşehir alluvial aquifer by applying the GIS-integrated groundwater level change method. In order to monitor the groundwater level and determine the aquifer storage, 16 monitoring wells were drilled in the research area of the aquifer. In addition to that, pumping tests were carried out within the drilled wells in order to understand the spatial distribution of the groundwater levels and storage of the unconfined aquifer. The field pumping tests were performed for 8 monitoring wells in the study area. The depths of the pumping wells were on the average of 100 m, and the diameter was 22 cm. The monitoring well with the diameter of 10 cm was drilled next to each pumping well for monitoring the drawdown of water level during the pumping test (Fig. 5). At least 5 L/s flow rate pump was used for the pumping test, and a 12-h test, considered as short-term, was performed in this study. Due to the dynamic water level reaching the steady-state condition in the monitoring well, the pumping duration was performed here for 12 h. In addition, the previous pumping test results employed by GDHW (2014) were used, and an aquifer hydraulic parameter data set was created (Table 2).

The drawdown of the water level was recorded every 5 s by the water table data logger installed in the monitoring and pumping wells. The monthly water levels are presented in Table 1. About 20 groundwater data loggers were installed in the monitoring wells to record the water level changes, as well as the level measurements were manually made every month during a hydrological period (1 year). The pumping test data were evaluated in the aquifer test program by using the Jacob Cooper and Thiem methods and the hydraulic parameters of largely unconfined aquifer in the study area (Cooper and Jacob 1946; Kruseman and de Ridder 1994).

In general, the Neumann method is used for unconfined aquifer that is homogeneous, isotropic, that the pumping well is fully penetrating, and that pump discharge is constant (Neumann 1972; Woodworth 2011). The hydraulic parameter results and the statistical overview of the alluvial aquifer taken from GDHW (2014) and pumping test results are presented in Table 2.

The water table fluctuation method was used to estimate the groundwater recharge for one hydrological year. The basic assumption of water fluctuation method is that the rise in the groundwater table in an unconfined aquifer is due to the recharge water arriving at the water table (Healy and Cook 2002). Groundwater recharge is calculated by Eq. (1):

$$R = S_y \frac{\Delta h}{\Delta t} \tag{1}$$

where, R is the groundwater recharge (L/T), S_y is the specific yield or aquifer storage, Δh is the rise in the water Table (L), and Δt is the rise time (T), which is a month in this study. Thus, R was computed for each month.

The evaluation method (Eq. 1) is compatible to the shallow water tables that display sharp water level rises and declines. Basically, recharge rates vary substantially within a basin, related to the elevation changes, geology, land surface slope, vegetation, and other factors. Related monitoring wells need to be located where the monitored water levels are representative of the whole catchment. Other complications exposed here are related to identifying the causes of the water level fluctuations and calculating a value for specific yield. Specific yield is treated as a storage term, independent of time, which in theory accounts for the instantaneous release of water from storage (Healy and Cook 2002).

Although this method is generally used by the change of one or several well level data for the groundwater recharge estimation, 16 monitoring wells data were used to determine the groundwater recharge using the spatial distribution maps of water levels in this study. In addition, aquifer storage was calculated using the aquifer test program, and the storage distribution map was generated for the estimation of the recharge

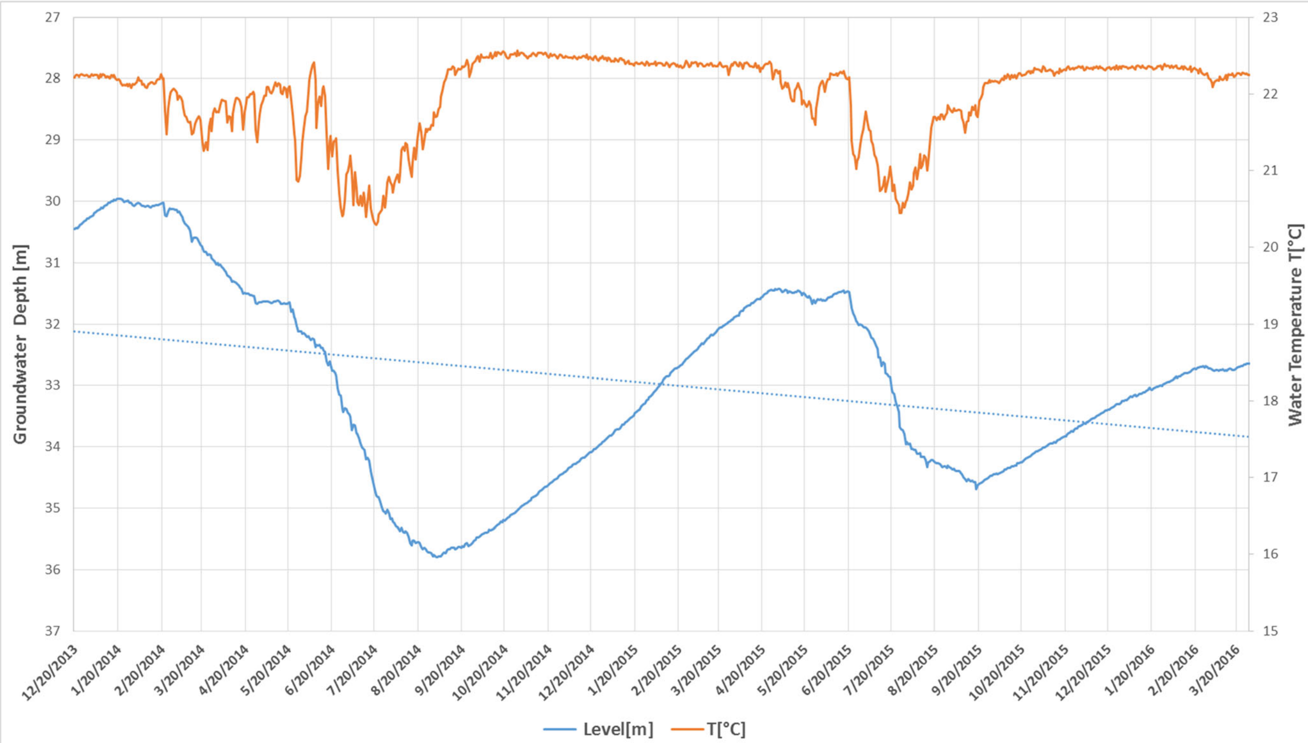

Fig. 4 Groundwater level changes in the alluvial aquifer in a long time period

in the alluvial aquifer. In this study, the level rise was determined and compared to the previous month (30 days), and the total volumetric change was determined by using the monthly groundwater maps in a hydrological year.

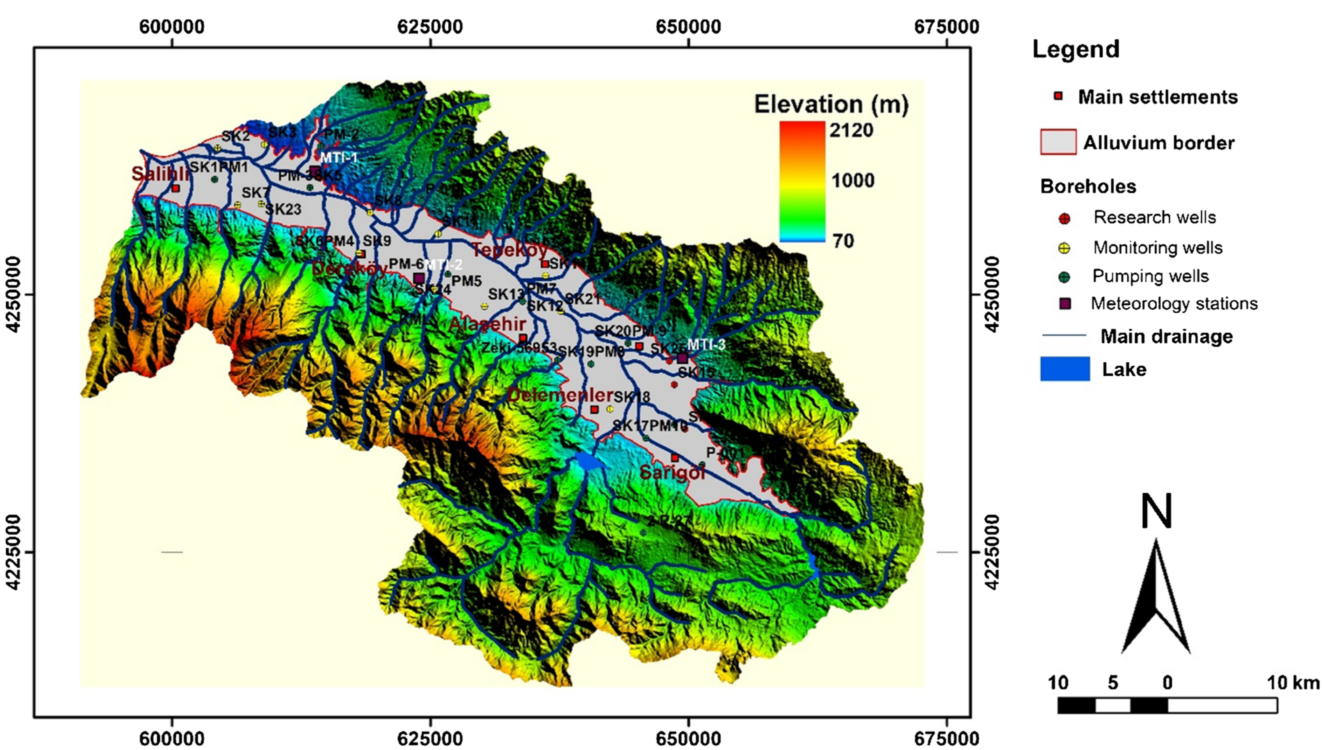

Fig. 5 Location map of the pumping and monitoring wells in the Alaşehir Basin

Table 1 Annual water levels in the monitoring and pumping wells

Well no	X	Y	Z (m)	Well depth (m)	Jan-17 (m)	Feb-17 (m)	Mar-17 (m)	Apr-17 (m)	May-17 (m)	Jun-17 (m)	Jul-17 (m)	Aug-17 (m)	Sep-17 (m)	Oct-17 (m)	Nov-17 (m)	Dec-17 (m)	Jan-18 (m)
SK2	604,422	4,264,190	87.00	30	84.77	84.91	84.94	84.76	84.77	84.43	84.30	84.43	84.42	84.43	84.45	84.62	83.71
SK3	608,939	4,264,550	95.00	40	90.70	90.91	90.76	90.64	90.52	90.28	90.00	90.88	90.60	90.32	90.29	90.36	90.25
SK7	605,760	4,258,440	131.29	50	105.49	105.79	106.49	101.32	101.59	101.96	99.92	99.17	99.12	99.24	99.20	99.20	99.41
SK8	619,179	4,257,930	109.96	41	106.18	106.20	106.23	106.26	106.59	106.39	105.76	105.54	105.42	105.56	105.68	105.68	105.86
SK9	618,086	4,254,020	135.27	46.5	113.77	113.67	113.98	113.77	113.37	113.53	112.40	111.27	111.67	111.78	112.07	112.53	112.83
SK11	625,770	4,255,890	119.96	50	109.70	110.14	109.89	108.28	109.56	109.52	103.06	105.63	106.43	107.57	108.16	108.72	109.12
SK13	630,254	4,248,860	101.00	50	77.20	77.80	78.05	77.82	77.46	77.48	76.56	76.00	75.78	75.83	76.03	76.41	76.52
SK14	636,158	4,251,807	148.00	50	122.20	122.48	122.71	122.20	121.21	121.78	119.40	119.91	119.82	119.90	120.15	122.64	122.88
PM-1	604,153	4,261,160	91.79	70	87.65	85.81	85.71	85.74	85.59	85.46	84.46	87.84	84.66	85.00	84.99	85.41	85.40
PM-3	613,351	4,260,370	96.57	100	93.37	93.40	93.64	93.27	93.47	93.43	92.73	96.57	96.58	96.56	96.55	96.40	97.48
PM-5	626,709	4,251,960	143.07	100	116.77	116.62	117.11	113.78	115.17	115.17	107.76	110.01	110.82	111.98	112.55	113.69	114.25
PM-6	623,982	4,251,770	150.96	100	117.93	117.91	118.41	118.01	117.62	118.03	114.40	112.56	113.31	114.21	114.68	115.49	116.08
PM-7	633,948	4,249,360	140.00	100	120.50	122.48	119.04	120.85	120.30	118.50	116.95	116.17	116.14	117.46	119.32	121.03	120.61
PM-8	640,552	4,243,260	159.00	100	142.56	143.88	141.15	139.97	142.20	140.00	132.80	136.80	136.17	140.70	141.49	142.04	140.92
PM-9	644,149	4,245,280	166.60	100	146.78	147.00	146.70	148.04	148.20	148.18	147.73	147.60	147.10	147.41	147.46	147.56	147.40
PM-10	645,856	4,236,080	181.00	100	164.35	165.15	165.12	164.07	164.90	157.30	155.06	158.42	158.68	159.44	160.52	162.64	162.13

Table 2 Statistics of the aquifer parameters

Hydraulic parameters	Transmissivity (m^2/d)	Hydraulic conductivity (m/d)	Specific capacity (L/s/m)	Aquifer storage
	(n = 66)	(n = 66)	(n = 66)	(n = 12)
Min	7.31	0.02	0.0859	0.0004
Max	5694	46.00	26.43	0.342
Mean	782.03	9.05	4.30	0.0702

After obtaining data from the monitoring wells for one hydrological period, the data was evaluated in the GIS platform. For the GIS platform, the locations of the wells were determined by hand-held GPS X, Y coordinates with an accuracy of ±3 m, and their attributes were collected. All the spatial information and the attribute data were imported into the GIS platform and geo-referenced (geo-registered) in WGS84 datum, UTM projection, and 35 N zone. After geo-referencing, the spatial distributions of monthly groundwater levels according to the well data and the border of the alluvial layer in the Alaşehir Basin were determined using the surface interpolation technique with a grid cell size of 30 m for all raster image maps. Next, the groundwater level differences between two successive months were computed, and their volumes above and below the reference plane heights, which is assigned to zero, were computed using the 3-D spatial analysis tool in the GIS platform. Also, the aquifer storage map (S) was computed beforehand. Finally, the groundwater recharges were computed according to the change in the volumes, which were found by multiplying the groundwater level changes by the aquifer storage map. These results were combined and overlaid with the other auxiliary GIS data for analysis and visualization such as DEM, settlement locations, wells, and etc. The generated maps and raster models illustrating the groundwater levels and volumes were employed for the analyses and interpretation. The milestone of the GIS assessment method was given in Fig. 6.

Provided groundwater recharge and aquifer hydraulic parameter values (see Table 2) were transferred into the GIS platform; grid files were created for each parameter within the domain of the alluvial aquifer using the inverse distance weighted (IDW) interpolation technique. First, the spatial distributions of these recharge monthly groundwater level and aquifer storage parameters were assessed. The parameter grids were then transformed into index grids using a computer program developed for this study.

Method results and discussion

Test results performed using the GIS-integrated groundwater level change method by taking into account of the aquifer hydraulic parameters and the spatial distribution maps of the aquifer storage (S) and hydraulic conductivity (K) were presented in Figs. 7 and 8. Regarded wells were drilled representing site to obtain a homogeneous distribution within the alluvial aquifer. In Fig. 7, the aquifer storage values vary from 0.0004 to 0.35 with a mean value of 0.07. According to the aquifer storage changes demonstrated in Fig. 7, when recharge potential is considered, the Northwest part of the study area displays higher water storage in contrast to the other parts of the study area.

The transmissivity value evaluated from the basin ranges from 7.31 to 5694 m^2/d. On the other hand, the hydraulic conductivity (K) alternates from 0.02 to 46 m/d (Table 2). Around Dereköy and Delemenler villages, where alluvial fans with gravel to sand bearings are observed, are likely the most permeable part of the study area according to Fig. 8. Moreover, the specific capacity in the basin is ranging from 0.0859 L/s/m to 26.43 L/s/m, especially in the Northwestern part of the alluvial aquifer. The hydraulic parameters clearly indicate that the Northwestern part of the aquifer, along the alluvium fans, is more permeable than other parts of the basin (Fig. 8).

The spatial distributions of groundwater level maps for 12 mounts were employed by using monthly level data as given in Table 1. To present as an example for a 12- month variation, the groundwater level map was prepared for January 2017 in Fig. 9. According to this figure, the general groundwater flow direction in January was observed is from the Southeast to the Northwest and parallel to the Alaşehir Creek. The groundwater level occurs higher in the Southeast and along the Northwest site of the plain (Fig. 9). The groundwater level variation, depending on the seasonal change, is in agreement with the general consensus that high levels are observed during the highest precipitation period and the contrary conditions occur during the summer season. The drought conditions give rise to discharge of large amount of groundwater due to the irrigation purposes in the basin. Therefore, the groundwater level dramatically decreases between May and September.

Monthly groundwater level change maps were prepared after the 12-month groundwater level distribution maps were generated in the study area. The aim of this procedure was to determine the increase and decrease of the groundwater level between the successive months in the GIS platform, as shown in Fig. 10. The groundwater level increase in the map (Fig. 10) is displayed as (+), and decrease level is shown as (−) in comparison with the previous month. By employing this

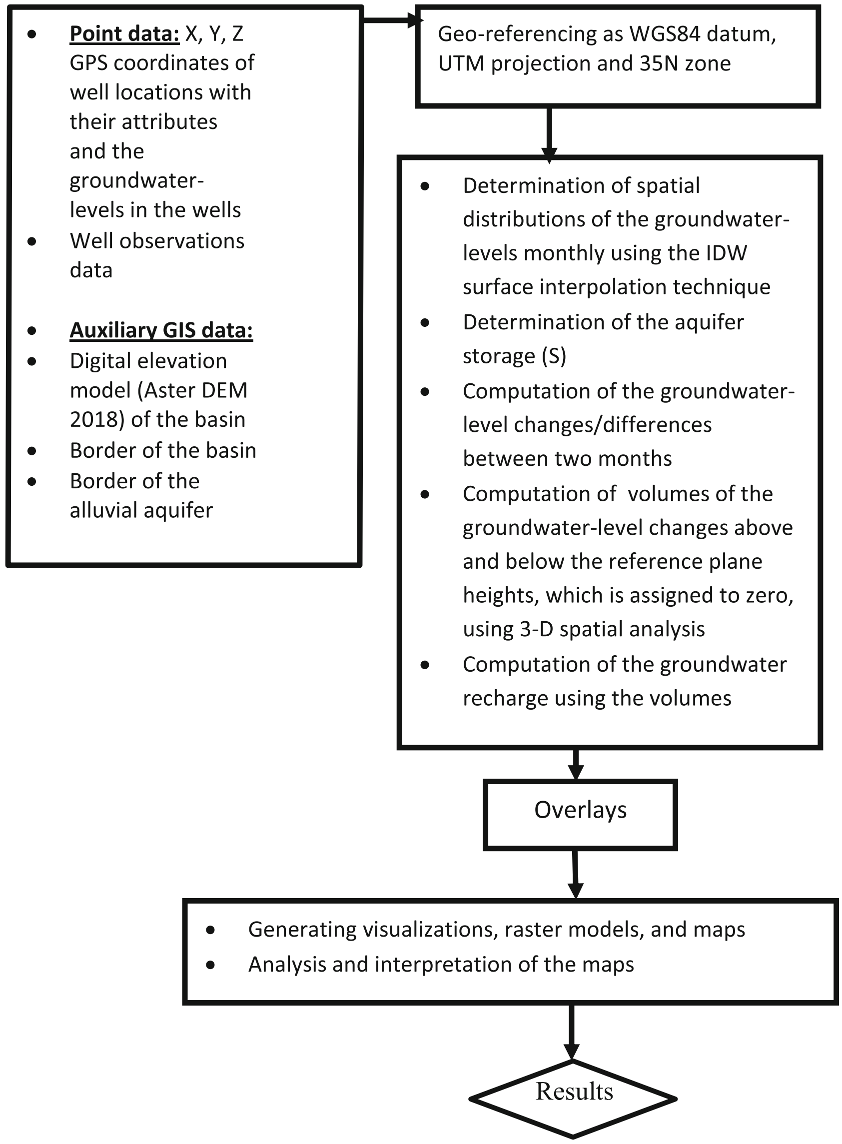

Fig. 6 Methodology steps in the GIS-integrated assessment method

application, the total groundwater level changes in the aquifer system were annually estimated. According to this data set, the water levels range from 0.5 to 1.56 m in January and February, and the positive trend of the water table is observed in the Southeast of the alluvial aquifer. However, depending on the rainfall decrease between March and May in the basin, the groundwater level decreased, with respect to the shortage of rain, in most part of the alluvial aquifer (Fig. 10). Within this period, the groundwater level increased in a local site known as middle of alluvial aquifer due to the groundwater level interaction between the surface water and/or aquifer lithology. However, after July, the groundwater levels displayed a negative trend related to the dry season period and resulted in the groundwater discharge from the aquifer for irrigation purposes. Moreover, pumping of the 90% groundwater during dry periods contributes to this fact mentioned above. Increase of the groundwater level at the end of the dry season was reported in the Western part of the alluvial plain, where relatively permeable zone exists in the study area.

Estimation of the total recharge and discharge

As to the final phase of the method, each groundwater difference map, which was accepted as a 30-day level change, was multiplied by the storage distribution map in the GIS platform. After this operation, monthly net volume changes were calculated. The positive volume change, based on the zero reference level, represents the groundwater total recharge. This total recharge is meant a raise in the groundwater level due to recharge (infiltration from the precipitation, surface drainage layers, as well as the boundary of the lateral alluvial layer) arriving at the water table. The total discharge, including discharge from the aquifer (irrigation and drinking purposes) and natural groundwater flow in the aquifer system, refers to the

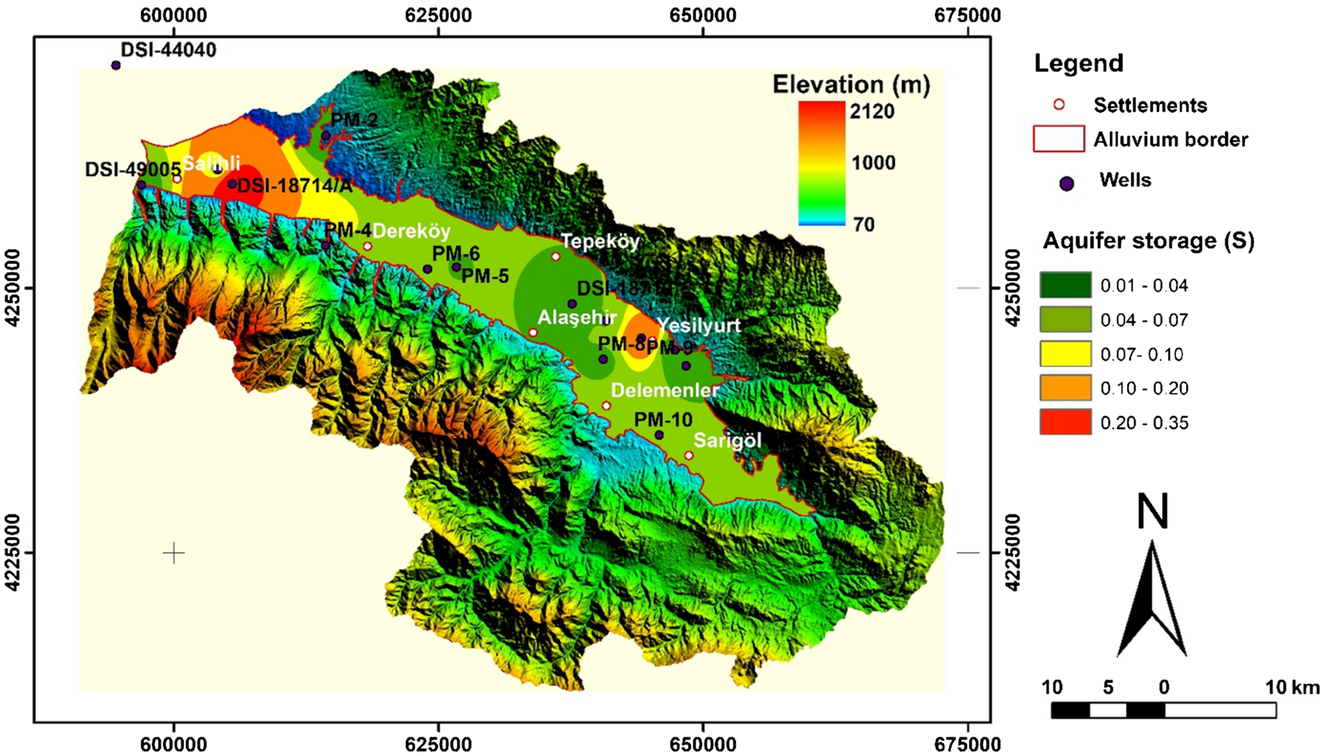

Fig. 7 Spatial distribution map of the storage parameter for alluvial aquifer

decrease in groundwater level according to zero reference level. With respect to estimating the groundwater budget for the aquifer, the recharge and discharge volumes in a hydrological period are determined easily.

The groundwater volume changes were calculated monthly using the 3-D spatial analysis tool. Monthly groundwater volume changes are given in Table 3. Total increasing volume due to the rise in the water table ranged from 0.00 to 83.50 hm^3, and the

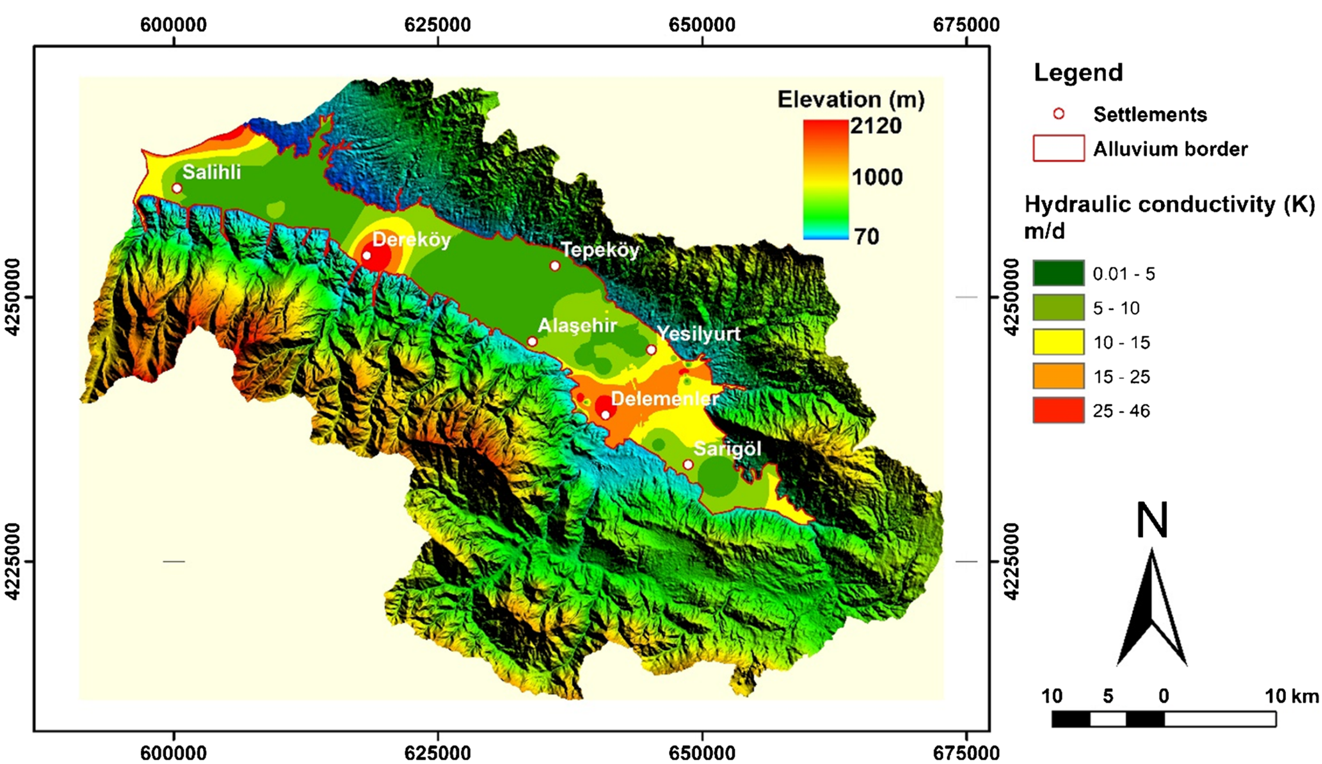

Fig. 8 Spatial distribution map of the hydraulic conductivity for alluvial aquifer

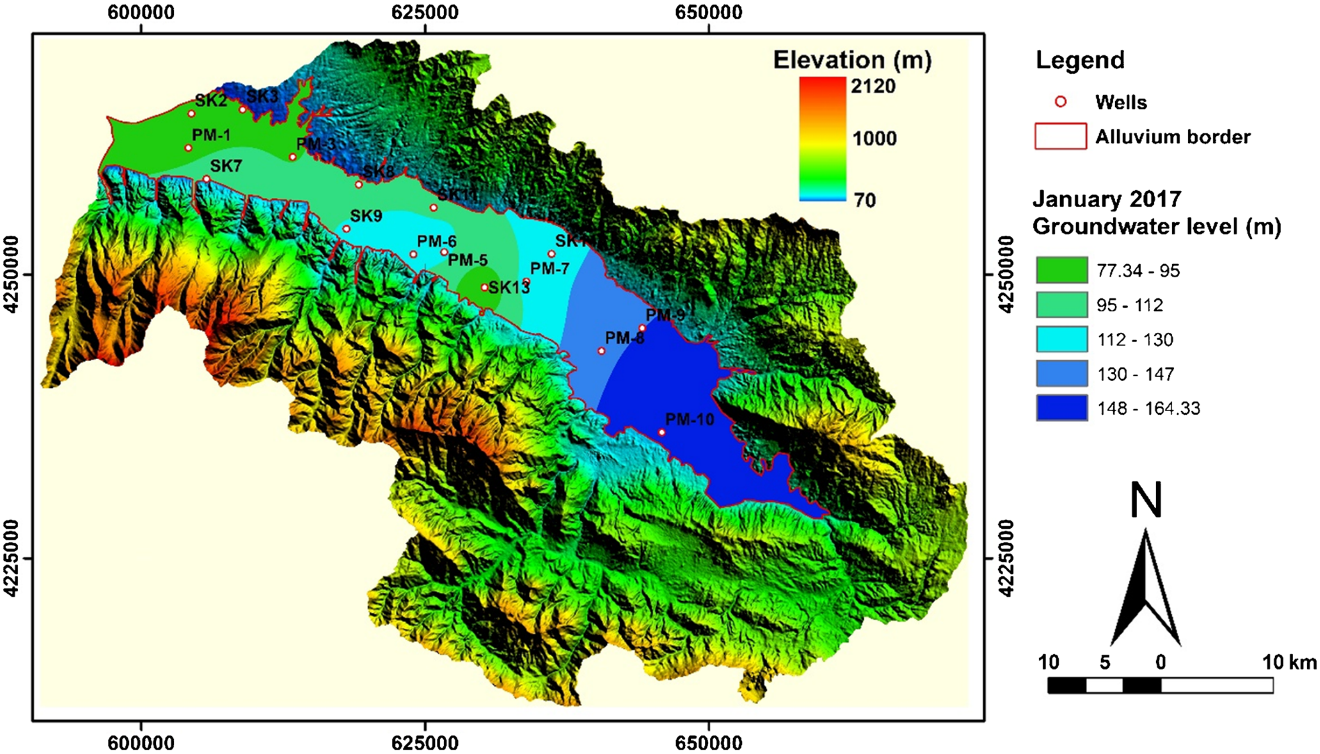

Fig. 9 Spatial distribution map of the groundwater level map in January 2017

highest increase volume was obtained in December and January wet season. On the other hand, the lowest volume increase was obtained from May to September period that is a dry season as well as the agricultural irrigation period. Total increasing volume recharge arriving at the water table in a hydrological period was calculated as 186.99 hm^3, while the decrease of groundwater volume was 235.82 hm^3. The highest decrease in the volume was estimated in a dry season as given in Table 3. When the

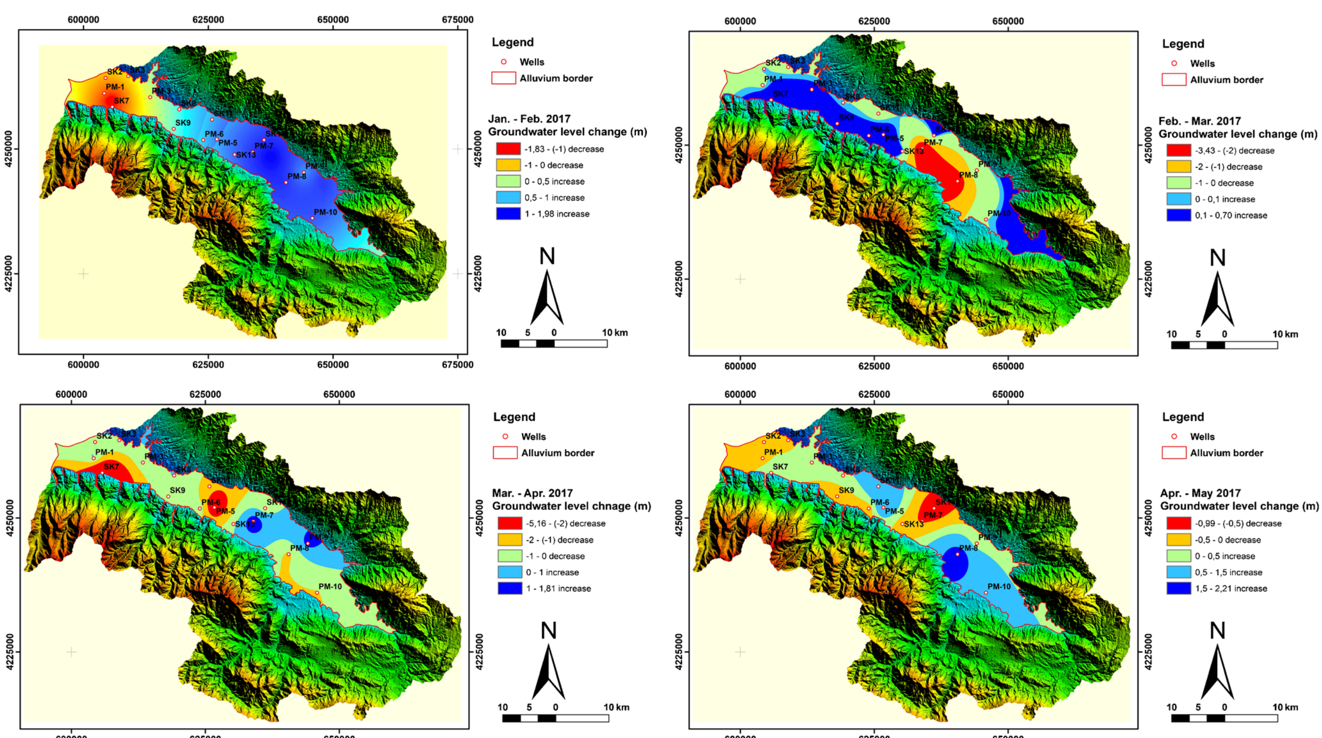

Fig. 10 Groundwater level changes compared to the previous month

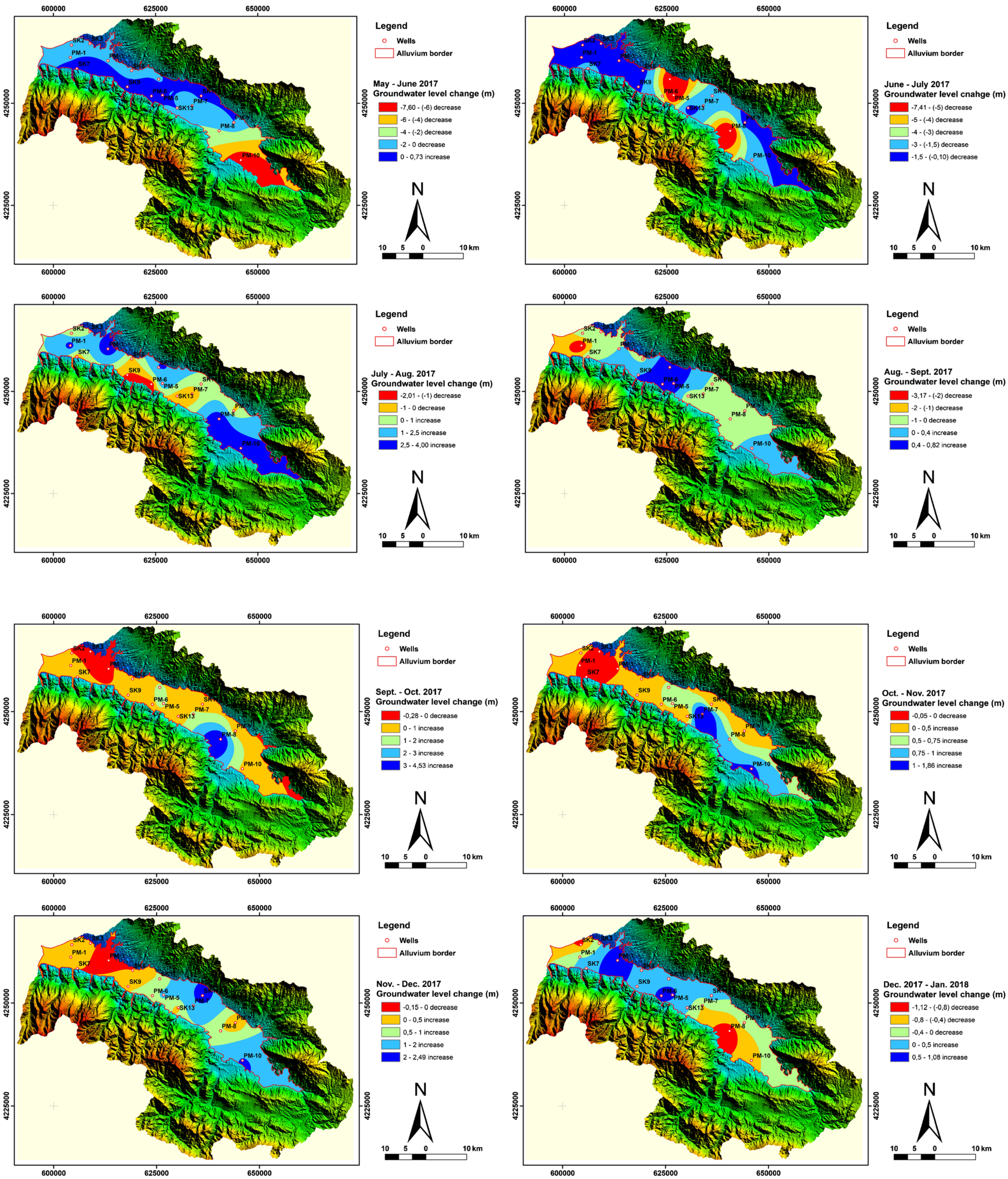

Fig. 10 (continued)

groundwater budget in the aquifer system was considered, the decreasing volume was higher than the increasing volume in a hydrological period because of the over exploitation from the groundwater. About 48.84 hm^3 water was consumed more than the groundwater recharge ratio in the alluvial aquifer. In order to compare these results, the amount of the groundwater recharge determined by the water table fluctuation method was used in the aquifer via a single well data (GDHW 2014). The groundwater

Table 3 Evaluated groundwater volume in the Alaşehir Basin Aquifer

Months	Increase volume (hm^3)	Decrease volume (hm^3)	Net volume (hm^3)
Jan–Feb 2017	13.15	3.84	9.31
Feb–Mar 2017	4.59	12.95	− 8.36
Mar–Apr 2017	3.08	25.70	− 22.62
Apr–May 2017	12.37	2.30	10.07
May–June 2017	1.65	49.34	− 47.69
June–July 2017	0.00	71.09	− 71.09
July–Aug 2017	2.65	50.95	− 48.30
Aug–Sep 2017	4.02	11.40	− 7.38
Sep–Oct 2017	22.20	0.41	21.79
Oct–Nov 2017	13.86	0.15	13.70
Nov–Dec 2017	25.92	0.22	25.70
Dec 2017–Jan 2018	83.50	7.47	76.03
Total volume changed	186.99	235.82	− 48.84

estimation was calculated as to be 154 hm^3 in 2014 using singe well data (GDHW 2014). The total annual discharge of groundwater in the alluvial aquifer was estimated as to be 179 hm^3 including agricultural, domestic, and industrial usage (GDHW 2014). Based on the single well method, about 25 hm^3 water was consumed more than the groundwater recharge ratio in the alluvial aquifer. There are some differences in both methods. While the meteorological data in this method was used in long-term annual average, field-measured meteorological data was preferred during the project.

The GIS-integrated water table method shows higher groundwater recharge compared to single well data used for the groundwater recharge in the alluvial aquifer. One of the most challenging reasons is thought to be the evaluation of a large number of well data in the GIS platform. The water table fluctuation method is the best to be applied to the system with a shallow water table that displays sharp increases and decreases. However, it can be stated that a large number of well data are needed for an accurate evaluation of the water table.

Summary and conclusions

Accurate groundwater recharge estimation plays an important role for groundwater sustainability in a surficial aquifer that is under overexploitation pressure. The groundwater levels in surficial aquifer are mostly related to the precipitation patterns, and an alluvial aquifer is strongly influenced from the precipitation patterns. Among the many of recharge estimation methods, the water table fluctuation is the most relevant one using single and/or multiple water level data. For the determination of more accurate groundwater recharge estimation, many of the well data are needed to represent the related aquifer. The GIS interpolation method is a very easy tool for the analysis representing the aquifer boundary as opposed to the local assessment method. This technique serves as an uncomplicated, user-friendly estimation of the groundwater recharge with water-level data obtained from a surface aquifer in an alluvial plain just to serve for the needs of water budget evaluations.

Based on the GIS-integrated interpolation technique, this paper focuses on the estimation of the groundwater recharge by taking into account the Alaşehir Basin as a case location. For this purpose, monthly level data in the study area, where 16 monitoring wells were drilled, were employed. In the first part, monthly groundwater level maps and level differences maps between consecutive months were prepared by using the inverse distance weighted (IDW) interpolation technique for a hydrological period. Then, the monthly groundwater level difference map was multiplied by the aquifer storage distribution map, and the water volume was calculated using the 3-D GIS tool.

Based on the GIS calculator, the positive volume change of the groundwater in the Alaşehir Basin Aquifer was estimated as to be 186.99 hm^3 in a hydrological period. This application also produced the total discharge of groundwater from the aquifer in the same period. The decrease of groundwater volume was calculated as to be 235.82 hm^3, and the highest volume decrease was estimated in a dry season. It was estimated that the volume decrease was higher than the volume increase in a hydrological period because of overexploitation from the groundwater. When the long-term groundwater level data were analyzed, the groundwater level displayed decreasing trend as to be 1 m annually. Besides, the decrease in the groundwater explains the high decreasing volume of water storage in the alluvial aquifer.

Considering that the data sets are prepared in the GIS environment by this evaluation method, it is recommended as an available and ease of use for determining the groundwater budget. It is concluded and evaluated that the increasing groundwater volume should be considered as rainwater drainage, infiltration from streams, and lateral inflow in the aquifer system. On the other hand, the decreasing groundwater volume should be considered as natural and artificial discharge from the aquifer system. The GIS-integrated technique results are mainly a function of the data quality and the extent of representation of the aquifer system.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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