Pamukkale Univ Muh Bilim Derg, 28(3), 483-492, 2022

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Investigation of over-exploited groundwater in Çumra Plain (Konya-Turkey) with environmental isotopes

Çumra Ovası'nda (Konya-Türkiye) aşırı tüketilen yeraltısularının çevresel izotoplar ile incelemesi

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Received/Geliş Tarihi: 28.04.2021 Revision/Düzeltme Tarihi: 16.07.2021 doi: 10.5505/pajes.2021.42272
Accepted/Kabul Tarihi: 24.08.2021 Research Article/Araştırma Makalesi

Abstract

The groundwater in the Çumra plain, a semi-arid climate region, is intensively exploited for human needs due to especially agricultural and demographic development. In the study area, there are two main aquifers which are the semi-confined Neogene aquifer and the unconfined Quaternary aquifer. This paper presents isotopic characteristics of groundwater of the over-exploited two aquifer systems in the Çumra Plain of Konya. $\delta^{18}O$ and δD contents of the Neogene aquifer samples respectively range from -9.89‰ to -6.76‰ and -68.30‰ to -47.50‰ in dry season and range from -10.32‰ to -7.61‰ and -68.63‰ to -53.11‰ in wet season. $\delta^{18}O$ and δD contents of the Quaternary aquifer samples respectively range from -8.43‰ to -5.53‰ and -58.67‰ to -45.61‰ in dry season and range from -8.77‰ to -5.89‰ and -60.18‰ to -46.45‰ in wet season. The $\delta^{18}O$ and δD contents of groundwater samples in two aquifers indicate a meteoric origin. The average lower Oxygen-18 values of the Neogene aquifer samples indicate recharge from higher elevations while more enriched Oxygen-18 values of the Quaternary aquifer samples show recharged from lower elevation. The groundwater of the Quaternary aquifer was more affected by the evaporation eventuated during or after recharge. Besides, positive correlation of $\delta^{18}O$ with both Cl and total dissolved solids (TDS) in the Quaternary aquifer samples reveals that the evaporation caused salinity increases of the Quaternary aquifer samples. Tritium contents of the Neogene aquifer samples vary from 0.22 to 2.15TU in dry season and from 0.85 to 2.64TU in wet season, while tritium contents of the Quaternary aquifer samples vary from 1.18 to 4.37TU and from 1.52 to 5.48TU in dry and wet seasons, respectively. Accordingly, the samples of the Neogene aquifer reflect relatively higher residence time. Besides, the Neogene aquifer is under the influence of relatively recent precipitation, but recent precipitation has contributed more to the Quaternary aquifer.

Keywords: Çumra Plain, Groundwater, Environmental isotopes, Evaporation.

Öz

Yarı kurak bir iklim bölgesi olan Çumra ovasındaki yeraltısuları, özellikle tarımsal ve demografik gelişmeden dolayı yoğun olarak insan ihtiyaçları için kullanılmaktadır. Çalışma alanında yarı basınçlı Neojen akiferi ve serbest Kuvaterner akiferi olmak üzere iki ana akifer sistemi bulunmaktadır. Bu çalışmada, Konya'nın Çumra Ovası'ndaki iki akifer sisteminin aşırı çekilen yeraltısuyunun izotopik özellikleri değerlendirilmektedir. Neojen akifer örneklerinin $\delta^{18}O$ ve δD içerikleri sırasıyla kurak dönemde -9.89‰ ile -6.76‰ ve -68.30‰ ile -47.50‰ arasında, yağışlı dönemde ise -10.32‰ ile -7.61‰ ve -68.63‰ ile -53.11‰ arasında değişmektedir. Kuvaterner akifer örneklerinin $\delta^{18}O$ ve δD içerikleri ise sırasıyla kurak dönemde -8.43‰ ile -5.53‰ ve -58.67‰ ile -45.61‰ arasında, yağışlı dönemde -8.77‰ ile -5.89‰ ve -60.18‰ ile -46.45‰ arasında değişmektedir. İki akiferdeki yeraltısuyu örneklerinin $\delta^{18}O$ ve δD değerleri, meteorik bir kökene işaret etmektedir. Neojen akifer örneklerinin ortalama daha düşük Oksijen-18 değerleri, daha yüksek kotlardan beslenmeyi gösterirken, Kuvaterner akifer örneklerinin daha yüksek Oksijen-18 değerleri, daha düşük kottan beslenmeye işaret etmektedir. Kuvaterner akiferinin yeraltısuyu, beslenme sırasında veya sonrasında meydana gelen buharlaşmadan daha fazla etkilenmiştir. Bununla birlikte Kuvaterner akifer örneklerinin $\delta^{18}O$ değerinin hem Cl hem de toplam çözünmüş katılar (TDS) ile pozitif korelasyonu, buharlaşmanın çalışma alanındaki Kuvaterner akiferinin yeraltısuyunda tuzluluk artışına neden olduğunu ortaya koymaktadır. Neojen akifer örneklerinin trityum içeriği kurak dönemde 0.22 ile 2.15TU, yağışlı dönemde 0.85 ile 2.64TU arasında değişirken, Kuvaterner akifer örneklerinin trityum içeriği kurak ve yağışlı dönemlerde sırasıyla 1.18 ile 4.37TU ve 1.52 ile 5.48TU arasında değişmektedir. Bu verilere göre, Neojen akiferinin yeraltısuyu, nispeten daha uzun dolaşımlıdır. Ayrıca Neojen akiferi nispeten güncel yağışların etkisi altındadır fakat güncel yağışlar Kuvaterner akiferine daha çok katkıda bulunmuştur.

Anahtar kelimeler: Çumra Ovası, Yeraltısuyu, Çevresel izotoplar, Buharlaşma.

1 Introduction

Environmental isotopes as a natural tracer of physical processes affecting water provide information about the origin of surface and groundwater, water quality, groundwater circulation processes, groundwater residence time, evaporation processes, its geochemistry, renewability of water, recharge sources and hydraulic interconnections [1],[2] and these data are essential for sustainable usage of the water and to develop management plans of the water resources. Additionally, in particular, to identify of groundwater recharge in arid and semi-arid climates, usage of the isotopic data is almost the best method. Moreover, pollution of both shallow and deep aquifers by anthropogenic contaminants due to overexploitation of unconfined aquifers is one of the principal troubles in water resource management, and environmental isotopes, thereby, can be also used as a tracer for evaluation of pollution distribution and observation of temporal changes in pollution patterns [3]. In order to develop sustainable use of surface and groundwater, the most accurate management plan and to obtain basic data about water resources, many

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researchers have investigated surface and groundwater resources by using environmental isotopes (e.g., [4]-[8]).

The Çumra located on the Konya-Karaman highway approximately 40 km southeast of Konya and is characterized by a semiarid climate region covers an area of nearly 2000 km2 Figure 1. In the study area where extensive agricultural activity has been carried out, there are two main aquifers, the first is the semi-confined Neogene aquifer and the other is the unconfined Quaternary aquifer. In generally, the groundwater recharging from Neogene aquifer is used for domestic, industrial and especially agricultural purposes, while groundwater of the Quaternary aquifer is used for agricultural activities and as the drinking for animals. In the region, there are more than 250 wells drilled by the State Hydraulic Works of Turkey (DSI) and private companies, which are still in operation, and unfortunately, continues to be drilled uncontrolled wells for irrigation in recent years [9]. The use of groundwater in the Çumra Plain has increased due to both the presence of fertile lands for agriculture and the developing industrialization because of its proximity to center of Konya, causing the decrease of the groundwater level. Moreover, the extremely abstraction of the groundwater due to increasing water demands has given rise to groundwater level to drop by about one meter per year over especially the last few decades [10] and, thereby, causing drilled of deeper wells (up to 240 m).

The decline of groundwater level can also cause deterioration in water quality, thus, for the sustainable usage and management of the groundwater in this region; the determination of the origin of groundwater, recharge sources, the circulation time and the effect of the processes like evaporation and pollution caused by anthropogenic effects due to overuse are very essential. The aim of present study is, thus, using environmental isotopes, to investigate the origin and residence time of the groundwater of both the Neogene and Quaternary aquifers in the Çumra Plain; to determine different processes like evaporation and water-rock interaction related to the changing of the isotopic composition of groundwater of two aquifers.

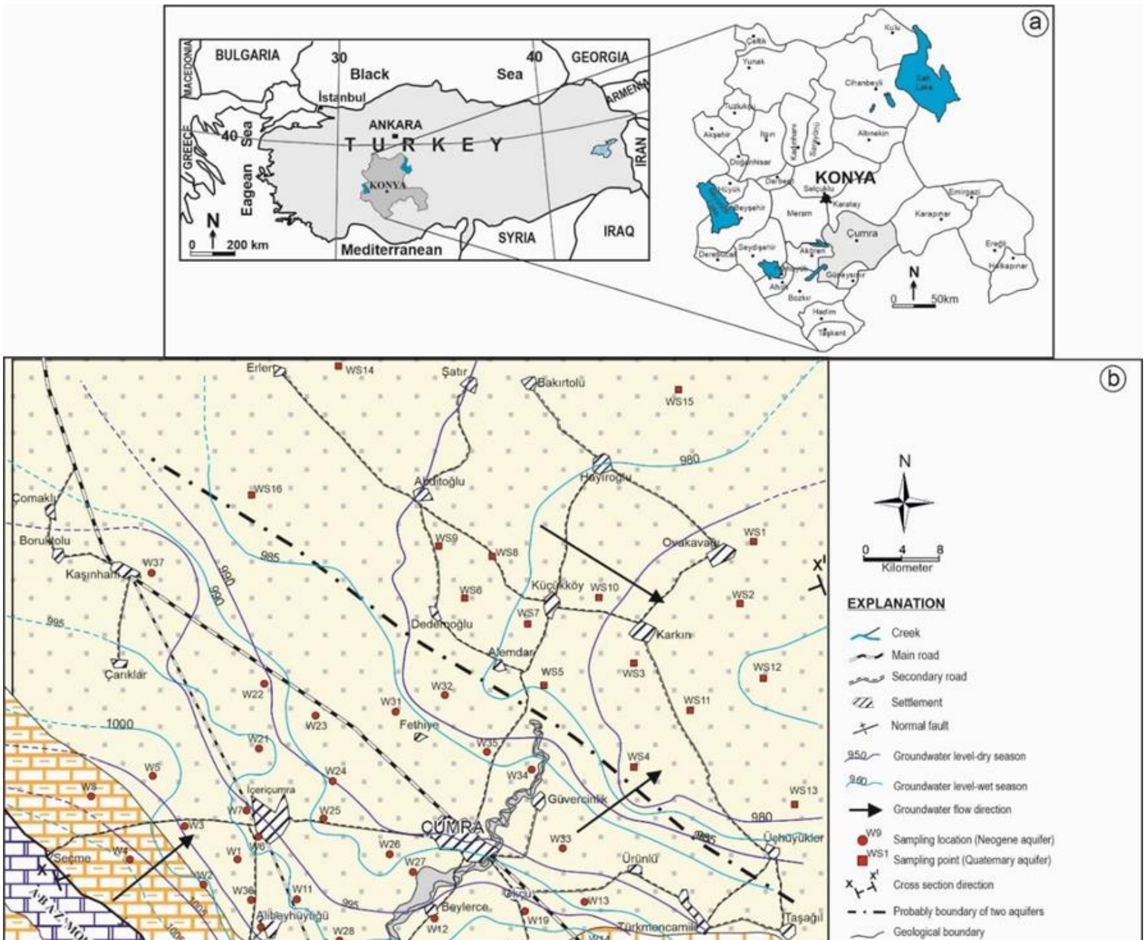

Figure 1(a): The location map and (b): Geological (modified from [11]-[14]), hydrogeological maps and groundwater sampling locations.

2 Study area

2.1 Climate and topography

The study area located in the Central Anatolia lies at 4141355N-4185000N and 455800E- 500000E and covers an area of about 2000 km^2 Figure 1. The study area has a fairly flat topography, the average elevation for flat parts covering majority of the study area vary between about 1000-1050 m. Only south of the study area is a NW-SE trending mountainous region with elevations ranging from about 1200 to 1450 m. The study area has a semi-arid climate with cold and rainy winters and hot and dry summers. According to the long period (1982-2012) meteorological data recorded at Konya Meteorological Station between 1982-2012 years by Turkish State Meteorological Service, the average annual precipitation is 309.83 mm and the average temperature is 11.62 ^{o}C. The average highest temperatures occur in June, July and August (between 20.4 and 27.3 ^{o}C), while the lowest temperatures are observed in December, January and February (between -4.67 and 1.5 ^{o}C). The highest precipitation is observed in November, December (36.2 and 46.8 mm) and April and May (35.8 mm), while the lowest precipitation is observed in July and August (5.9 and 6.7 mm).

2.2 Geological and hydrogeological settings

The Çumra Plain, located in the Central Taurides section of the Taurus Main Tectonic Unit, contains geological units deposited from the Paleozoic to Quaternary-Recent Figure 1.

The Upper Triassic-Lower Cretaceous Lorasdağı formation consisting of crystallized limestone, dolomite and limestone forms the basis of the study area [12],[15]. The Lorasdağı formation is exposed at Abaz Mountain and other elevations at the southern border of the study area. The Upper Miocene-Lower Pliocene İnsuyu formation, which are made up of mostly lacustrine limestone and clayey limestone, and sandstone, conglomerate, marl, gypsiferous clay and gypsum in places, unconformably overlies the basement unit and has a thickness varying between 200 and 400 m [12],[15],[16]. These units are conformably overlain by the Upper Pliocene-Quaternary aged Topraklı formation which are made up of sand, clay, sandstone, conglomerate, mudstone, silt gravel, and gypsiferous clay, and gypsum which increases in amount towards the east and northeast of the study area [11],[12]. The unit with variable thickness reaches to 100-120 meters to the northeast and east [11]. İnsuyu and Topraklı formations are characterized by vertical and horizontal heterogeneity in many regions of Konya Closed Basin. In a narrow area along the Çarşamba stream, which flow seasonally, the Quaternary-Recent alluvium is observed Figure 1, 2.

The limestones of the İnsuyu formation, which contains shallow lake with evaporite-level and fluvial facies deposits, are generally medium-thick, partly thin and horizontally bedded, and present fractured, cracked and karstic. The limestones have good permeability due to fractures and cracks and form the main aquifer (Neogene aquifer) in the study area. The Neogene aquifer is unconfined where it cropped out in the south of the study area, but this aquifer continues east-northeast and north from under of the Topraklı formation (Quaternary aquifer) and is confined [9]. The depth from the land surface of the Neogene aquifer is about 5-10 m around the Çumra and gradually gets deeper under the Quaternary units [11]. Sandstone, conglomerate, sand and gravels of the Topraklı formation are permeable and form Quaternary aquifer. The thickness of the Quaternary aquifer is variable and reaches up to 100-120 m in the northeast-east part of the study area [9],[11], Figure 1, 2.

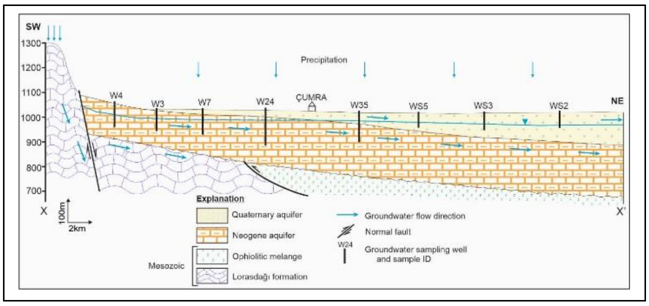

Figure 2. Conceptual hydrogeological cross section (X-X') of the Figure 1(b) (modified from [9]).

3 Sampling and analytical procedures

Electrical conductivity (EC), temperature (T ^{o}C) and pH values of the groundwater samples from 54 different locations in September 2012 (dry season) and April 2012 (wet season) were measured in the area with portable measuring instruments. Additionally, in the dry and wet seasons, the static water levels of the sampling points, which are accessible and operational wells belonging to Neogene and Quaternary aquifers, were determined Table 1.

A total of 70 groundwater samples for oxygen-18 ($\delta^{18}O$) and deuterium (δD) analyses were collected from 35 different sampling locations in April 2012 representing wet period and September 2012 representing dry period. For tritium (^{3}H) analyses, thirteen and eighteen groundwater samples were collected in April 2012 and September 2012, respectively (Table 2). The groundwater samples from selected 35 locations were also collected for chloride (Cl) and total dissolved solids (TDS) analyses.

The oxygen-18 ($\delta^{18}O$) and deuterium (δD) stable isotope analyses were completed with a GVI Optima isotope mass spectrometer (SIRMS) at the Davis Stable Isotope Laboratries of Califormia University, U.S.A. Vienna-Standard Mean Ocean Water (V-SMOW) was used a reference standard and expressed in per mille (‰). The analytical precisions are ±0.3‰ for δD and ±0.12‰ for $\delta^{18}O$. Tritium (^{3}H) analyses were performed at the Technical Research and Quality Control (TAKK) Isotope laboratories of General Directorate State Hydrolic Works, Ankara. The chloride (Cl) was determined by potentiometric titration, and TDS was determined by turbidimetry in the Water (DSI) Quality Control Laboratory of the Konya Metropolitan Municipality, Konya.

4 Results and discussions

4.1 Physicochemical characteristics of groundwater in the study area

Table 1 indicates in-situ temperature (^{o}C), EC and pH values of a total of 54 groundwater samples from the Neogene aquifer (n=38) and Quaternary aquifer (n=16) for two seasons.

The pH values of groundwater samples from aquifer systems in the study area are a ranging from 6.81 to 7.90 in the dry season and from 6.90 to 8.00 in the wet season. The EC values of the Neogene aquifer samples vary between 582 and 1823 µS/cm with an average of 808.21 µS/cm in the dry season, and 567 and 1847 µS/cm with an average of 825.63 µS/cm in the wet season.

Table 1. Coordinate, altitude, well depth, static water level (m) of the sampling points, temperature (°C) pH and EC (µS/cm) values determined in the area of the Neogene and Quaternary aquifer samples for two seasons.

Sample ID	Coordinate (UTM 36N WGS84)		Altitude (m)	Well Depth (m)	Static Water Level (m)		T (°C)		pH		EC (µS/cm)	
					Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
Neogene Aquifer (38)												
W1	4157513	467988	1030	110	1000	998	16.1	15.2	7.13	7.1	729	711
W2	4156653	466119	1037	110	1003	1002	18.0	15.7	7.07	7.05	788	812
W3	4159217	465690	1036	80	-	-	16.6	15.4	7.13	7.11	795	783
W4	4157894	462647	1050	150	1008	1007	16.9	15.4	7.3	7.25	701	756
W5	4162607	463429	1029	100	1000	1006	21.0	20.5	6.9	6.81	1296	1289
W6	4158405	469049	1026	100	996	994	15.4	14.7	7.2	7.18	672	659
W7	4160321	468689	1025	100	-	-	15.7	15.4	7.4	7.32	716	682
W8	4162319	459371	1025	110	1003	1001	16.3	17.0	7.18	7.16	751	718
W9	4150189	467617	1057	150	1008	1007	15.5	14.9	7.1	7.05	748	663
W10	4153610	466592	1039	100	1003	1001	16.1	15.7	7.41	7.41	714	623
W11	4155793	471672	1031	100	996	994	16.5	14.3	7.26	7.2	929	840
W12	4154523	479293	1025	90	995	992	15.0	15.6	7.2	7.18	667	616
W13	4155475	487190	1020	100	990	989	16.0	14.9	7.3	7.26	786	758
W14	4152978	487468	1017	150	1000	997	16.1	16.3	7.0	6.97	789	801
W15	4149998	486277	1036	100	1003	1001	15.7	15.5	7.31	7.21	927	847
W16	4152895	483698	1040	110	1000	998	15.2	15.3	7.2	7.16	782	756
W17	4150157	480364	1040	240	-	-	16.2	15.2	7.38	7.31	917	1012
W18	4152419	482190	1030	100	1000	998	15.1	14.6	7.4	7.31	748	699
W19	4155078	483936	1023	55	995	993	14.5	14.4	7.4	7.36	764	773
W20	4148411	477943	1037	87	1010	1009	15.8	15.0	7.43	7.43	917	910
W21	4163571	469529	1012	180	990	988	16.0	15.3	7.41	7.36	718	694
W22	4166984	469648	1018	180	991	991	16.4	14.7	7.21	7.17	756	768
W23	4165198	472506	1013	120	985	984	19.7	15.4	7.35	7.31	710	612
W24	4162500	473895	1019	150	991	990	15.1	14.4	7.58	7.5	659	617
W25	4159841	472982	1022	150	991	989	15.0	14.5	7.5	7.43	567	582
W26	4158015	474927	1019	150	991	989	17.0	15.2	7.48	7.45	607	585
W27	4157023	477665	1021	150	-	-	16.0	15.0	7.34	7.27	638	654
W28	4153610	473696	1026	150	996	994	16.5	16.1	7.45	7.4	656	673
W29	4153517	469410	1030	150	1001	999	16.3	17.0	7.4	7.36	697	649
W30	4150474	470998	1037	150	1009	1007	17.5	16.3	7.2	7.28	769	743
W31	4164889	476672	1018	150	986	985	18.5	17.4	6.95	6.92	893	799
W32	4166475	478995	1010	100	-	-	17.1	15.5	7.2	7.19	1597	1620
W33	4159067	485398	1012	100	986	982	15.0	14.0	7.53	7.46	636	624
W34	4161977	484075	1010	110	985	982	15.8	15.0	7.65	7.58	683	690
W35	4163141	480423	1011	100	-	-	15.5	15.0	7.6	7.51	1253	1325
W36	4155310	469152	1039	110	1001	999	15.1	14.4	7.58	7.51	706	703
W37	4173196	463966	1013	100	998	994	15.2	15.0	7.72	7.64	1847	1823
W38	4145631	483678	1060	100	1009	1008	16.4	15.7	7.23	7.1	846	843
Quaternary Aquifer (16)												
WS1	4174482	495570	1010	70	975	974	17.0	14.2	7.68	7.63	2984	2712
WS2	4170843	494782	1006	50	972	970	14.0	15.8	7.62	7.58	4026	3724
WS3	4167436	489193	1012	70	-	-	17.5	16.7	7.18	7.14	2134	1825
WS4	4161384	489689	1009	60	972	971	15.3	15.0	7.58	7.52	4720	4598
WS5	4167073	484199	1007	80	975	974	16.5	14.2	7.55	7.54	2417	2380
WS6	4178747	490946	1003	80	980	978	16.5	16.2	7.15	7.03	1658	1603
WS7	4171240	481520	1000	70	-	-	16.5	16.7	7.27	7.16	1182	1062
WS8	4175506	484398	1002	80	979	975	17.5	16.8	7.18	7.09	1233	1195
WS9	4180170	481487	1007	70	-	-	17.5	16.2	7.21	7.1	956	915
WS10	4171174	487837	1009	70	975	975	17.0	17.3	7.2	7.12	1113	1063
WS11	4165386	492302	1012	60	972	971	17.5	16.8	7.64	7.58	3392	3372
WS12	4167205	496502	1007	55	972	969	17.6	15.7	7.68	7.55	6352	6240
WS13	4161582	495312	1010	38	-	-	17.8	16.9	8.0	7.9	5976	5855
WS14	4183966	473828	1002	70	980	977	15.8	16.2	7.15	6.88	2352	2304
WS15	4182538	492111	1005	80	980	978	16.0	16.5	7.88	7.8	2035	1888
WS16	4177008	469224	1002	50	975	973	15.8	15.4	7.47	7.3	1942	1957

The EC values of the Quaternary aquifer samples vary from 915 to 6240 µS/cm with an average of 2668.31 µS/cm in the dry season, and from 956 to 6352 µS/cm with an average of 2780 µS/cm in the wet season. The pH and EC values of the groundwater aquifer systems in the study area are higher in the wet season. The increase in pH and EC values of groundwater samples in two aquifer systems may be related to the increase in the interaction between rock and rainwater in the wet season. As the increased the water-rock interaction increases dissolution, and the pH and EC values rise [17],[18]. The EC values of the Quaternary aquifer samples are considerably higher than those of the Neogene aquifer samples. While the groundwater evaporates or the water level decreases, the salts remaining in the intermediate parts or pores of the clays are filtered back into the groundwater in the wet season [19],[20], therefore, groundwater samples of the Quaternary aquifer with high clay content can have higher EC values in wet season Table 1.

[9] pointed out in the hydrogeochemical study of the same region that the ion sequence of groundwater samples of the Neogene aquifer is Ca>Mg>Na>K and HCO_3>SO_4>Cl, and the ion sequence of groundwater samples of the Quaternary aquifer is Mg>Na>Ca>K and SO_4>HCO_3>Cl. According to the Piper diagram, the groundwater of Neogene aquifer is dominantly Ca-Mg-HCO_3 facies but indicate a tendency toward a Ca-Mg-HCO_3-SO_4 or Mg-Ca-HCO_3-SO_4 facies the throughout of the groundwater flow direction because of dissolution of gypsum mineral in the aquifer Figure 3. The groundwater samples of Quaternary aquifer show a clear migration tendency from Ca-zone to Mg-zone in the cation facies and from HCO_3-zone to SO_4-zone in the anion facies. Additionally, the Quaternary aquifer samples in the east of the study area representing the discharge area are in SO_4-Cl facies [9], Figure 3.

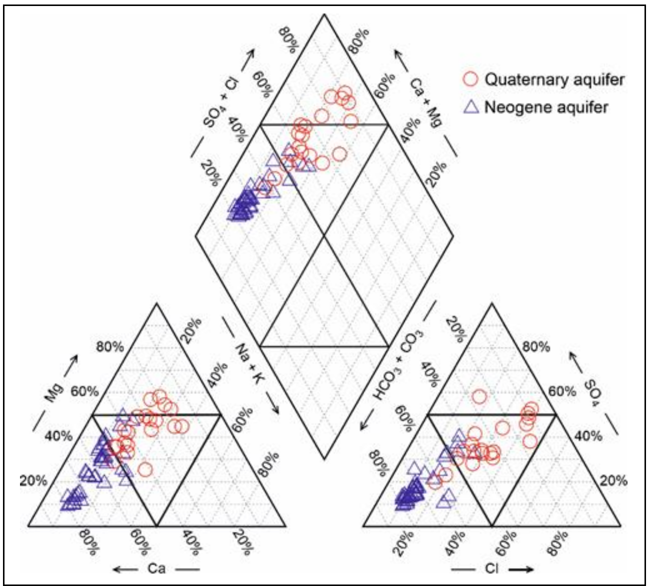

Figure 3. Piper diagram of the Neogene and Quaternary aquifer samples (taken from [9]).

According to the hydrogeochemical studies conducted by [9], the main processes controlling the main ion chemistry in the groundwater of both Neogene and Quaternary aquifers are water-rock interactions which include dissolution of carbonates and gypsum, calcite precipitation and dedolomitization. However, reverse ion exchange, evaporation and leaching soil salts are other major hydrogeochemical processes in the Quaternary aquifer. [9] also argued that evaporation and leaching of soil salts due to agricultural activities increase the concentration of the major ions in the Quaternary aquifer.

4.2 Isotopic results

The result of $\delta^{18}O$, δD, tritium (^3H) analyses of the groundwater taken from the Neogene and Quaternary aquifers for dry and wet seasons are given in the Table 2.

In the dry season, Oxygen-18 and deuterium values of groundwater samples taken from the Neogene aquifer range from -9.89‰ to -6.76‰ with an average of -8.51‰, and -68.30‰ to -47.50‰ with an average of -58.61‰, respectively. $\delta^{18}O$ and δ^2H values of samples from the Quaternary aquifer vary from -8.43‰ to -5.53‰ with an average of -6.78‰, and -58.67‰ to -45.61‰ with an average of -50.18‰, respectively. In the wet season, Oxygen-18 and deuterium values for the Neogene aquifer samples vary from -10.32‰ to -7.61‰ with an average of -9.05‰, and -68.63‰ to -53.11‰ with an average value of -60.84‰, respectively. For Quaternary aquifer samples, $\delta^{18}O$ and δD values range from-8.77‰ to -5.89‰ with an average value of -6.97‰ and -60.18‰ to -46.45‰ with an average value of -51.07‰, respectively Table 2.

The isotopic compositions of the groundwater of the two aquifers in dry season are slightly enriched with heavy isotopes due to evaporation. The average Oxygen-18 values (-6.78‰ and -6.97‰ for dry and wet seasons, respectively) of groundwater from the Quaternary aquifer are higher than the average Oxygen-18 values (-8.51‰ and -9.05‰ for dry and wet seasons, respectively) of the groundwater of the Neogene aquifer. In their study about isotopic characteristics of groundwater in the Qingshuihe Basin (China), [21] pointed out that the average Oxygen-18 concentration of rainfall from which groundwater was derived, corresponds to the value in groundwater samples that are isotopically most depleted groundwater samples, and the value represents the heavy precipitations in the region and/or groundwater was recharged by rainfall from higher altitudes. Accordingly, the average lower Oxygen-18 values of the groundwater in the Neogene aquifer may indicate recharge from higher elevations and the heavy precipitation events. However, more enriched Oxygen-18 values of the Quaternary aquifer samples may show recharged by rainfall from lower elevation and/or short precipitation event. The Taurus Mountains in the south of the study area and Abaz Mountain within the borders of the study area represent the recharge areas for the two aquifers. However, the groundwater of the Quaternary aquifer may have been isotopically enriched due to different processes.

4.2.1 $\delta^{18}O$ and δD

In Figure 4 showing the relationship between $\delta^{18}O$ and δD of the groundwater samples, the Global Meteoric Water Line (GMWL) [22] and the Konya Meteoric Water Line (MMWL) [23] have been shown as reference lines. In the diagrams, the groundwater samples of the two aquifers plotted along the GMWL suggesting that origin of recharge is rainfall.

Some groundwater samples, especially most of the groundwater samples from the Quaternary aquifer show deviations from the GMWL line.

Table 2. $\delta^{18}O$, δD, ^{3}H and deuterium-excess data and Cl and TDS values of the groundwater samples from the Neogene and Quaternary aquifers.

Sample ID	Dry Season						Wet Season					
	δD (‰)	$\delta^{18}O$ (‰)	d-excess	^{3}H (TU)	Cl (mg/l)	TDS (mg/l)	δD (‰)	$\delta^{18}O$ (‰)	d-excess	^{3}H (TU)	Cl (mg/l)	TDS (mg/l)
Neogene aquifer												
W5	-67.0	-9.78	11.3	1.98	60.24	1122	-68.3	-10.32	14.2	2.25	74.55	1134
W7	-48.0	-6.76	6.0		31.60	565	-53.4	-7.61	7.5		35.50	609
W8	-64.1	-8.92	7.3	1.48	28.76	623	-64.5	-9.36	10.4	2.15	34.85	625
W9	-68.3	-9.89	10.8		23.33	611	-68.6	-10.17	12.7		26.70	632
W10	-65.2	-9.41	10.1		18.40	548	-66.7	-9.82	11.8		37.23	603
W12	-54.8	-8.03	9.4	1.84	26.63	521	-59.2	-9.14	14.0		31.06	552
W13	-56.6	-8.04	7.7	2.05	42.60	596	-58.3	-8.95	13.3	2.64	51.48	647
W16	-55.0	-8.27	11.1		24.48	595	-59.3	-8.88	11.8		30.07	649
W17	-59.6	-8.65	9.6	0.79	62.57	802	-62.4	-9.23	11.5	1.32	46.15	762
W18	-58.4	-8.64	10.8		27.77	522	-62.6	-9.34	12.2		31.13	613
W20	-58.8	-8.89	12.3	2.15	45.97	686	-60.6	-9.25	13.4		42.60	736
W22	-56.5	-7.94	7.0	0.45	23.38	651	-57.4	-8.32	9.2		23.43	637
W24	-51.3	-7.27	6.9	1.57	22.98	524	-53.1	-8.09	11.6	1.97	31.24	543
W26	-54.4	-7.83	8.3		30.53	453	-56.4	-8.79	14.0		25.74	484
W28	-67.1	-9.53	9.1		30.18	526	-67.3	-9.78	10.9		30.18	522
W30	-64.3	-9.58	12.3		34.79	639	-65.8	-9.84	12.9		36.20	641
W31	-63.8	-9.18	9.7	0.22	28.91	656	-63.9	-9.23	10.0	0.85	28.84	701
W32	-47.5	-7.32	10.9		154.43	1224	-54.3	-8.38	12.8		140.23	1138
W33	-51.6	-7.61	9.3	0.84	21.93	505	-58.5	-8.13	6.6	1.18	25.276	502
W34	-50.3	-7.51	9.8		27.61	538	-53.7	-8.00	10.3		35.50	526
W35	-53.9	-7.86	9.0		86.78	977	-54.3	-8.10	10.5		85.20	947
W36	-64.5	-9.29	9.8	1.38	31.24	591	-65.3	-9.87	13.7	1.23	23.61	594
W37	-63.5	-9.24	10.4		113.6	1459	-64.1	-9.57	12.5		104.73	1472
W38	-62.1	-8.92	9.3	1.05	24.14	683	-62.8	-9.29	11.5		30.18	695
Quaternary aquifer												
WS-1	-45.6	-5.73	0.2	1.67	323.76	2078	-46.5	-6.17	2.9	2.54	398.67	2250
WS-2	-46.3	-5.53	-2.1	3.56	642.55	2801	-46.9	-5.97	0.8		704.68	2970
WS-3	-48.2	-6.17	1.2		164.90	1432	-49.5	-6.59	3.2		209.45	1541
WS-4	-51.2	-6.88	3.9		678.05	3701	-52.1	-6.43	-0.6		787.39	3900
WS-5	-58.7	-8.43	8.8	1.18	161.02	1881	-60.2	-8.77	10.0	1.52	195.25	1886
WS-6	-55.4	-8.23	10.4	1.37	156.85	1320	-55.7	-8.10	9.1		233.24	1365
WS-9	-52.8	-7.88	10.3		45.68	791	-53.1	-7.60	7.7		52.25	804
WS-11	-46.9	-6.13	2.1		563.39	2475	-47.3	-6.76	6.8	1.64	564.45	2486
WS-12	-47.6	-6.26	2.5	3.76	701	5425	-48.3	-6.52	3.8		791.65	5538
WS-13	-46.5	-5.74	-0.6	4.37	778.87	5041	-46.8	-5.89	0.3	5.48	809.40	5122
WS-14	-51.6	-7.28	6.6		305.30	1803	-53.8	-7.94	9.6		307.08	1836
WS-15	-51.4	-7.06	5.1		242.11	1622	-52.6	-6.89	2.5	2.10	262.70	1672

According to the relationship between $\delta^{18}O$ and δD values of all groundwater samples in the study area, evaporation lines with "D=5.12*$\delta^{18}O$-13.20" in the dry season and "D=4.74*δ18O-18.80" in the wet season were obtained. The slopes of this evaporation lines determined were 5.12 for the dry season and 4.74 for the wet season. [1] stated that if the relative humidity is between 25% and 75%, the slope of the evaporation line is mostly between 4 and 5. According to the data compiled from the Konya Meteorology General Directorate, the relative humidity in the study area calculated for long-period (1970-2015) was approximately 59%. Additionally, the slopes of the detected evaporation lines for two seasons are lower than the slope of the GMWL line (slope=8) indicating that the groundwater samples falling along the evaporation line are affected by evaporation [1].

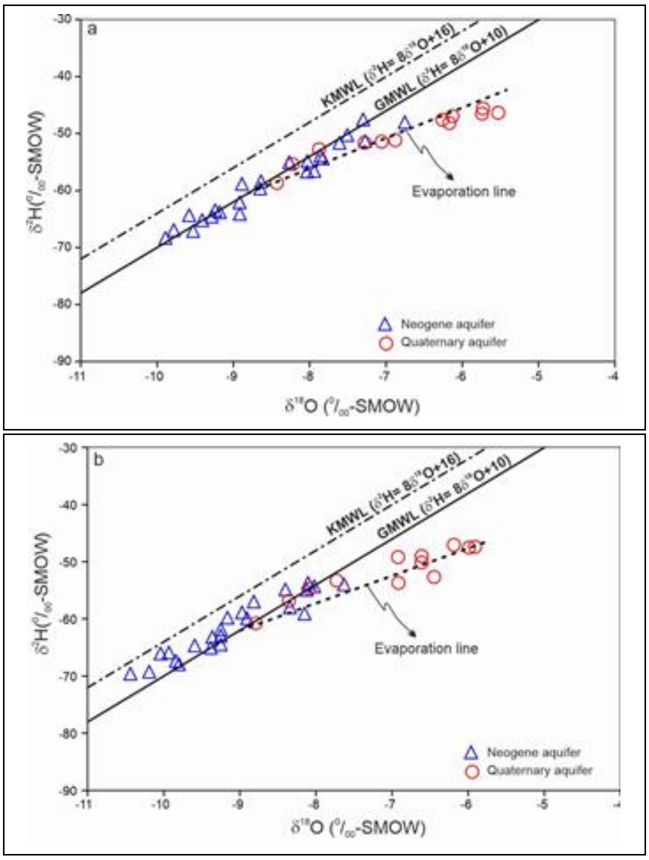

Figure 4. Relationship of δ^2H and $\delta^{18}O$ in groundwater of both Neogene and Quaternary aquifers for, (a): Dry season and (b): Wet season.

In mostly semi-arid and arid regions, the evaporation has an important influence on groundwater evolution, and the geochemical mechanisms of caused by the evaporation can be evaluated by the isotopic documents [21]. Most groundwater samples of the Quaternary aquifer were generally more affected by evaporation and enriched in Oxygen-18 and deuterium. The variation in Oxygen-18 and deuterium isotope contents in all groundwater samples shows that the groundwater of two aquifers is affected by different evaporation degrees. In addition, that there is an evaporative enrichment in two seasons can be due to the evaporation of the groundwater used as agricultural irrigation water during filtering back into the aquifer Figure 4.

[24] declared that If salinity is result from the leaching by rapid infiltration of evaporitic salts, the relationship between $\delta^{18}O$ and δD of the groundwater should be like that of regional precipitation. Because, rapid percolation does not affect the isotopic composition of the groundwater, so there is no relationship between the isotope concentration of the water and the chloride concentration. If salinity is resulted from the enrichment of salts by evaporation, the relationship Oxygen-18 and deuterium would reflect a lower slope than the slope of the GMWL line, and thus, a linear relationship occurs between chloride and Oxygen-18 or deuterium, that is, as the evaporation increases, isotopically enrichment occurs and chloride content increases [21],[25]. In the graphs of $\delta^{18}O$-Cl, it is clear that there is a positive correlation between Oxygen-18 and chloride of groundwater samples of only Quaternary aquifer for both dry and wet seasons Figure 5(a, b).

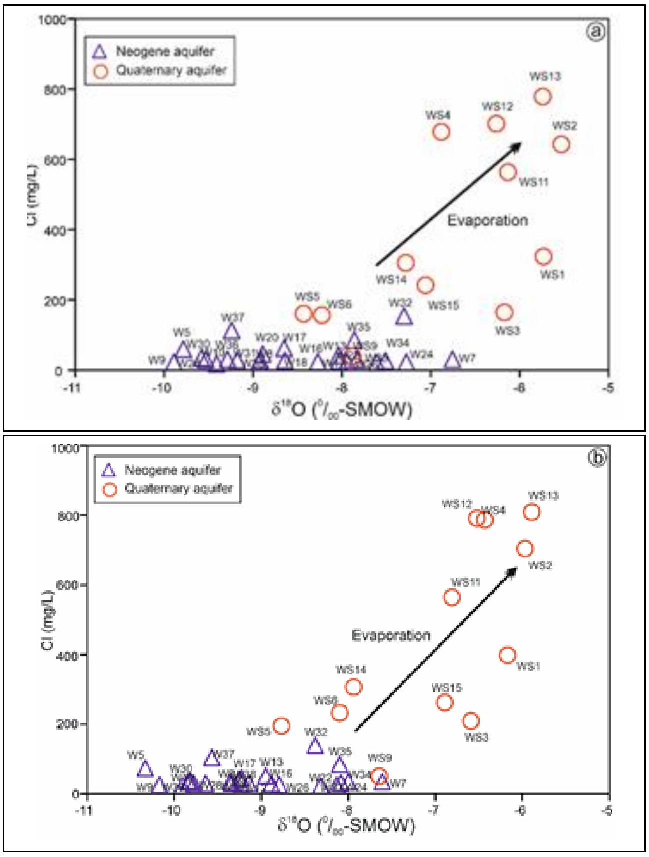

Figure 5. Relationship of $\delta^{18}O$ and Cl (mg/L) in groundwater of both Neogene and Quaternary aquifers for, (a): Dry season, (b): Wet season.

In addition, the graphs of $\delta^{18}O$-TDS indicate a positive correlation for most of the groundwater samples of only Quaternary aquifer for two seasons Figure 6(a, b). Therefore, the evaporative enrichment is a process, which caused salinity increases of groundwater in the Quaternary aquifer system in the study area. In addition, the trend of salinity increasing in the Quaternary aquifer in the direction of groundwater flow reflects the dissolution of salts on the groundwater flow path.

4.2.2 Deuterium excess (d-excess ‰)

Deuterium-excess, which is used as a data for determining secondary processes affecting atmospheric vapor content in the evaporation-condensation cycle in nature, also shows the effect of evaporation on the physicochemical properties of water [22],[26]. The d-excess is expressed by the equation $d=\delta^2H-8\delta^{18}O$, which is the intersection point of GMWL [26]. Although the d value of meteoric waters on a global scale is close to 10, it may vary significantly from region to region geographically [27],[28].

The d-excess values of groundwater samples were calculated in order to determine the effect of evaporation on the groundwater chemistry. The d values of the samples of the Neogene aquifer are varying from 6.03‰ to 12.32‰ with an average value of 9.50 ‰ in dry season and 6.57‰ to 14.46 ‰ with an average value of 11.65 ‰ in wet season. Besides, the d values of the Quaternary aquifer samples range from -2.11‰ to 10.41‰ with an average value of 3.98‰ in dry season, and -0.63‰ to 9.98‰ with an average value of 4.67‰ in wet season Table 2.

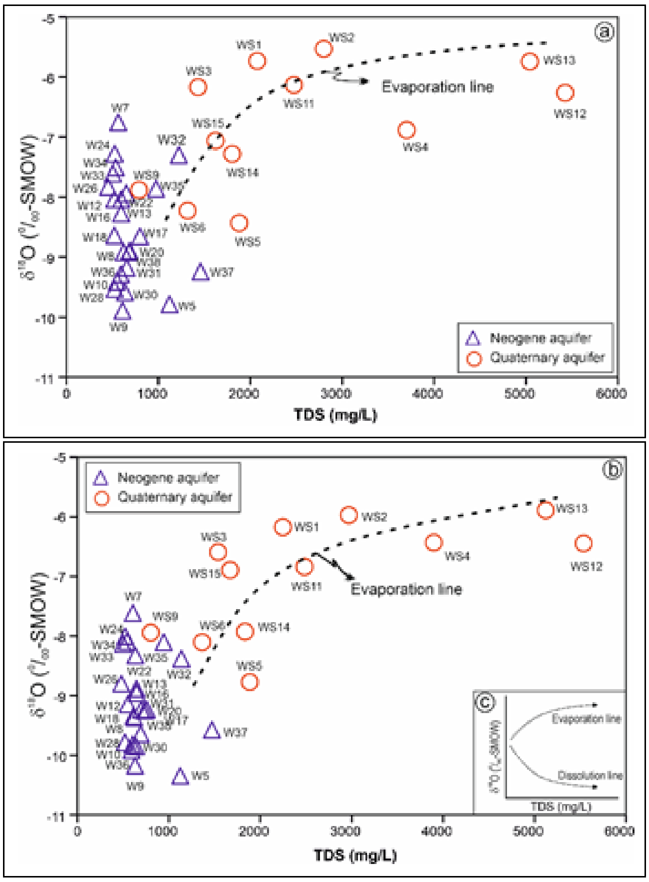

Figure 6. Relationship of δ18O and TDS (mg/L) in groundwater of both Neogene and Quaternary aquifers for, (a): Dry season, (b): Wet season, (c): δ18O- TDS relationship [21].

Many researchers indicate that samples with very low d values (e.g. d <3‰) are a possible effect of evaporation post-rainfall [29],[30]. However, [31] determined that some samples with very low d values were not significantly affected by evaporation after precipitation or after sampling, indicating that the samples with very low d values are derived from locally isolated humid air masses with very low d values. Actually, d value of water vapor is a function of humidity, surface temperature, isotopic composition of water vapor in the environment and evaporated water [28].

In two season, the very low d values (+3.98‰ and 4.67‰, respectively) of the Quaternary aquifer samples compared to the Neogene aquifer samples and the negative correlation between the δ18O and d values of the Quaternary groundwater samples confirms high evaporation affecting groundwater of the Quaternary aquifer Figure 7(a, b). Additionally, the negative correlation between δ18O and d-excess especially in the Quaternary aquifer system and thus, the enriched stable isotope values associated with low d values suggest that evaporation eventuated during and after recharge process.

Furthermore, from the wide range in d values (-2.11 to 10.41 ‰) of especially the Quaternary aquifer samples, it can be also revealed that groundwater in this system originated from water with different d-excess values, which may be possibly derived from rainfall, and irrigation return flow. Accordingly, it can be said that the Quaternary aquifer at shallower depth could have been more affected from irrigation return flow and thus, evaporation. Moreover, the higher evaporation effect in the Quaternary aquifer system is probably due to slow leaching controlled with lower permeability of this aquifer with the high clay content, and the high evaporation effect in Quaternary aquifer system was contributed to the higher mineralization in the groundwater. The results obtained from Oxygen-18 and deuterium values coincide with the results revealed by the hydrogeochemical studies conducted by [9] in the same region.

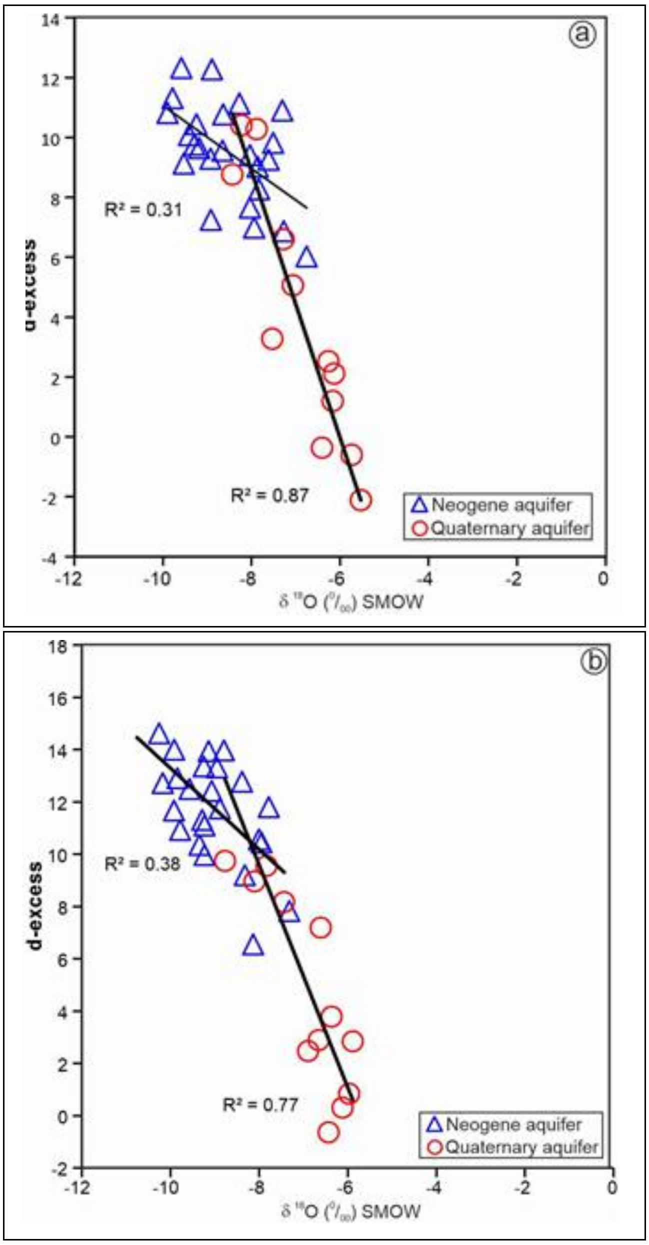

Figure 7. Relationship of δ18O (‰) and d-excess (‰) in groundwater of both Neogene and Quaternary aquifers for, (a): Dry season, (b): Wet season.

4.2.3 Tritium (^{3}H)

Tritium, with a half-life of 12.43 years, is frequently used as a radioisotope tracer to identify the modern recharge and estimate the residence time in groundwater [1],[32],[33].

Tritium contents of both the Neogene and Quaternary groundwater samples are presented in Table 2 for two seasons. Tritium content of Neogene aquifer samples range from 0.22 to 2.15 TU with an average of 1.32 TU in dry season, and 0.85 to

2.64 TU with an average of 1.70TU in wet season. Tritium content of the Quaternary aquifer samples vary from 1.18 to 4.37 TU with an average of 2.65 TU, and 1.52 to 5.48 TU with an average of 2.66 TU in dry and wet seasons, respectively.

The natural production of tritium provided about 5 TU to precipitation and surface water before nuclear bomb tests (between 1952 and 1963). Nuclear bomb tests beginning in 1952 in the northern hemisphere added large amounts of tritium to the atmosphere and reached several thousand TU in precipitation, and reached its maximum peak in 1963 and then, values decreased thereafter [34].

Therefore, considering that the groundwater sampling time (2012) for the study area was 49 years after the nuclear bomb tests, the tritium content is expected to be around 0.32 TU or less in the groundwater, which was recharged from precipitation during and before 1963. According to the tritium values, only sample of W31 of the Neogene aquifer was recharged by precipitation before nuclear tests while the rest of the samples of two aquifer were recharged by mostly modern precipitation.

However, the recent precipitation has contributed more to the Quaternary aquifer than the Neogene aquifer Figure 8. Additionally, from low tritium values (<2TU), it can be said that the Neogene aquifer is under the influence of relatively recent precipitation but partially mixed with deep circulation water. Moreover, the graph of tritium-$\delta^{18}O$ shows that the Neogene aquifer samples reflect recharging from higher altitudes and the higher residence time in the aquifer compared to the Quaternary aquifer samples Figure 8.

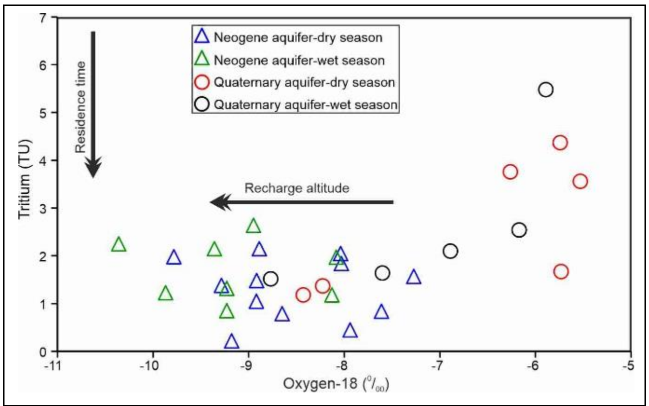

Figure 8. The relationship between $\delta^{18}O$ (‰) and tritium (TU) in groundwater of both Neogene and Quaternary aquifers.

5 Conclusions

This study was conducted to determine isotopic characteristics of groundwater of the over-exploited two aquifer systems in the Çumra Plain of Konya. With this scope, groundwater samples were collected from two main aquifers during dry and wet seasons, and $\delta^{18}O$, δD and tritium (^3H) analyzes were performed. In the dry season, the $\delta^{18}O$ and δD contents of the samples of Neogene aquifer respectively range from -9.89‰ to -6.76‰ and from -68.30‰ to -47.50‰ while the isotopic values for Quaternary aquifer samples vary from -8.43‰ to -5.53‰ and from -58.67‰ to -45.61‰, respectively. In the wet season, the $\delta^{18}O$ and δD contents of Neogene aquifer samples respectively, vary from-10.32‰ to -7.61‰ and -68.63‰ to -53.11‰ while the isotopic values for Quaternary aquifer samples range from -8.77‰ to -5.89‰ and -60.18‰ to -46.45‰, respectively.

The average lower Oxygen-18 values of the groundwater in the Neogene aquifer may indicate recharge from higher elevations and the heavy precipitation events. However, more enriched Oxygen-18 values of the Quaternary aquifer groundwater may show recharged by rainfall from lower elevation and/or short precipitation event. Majority of the samples of the two aquifers plotted along the GMWL suggesting that origin of recharge is rainfall but especially most of the Quaternary aquifer samples showed deviations from the GMWL line due to evaporative enrichment. The variation in Oxygen-18 and deuterium isotope contents in all groundwater samples suggests that the groundwater of two aquifers is affected by different evaporation degrees. In addition, the evaporative enrichment determined in two seasons can be due to the evaporation of the groundwater used as agricultural irrigation water during filtering back into the aquifer. The $\delta^{18}O$-Cl and $\delta^{18}O$-TDS graphs indicated a positive correlation for most of the groundwater samples of only Quaternary aquifer for both dry and wet seasons revealing that the evaporative enrichment contributed salinity increases of the Quaternary aquifer samples in the study area. The enriched $\delta^{18}O$ values associated with low d-excess values suggest that evaporation eventuated during or after recharge process. The wide range in d-excess values (-2.11 to 10.41 ‰) of especially the Quaternary aquifer samples can be also indicated that groundwater in Quaternary aquifer system originated from water with different d-excess values, which may be possibly derived from rainfall, and irrigation return flow. According to the tritium values, it can be said that the Neogene aquifer is under the influence of relatively recent precipitation but partially mixed with deep circulation water, and recent precipitation have contributed more to the Quaternary aquifer than the Neogene aquifer.

6 Acknowledgement

This research was made possible with the support of the Selçuk University Scientific Research Projects (BAP 11401151).

7 Author contribution statement

As the only author, Ayla Bozdağ contributed literature review, conceptualization, data collection and writing and evaluation of the obtained results.

8 Ethics committee approval and conflict of interest statement

There is no need to obtain an ethics committee approval for this manuscript. There is no conflict of interest with any person/institution in the manuscript.

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