

Potential health risk assessment related to arsenic pollution and hydrogeochemistry of groundwaters in Akşehir and surroundings (Konya/Turkey)

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ABSTRACT

Groundwater is an important water resource used for drinking, domestic and agricultural activities in Akşehir and surroundings. However, intensive agricultural and human activities in the region adversely affect groundwater quality. In this study, 31 water samples were collected from wells. According to the Piper diagram, groundwater in the study area was in the Ca–Mg–HCO₃ and Ca–HCO₃ water facies. As a result, it is not appropriate to use groundwater as drinking water in the study area in terms of trace elements and pollutant analysis results of water samples compared to limit values determined by WHO and ITHASY drinking water guidelines. The arsenic concentration in groundwater was studied in detail. The origin and concentration of arsenic in groundwater is associated with agricultural activities and pesticides in the region. Accordingly, a health risk assessment was carried out for the use of groundwater in the study area as drinking water. The results for all samples analyzed indicate that the groundwater concerned was not suitable for drinking purposes because of arsenic concentrations which exceeded maximum acceptable levels.

Key words | Akşehir, arsenic, drinking water, groundwater pollution, health risk assessment

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HIGHLIGHTS

- Akşehir and surroundings is where intensive agricultural activities are carried out, so it is important to determine the pollution status and usage areas of groundwater and to determine their effects on human health related to the use of these waters.
- In this study, health risk assessment is important due to arsenic pollution in groundwater in Akşehir, Konya (Turkey).

INTRODUCTION

Environmental pollution is one of the most important obstacles to the sustainable development of countries. Water in our country, as in the whole world, is an extremely valuable, economic and strategic natural resource. In total, 95% of domestic wastewater and 70% of industrial wastewater are discharged to receiving environments without

treatment in underdeveloped and developing countries. As a result, clean water sources become contaminated and access to safe drinking water becomes a major problem. Groundwater is especially preferred as drinking water because it is less frequently polluted (Şener *et al.* 2019). Therefore, about half of the world's drinking water is taken from groundwater aquifers (Li *et al.* 2018). However, groundwater quality and chemistry are controlled both by natural processes (weathering and soil erosion) and by anthropogenic inputs (agricultural activities, municipal and

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industrial wastewater discharge, solid wastes, etc.). Chemical composition of groundwater is based on the physical properties, composition and contact time of the substances it comes into contact with. The longer the contact time of the water with the substances in question, the more minerals dissolve in the water.

Groundwater arsenic (As) pollution is a problem frequently observed in many countries worldwide. Over 100 million people face the risk of arsenic poisoning due to naturally occurring groundwater arsenic pollution in many countries around the world (Varol & Şekerci 2018; Lone *et al.* 2020). Arsenic is a toxic and carcinogenic substance that can be found in nature and is both natural and anthropogenic. The presence of natural As in groundwater is controlled by mineral dissolution/precipitation, adsorption/desorption, oxidation/reduction reaction mechanisms and biological transformation. The use of pesticides is among the most important human activities that cause arsenic formation. Also, copper, nickel and gold mining and ore disposal operations, fossil fuels, and landfill leachate are among the anthropogenic sources of arsenic. Inorganic arsenic compounds vary depending on the redox conditions and the pH of the water and are generally seen in surface waters as arsenate (As^{5+}) and in groundwater as arsenite (As^{3+}) (Alpaslan *et al.* 2010). The maximum pollution level accepted for arsenic in drinking water is 0.01 mg/L (WHO 2011) around the world. In our country, the limit value for arsenic was accepted as 10 ppb (0.01 mg/L) as of February 2008 in the Regulation on 'Guidelines for Drinking Waters' (ITHASY 2005).

Accordingly, previous studies about water resources in the west and center of Turkey showed that natural and/or anthropogenic causes led to arsenic contamination. In this study, water resources of the Akşehir district and surrounding were selected as the study area. Akşehir and surroundings is a region where intensive agricultural activities and animal husbandry are carried out. Agricultural activities are gradually increasing on the land around Akşehir Lake, which is gradually drying up due to climate changes and other reasons. In addition, groundwater is used especially for drinking, domestic and irrigation purposes in the study area. In the study area where intensive agricultural activities are carried out, it is important to determine the pollution status and usage areas of groundwater

and to determine their effects on human health related to the use of these waters. Therefore, the present study aimed to investigate the main hydrochemical characteristics and groundwater quality, and potential health risk assessment was performed by taking into account the high As contents of groundwater in Akşehir, Konya (Turkey).

THE STUDY AREA

General characteristics and land use of the study area

The Akşehir District is located in the northwest of Konya within the Akarçay Basin (Figure 1). The study area has wide plains and is bordered by Sultandağları in the west and Akşehir Lake in the north. The study area is located north of the Isparta angle which is an important tectonic structure in Turkey. The Isparta angle was formed during the paleotectonic and neotectonic periods. There are several different geological units with different ages in the study area. The Çaltepe formation consists of recrystallized limestone, dolomite and nodular limestone. The Harlak, Değirmendere, Engilli and Seydişehir formations are metamorphic units in the study area. The Deresine, Hacılabaz and Derviş Formation, Limestone member are composed of carbonated rocks such as limestone, dolomite and recrystallized limestone. The Bağkonak and Bellekler formations are neo-autochthonous cover rocks which consist of conglomerate, sandstone, mudstone and claystone. The Devriş formation consists of marl, claystone and limestone. The Dursunlu formation generally consists of clay, marl, sandstone and gravels and contains lignite in places. Slope debris is composed of clay, silt, sand, gravel and block size materials. Quaternary-aged alluvium is generally observed in the plain. The unit consists of clay, silt, sand, gravel and block size material (Umut 2009a, 2009b).

The region has continental climate characteristics of the Central Anatolia Region and the transition climate of the Central Aegean Region with hot, dry summers, and cold and rainy winters. Average annual precipitation is 546 mm and annual total potential evaporation is calculated as 690.5 mm in the region. Akşehir Lake has the maximum surface area of 6,000–7,000 ha and depth of 1 m. The lake is 953.50 m above sea level. All surface waters (Karabulut

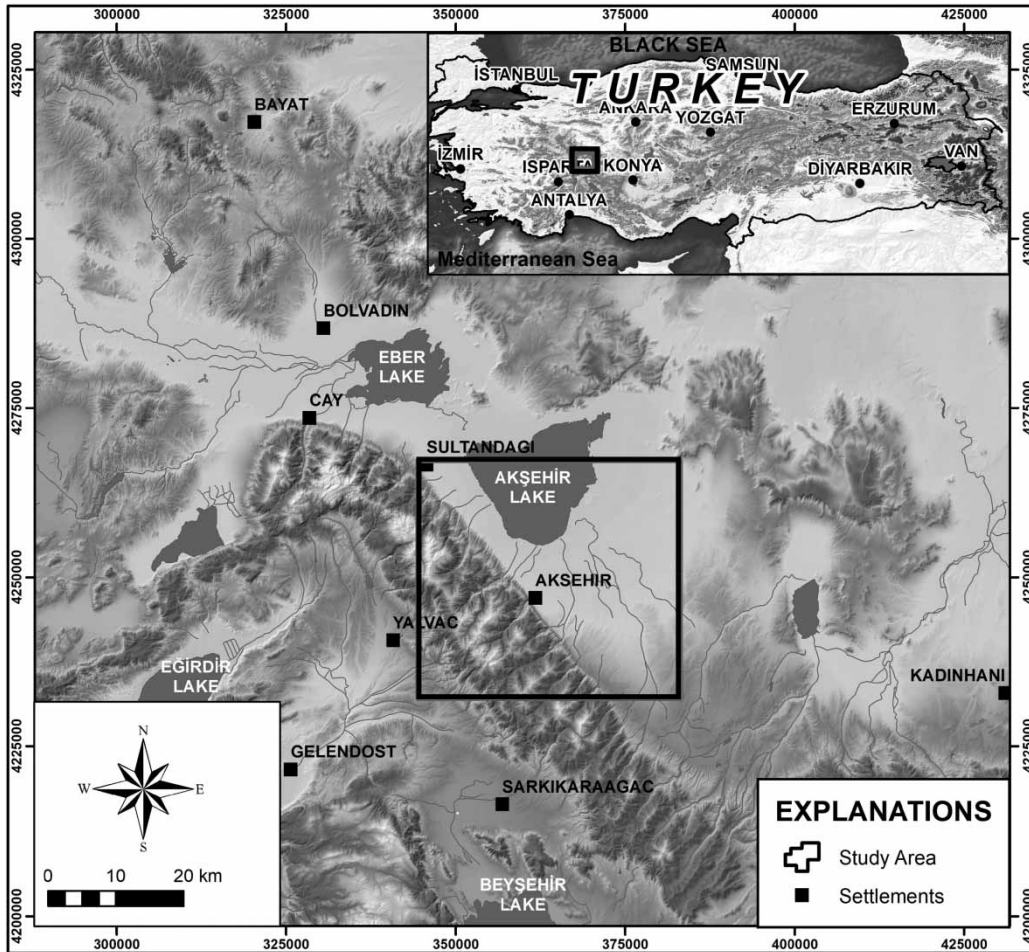


Figure 1 | Location map of the study area.

Stream, Adıyan Stream, Nadir Stream, Akşehir Stream and Saray Stream) in the study area discharge into Akşehir Lake. The most important surface water in the region is Eğriğöz stream and it continues its flow by recharging from Sultan-dağları and discharges into Akşehir Lake. The discharge parameters of the lake are evaporation and usage of irrigation water. There are not many springs in the study area. The main water source in the study area for domestic, industrial and agricultural use is groundwater. Agricultural activities are very common in the region and the total irrigation area is 115.8 km².

Akşehir district, which includes the study area, has a usage area of 85.300 ha. There are agricultural lands in 40.31% of the total area of use, forest areas in 27.51% and meadow-pasture areas in 6.17%. There is one solid waste

storage facility and ten industrial factories for bricks, sun-flower oil, biscuits, tomato paste, flour, marble, electrical wire, tractor spare parts, burner and dairy products in the study area. Apart from these, intensive agricultural activities are carried out in the region (ADR 2014). Grain and other vegetable cultivation areas comprise approximately 80% of the agricultural areas in Akşehir district and surroundings. The remaining area consists of approximately 10% fallow, 8% fruit and 2% vegetable areas (ADR 2014). With the decreasing size of Akşehir Lake, agricultural activities have begun in the areas around the lake. Accordingly, the total 'non-irrigated arable land' open to agricultural activities in the study area is 497.51 km² and the total 'permanently irrigated land' is 298.37 km². Other important land uses in the study area are forest areas, grassland and pastures with vineyards.

MATERIALS AND METHODS

Sampling and analysis

The total number of 31 groundwater samples was collected in October 2018 and the sampling point coordinates were loaded into the Magellan eXplorist 600 Manual Global Positioning System (GPS). Water samples were collected in two different plastic bottles. A few drops of 0.5% nitric acid (HNO_3) were added to one of the bottled waters for cation analysis and to reduce acidity. The water sample in the other bottle was not acidified for anion analysis. All water samples were transported in closed environment at 4 °C and stored until analysis. The *in situ* parameters such as pH, Eh, temperature (T , °C), electrical conductivity (EC, $\mu\text{S}/\text{cm}$) and total dissolved solids (TDS, mg/L) values of the groundwater samples were measured using a YSI Professional Plus handheld multi-parameter instrument. The major cation and heavy metal amounts were analyzed at the Bureau Veritas Mineral Laboratory (Canada-ISO 9002 Accredited Co.) by inductively coupled plasma mass spectrometry (ICP-MS). The anion analyses were carried out in the Geothermal Energy Laboratory, Groundwater, Mineral Resources Research Center of Suleyman Demirel University (Isparta, Turkey). Software was used to analyze chemical data. The charge–balance error for the samples was calculated to confirm accuracy of the chemical analysis, and it was less than 5%, which is within the limits of acceptability. Basic descriptive statistical analysis used SPSS (Version 15.0, SPSS Inc., Chicago, IL). The spatial distribution of trace elements in groundwater and potential health risks in society were prepared using ArcGIS 10.5 software and spatial analyst extensions.

Arsenic risk assessment

Exposure assessment

Arsenic can enter the human body in many different ways such as through the food chain, dermal contact and inhalation. However, the effect of intake by all other means can be neglected compared to oral intake. Therefore, exposure to As_T is measured in two main ways: oral (ingestion) and dermal (absorption) (Ehsan *et al.* 2020). USEPA (2005)

recommends a lifelong average daily dose as an exposure measure to estimate a person's daily exposure. The following equation is representation of daily exposure for the ingestion route modified from Chrostowski (1994) (Equation (1)):

$$\text{ADD} = \frac{C \times \text{IR} \times \text{ED} \times \text{EF}}{\text{BW} \times \text{AT}} \quad (1)$$

According to the formula, chronic daily intake (mg/kg/day) is ADD, drinking water contaminant concentration (mg/L) is C, ingestion rate per unit time (L/day) is IR, exposure duration (years) is ED, frequency of exposure (day/year) is EF, body weight (kg) is BW and average time (30/70 \times 365 days) is AT. Deterministic exposure assessment is made to estimate individual exposures for each trace element using Equation (1). As a result of this formulation, risk characterization must be done in order to make a risk assessment. Toxicity and exposure assessment results provide cancer risk and hazard indices with numerical estimates.

Human health risk assessment

In this study, both chronic and carcinogenic risk levels due to trace element concentrations in water sources were evaluated. HQ can be calculated by using the following equation:

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}} \quad (2)$$

As_T toxicity reference dose (RfD) used in the formula was determined as 0.0003 mg/kg/day by USEPA (2005). Non-cancer risk is represented in terms of hazard quotient (HQ) for a single substance for multiple substances and/or exposure pathways. If a substance's exposure level exceeds the specified reference dose value (RfD), that is, if the HQ value exceeds 1, it indicates that it may have potential non-carcinogenic but harmful effects. The higher this value, the higher negative and carcinogenic effects on health. Cancer risk (R_{cancer}) of a trace element on human health is calculated using the formula (Equation (3)) given below.

$$R_{\text{cancer}} = \text{ADD} \times \text{CSF} \quad (3)$$

According to the formula, the carcinogen risk is R_{cancer} , chronic daily intake (mg/kg/day) is ADD and pollutant's

slope factor $(\text{mg/kg/day})^{-1}$ is SF (Equation (3)). The slope factor (SF) of the contaminant for As_T was specified by USEPA (2005) as 1.5 mg/kg/day.

RESULTS AND DISCUSSION

Hydrochemistry

Groundwater quality and chemical properties depend on the properties of the aquifer rocks and anthropogenic inputs. Therefore, hydrochemical properties and water quality information are needed to determine the suitability of the water for different purposes (Adimalla 2019). The hydrogeochemical facies of groundwater in the study area was evaluated according to Piper (1944) using major cations (Ca, Mg, Na and K) and anions (HCO_3 , SO_4 and Cl) in meq/L units. According to Piper (1944), dominant water types are Ca–Mg– HCO_3 and Ca– HCO_3 in the study area. In

this study, the physicochemical, major ion and trace element contents of groundwater in the study area were determined and their geochemical properties are detailed below.

The physicochemical parameters and major ions of the groundwater samples, including temperature ($^{\circ}\text{C}$), pH, EC, Eh, TDS, Ca, Mg, Na, K, HCO_3 , SO_4 and Cl are listed as statistical summaries in Table 1. According to Table 1, the temperature ($^{\circ}\text{C}$) of groundwater samples range from 12.40 to 16.00 ($^{\circ}\text{C}$). The pH values of groundwater samples are between 7.15 and 8.10. This shows that the waters have features of alkaline water. All water samples in the study area are drinkable in terms of pH values since the pH values are within the limits specified in the drinking water guidelines (ITHASY 2005; WHO 2011). In the study area, Eh values of groundwater samples range from 260.00 to 350.00 (mV). EC values of groundwater samples range from 290.00 to 2,900.00 ($\mu\text{S/cm}$). High EC values in the water samples indicate the enrichment of salts and the presence of anthropogenic effects resulting from domestic and

Table 1 | Statistical summary of the physical and chemical parameters of the groundwater

| Parameters | Unit | N | Minimum | Maximum | Mean | Standard deviation | Water Quality Guidelines | |
|--------------------|--------------------|----|---------|----------|--------|--------------------|--------------------------|----------------|
| | | | | | | | WHO (2011) | TSI 266 (2005) |
| Temperature | $^{\circ}\text{C}$ | 31 | 12.40 | 16.00 | 14.21 | .87 | | |
| pH | | 31 | 7.15 | 8.10 | 7.72 | .22 | 6.5–8.5 | 6.5–9.5 |
| EC | $\mu\text{S/cm}$ | 31 | 290.00 | 2,900.00 | 811.19 | 582.10 | | |
| Eh | mV | 31 | 260.00 | 350.00 | 287.96 | 22.08 | | |
| TDS | mg/L | 31 | 150.00 | 1,780.00 | 488.09 | 361.10 | 500 | |
| Ca | mg/L | 31 | 40.00 | 175.50 | 79.54 | 32.39 | 300 | 200 |
| Mg | mg/L | 31 | 5.31 | 82.42 | 22.40 | 18.00 | 30 | 150 |
| Na | mg/L | 31 | 2.00 | 285.90 | 56.55 | 77.32 | 200 | 200 |
| K | mg/L | 31 | .78 | 18.51 | 5.27 | 4.91 | | 12 |
| HCO_3 | mg/L | 31 | 105.60 | 333.00 | 189.09 | 47.25 | 500 | |
| SO_4 | mg/L | 31 | 3.98 | 482.60 | 99.56 | 109.71 | 250 | 250 |
| Cl | mg/L | 31 | 8.80 | 519.80 | 88.78 | 113.79 | 250 | 250 |
| NO_3 | mg/L | 31 | .20 | 232.50 | 37.88 | 59.27 | 50 | |
| CO_3 | mg/L | 31 | 2 | 2 | 2 | 0 | | |
| Fe_T | $\mu\text{g/L}$ | 31 | 100.00 | 1,487.00 | 374.61 | 380.28 | | 200 |
| Pb_T | $\mu\text{g/L}$ | 31 | 58.00 | 697.00 | 112.51 | 126.09 | 10 | 10 |
| As_T | $\mu\text{g/L}$ | 31 | 10.60 | 112.34 | 43.16 | 22.05 | 10 | 10 |
| B | $\mu\text{g/L}$ | 31 | 100.00 | 958.00 | 321.48 | 218.93 | 2,400 | 1,000 |
| Valid N (listwise) | | 31 | | | | | | |

agricultural activities in the study area. In addition, TDS values of groundwater range from 150.00 to 1,780.00 (mg/L). The TDS limit value stated in the drinking water guidelines is 500 mg/L. Accordingly, samples S19, S21, S23, S24, S25, S26, S28, S29, S30 and S31 in the study area are not suitable for use as drinking water.

According to analysis results, the Ca ion concentration of the water samples in the study area ranges from 40.00 to 175.50 mg/L. Mg ion concentration of the water samples ranges from 5.31 to 82.42 mg/L. Na ion concentration of water samples ranges from 2.00 to 285.90 mg/L, and K ion concentration of water samples ranges from 0.78 to 18.51 mg/L. WHO (2011) sets the permissible drinking water limit for Mg and Na in the drinking water guidelines as 30 and 200 mg/L, respectively. Among the 31 samples, 7 samples (S5, S19, S21, S23, S25, S29 and S31) exceed the acceptable limit for Mg and 3 samples (S24, S25 and S29) exceed the limit for Na. Ca ions do not exceed the limit of drinking water set by WHO (2011) and ITHASY (2005) guidelines in any of the water samples. The HCO₃ ion concentration of the water samples in the study area ranges from 105.60 to 333.00 mg/L. SO₄ ion concentration of the water samples ranges from 3.98 to 482.60 mg/L. Cl ion concentration of the water samples ranges from 8.80 to 519.80 mg/L. CO₃ ion concentration of the water samples in the study area is 2 mg/L. The WHO (2011) guideline for drinking water quality sets the acceptable limit of HCO₃ ion concentration for drinking water as 500 mg/L. All water in the study area is below the limit value determined by drinking water guidelines (WHO 2011). The WHO (2011) and ITHASY (2005) guidelines for drinking water quality set the acceptable limit for SO₄ ion concentration in drinking water as 250 mg/L. In the study area, 5 samples (S23, S24, S25, S29 and S31) exceed the acceptable limit for SO₄ among 31 samples. Cl is another dominant anion found in groundwater. High chloride concentration (>250 mg/L) creates a salty taste in water (WHO 2011). In the study area, 16.12% of the samples (S23, S24, S25, S29 and S31) have values of more than 250 mg/L. This shows that groundwater in the study area is significantly affected by human activities (domestic wastewater, septic tanks), especially agricultural activities (fertilizers, pesticides), as well as natural sources such as precipitation of chloride-bearing minerals (Adimalla 2019). In this case, Cl

concentrations in groundwater have both natural and anthropogenic origin.

In this study, the results of the analysis of water samples were also evaluated in terms of trace elements (Fe_T, Pb_T, As_T and B) and nitrate (NO₃) concentrations, pollutant sources because they are characterized as unwanted ions in drinking water (Table 1). Fe_T ion concentrations of groundwater in the study area vary between 100 and 1,487.00 µg/L. The permissible Fe_T concentration in drinking water was determined as 200 µg/L by ITHASY (2005) drinking water guidelines. When the groundwater Fe_T concentration in the study area is evaluated for drinking water, it was determined that all water samples exceeded the determined limit value. High Fe_T concentration is risky for human health. Especially when such water samples are used for drinking, it can cause aesthetics and hemochromatosis (Boateng *et al.* 2019). Pb_T concentrations of groundwater in the study area range from 58.00 to 697.00 µg/L. According to the WHO (2011) and ITHASY (2005) criteria, the acceptable limit of Pb_T concentration for drinking water is 10 µg/L. Accordingly, all water samples in the study area exceeded the limit value. High Pb_T levels are an important risk factor for human health. This can cause brain damage and nervous system disruption (Boateng *et al.* 2019). As_T concentrations of groundwater in the study area range from 10.60 to 112.34 µg/L. According to the WHO (2011) and ITHASY (2005) criteria, the acceptable limit for As_T concentration in drinking water is determined as 10 µg/L. Accordingly, all water samples in the study area exceeded the limit value. The consumption of water containing arsenic involves a high risk of cancer (Varol & Şekerci 2018). Another trace element determined in the waters of the study area is B. B concentrations of groundwater in the study area are between 100.00 and 958.00 µg/L. The WHO (2011) and ITHASY (2005) guidelines state the acceptable limit of B concentration for drinking water is 2,400 and 1,000 µg/L, respectively. Accordingly, the B concentration of the water samples in the study area is below the limit values. In addition, NO₃ concentrations of groundwater in the study area are between 0.20 and 232.50 mg/L. The WHO guideline state the maximum value for NO₃ in drinking water is 50 mg/L. In the study area, 8 samples (S10, S23, S24, S25, S28, S29, S30 and S31) exceed the acceptable limit for NO₃ among 31 samples. The main source of NO₃ is wastewater due to agricultural

and industrial activities. NO_3 is one of the biggest contributors to groundwater pollution in the world.

Evaluation of arsenic pollution in groundwater

Arsenic is the 20th most abundant element found in the earth's crust, and its presence in the continental crust is at levels of 1–2 mg/kg (Taylor & McLennan 1985). Arsenic is released organically by natural processes such as decomposition and volcanic eruptions (geogenic) and from anthropogenic sources (human activities) and can be transported over long distances as water- or air-suspended particles and aerosols. However, inorganic arsenic, which constitutes the human health risk, is primarily present in the form of arsenate (As^{5+}) or arsenite (As^{3+}). In general, arsenate is dominant in oxidizing conditions, whereas arsenite composition is dominant in reducing conditions. Arsenic in soil may contaminate food products, including vegetables, fruits, and grains after application of drinking water and phosphate fertilizers. Arsenic-containing pesticides and herbicides release liquid and solid wastes containing arsenic that are likely to contaminate water bodies and soil upon disposal.

In the study area, As_T concentrations were between 10.60 and 112.34 ($\mu\text{g}/\text{L}$) in groundwater (Figure 2). Based on the World Health Organization (WHO 2011) and Turkish drinking water guidelines (TSI 266 2005), the maximum acceptable level of arsenic in drinking water is 10 $\mu\text{g}/\text{L}$. The results of the analysis showed that the concentration of As_T in all of the groundwater samples in the study area is well above the permissible limit value. Therefore, the source and transport mechanism of As_T contamination in groundwater was investigated in this study. All samples taken from the study area are in alluvium. Alluvium consists of clay, silt, sand, gravel and block size materials belonging to different surrounding formations (such as Dursunlu, Devriş, Bellekler formations and slope debris). The lithological features of these formations near the alluvium generally consist of clay, marl, sandstone, gravel, limestone, tuff and lignite. In addition, the thickness of the alluvium varies up to about 200 m in the region. The static water level of groundwater measured in the wells in the alluvium varies between about 2 and 10 m. The clay mineralogy, surface area, surface load and presence of sorption sites influence the absorption of arsenic on clay minerals. Studies (Lin & Puls 2000) have shown that arsenic sorption kinetics of clay minerals

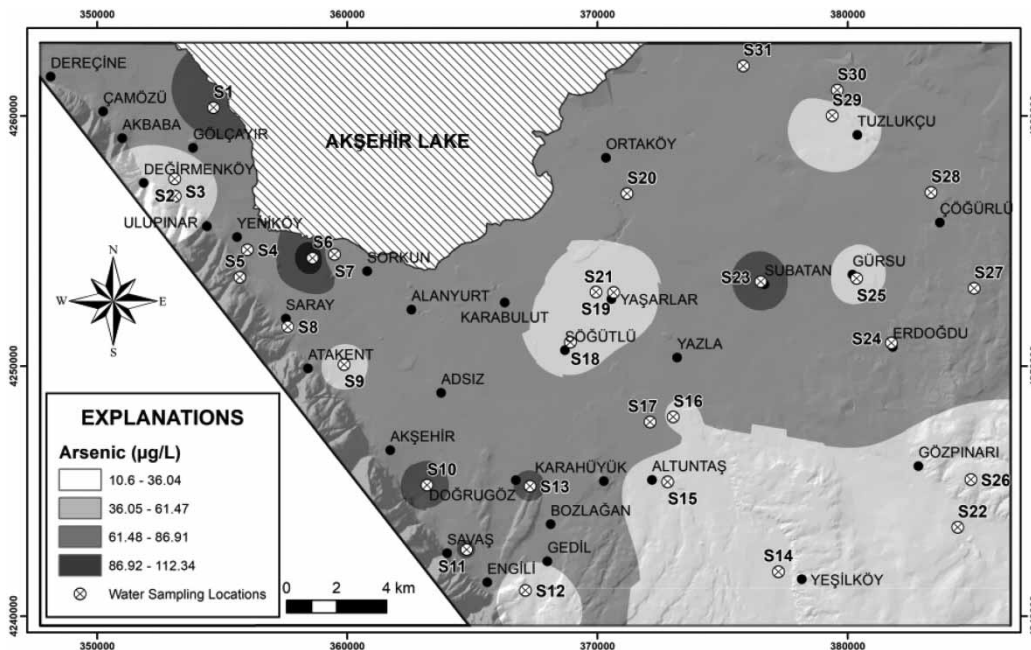


Figure 2 | Spatial distribution map of the arsenic (As) element in groundwater.

such as chlorite, kaolinite, illite, mixed illite–montmorillonite and halloysite are in the direction of As^{5+} compared to As^{3+} . Accordingly, one of the causes of arsenic contamination in groundwater in the study area is thought to be related to clays contained in the environment.

In addition, another cause, and the most important reason for arsenic pollution in the groundwater in the region, is intensive agricultural activities carried out throughout the study area. The main agricultural products grown in the study area are barley, safflower, wheat, potato, sunflower, oat, animal beet, corn, Sudan grass, clover and fruit and vegetables (www.tarimziraat.com). Chemicals due to excessive fertilizers and pesticides used in the cultivation of these agricultural products may cause negative effects on human health. Among them, artificial fertilizers containing phosphorus are the main source of pollution in groundwater from agriculture. Especially phosphate type fertilizers are the main source of arsenic. Other agrochemicals, such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and lead (Pb), have toxic properties and pollute groundwater. The pollution of groundwater negatively affects human health and causes fatal consequences due to carcinogenic effects (Varol & Şekerçi 2018).

Accordingly, the most commonly used fertilizer types in the study area were urea (containing 46% nitrogen (N) which is the highest nitrogen fertilizer among chemical fertilizers), 46% diammonium phosphate (containing 18% nitrogen (N) and 46% phosphorus (P_2O_5)) and 20.20.0 zinc (containing 20% nitrogen (N), 20% phosphorus (P_2O_5) and 1% zinc) in 2018 (KPEST 2019). Apart from the fertilizers, the most commonly used pesticides in the region are herbicides and insecticides. It was determined that the pesticide type which is mainly used in the region exceeds the drinking water guidelines (DTGMCP 2019). This chemical is often used to control weeds in corn products in the study area. All kinds of pesticides applied to wide and empty soil strips between plants pass into the soil during precipitation. Therefore, corn is a product known to carry a high risk of pollution. According to all these data, apart from geological factors, it is thought that arsenic pollution in groundwater is due to anthropogenic factors associated with agricultural activities.

Also, the Eh relationship with pH is an important factor for determining arsenic (As) species. The dominant arsenic

type is As^{5+} under oxidizing conditions and the dominant arsenic type is As^{3+} under reducing conditions. The Eh–pH diagram for As species shows that $\text{H}_3\text{AsO}_4^{2-}$ arsenate species is dominant in groundwater samples (Figure 3).

Arsenic health risk assessment

The consumption of drinking water contaminated with arsenic plays an important role in increasing diseases related to arsenic exposure. Risk assessment is defined in two groups as carcinogenic risk and non-carcinogenic risk. Geographical differences, arsenic (As_T) concentrations within the drinking water, differences in water consumption and anthropometric features such as height and body weight are indicative of the variability of arsenic exposure. Therefore, exposure and carcinogenic effect are determined by taking into account the daily intake, concentration, water consumption rate, body weight and all variations in sex. In the study area, groundwater is used as drinking, irrigation and domestic water by local people through wells. Therefore, in this study, a health risk assessment (chronic and carcinogenic effects such as average daily dose (ADD), $\text{HQ}_{\text{noncancer}}$ and carcinogenic risk (Rc)) was made for arsenic exposure from Akşehir groundwaters through drinking water intake. In addition, health risk values were calculated separately for adults and children and are given in Table 2.

According to Table 2, the values of ADD for As_T were between 0.0001 and 0.0015 (mg/kg) for an adult and between 0.0007 and 0.0072 (mg/kg) for a child. The values of $\text{HQ}_{\text{noncancer}}$ were between 0.4840 and 3.7042 for adults and between 2.2588 and 23.9395 for children. Also, values of Rc were between 0.0002 and 0.0023 for adults and between 0.0010 and 0.0108 for children. The carcinogenic risk is the possibility of developing cancer in the body if a person is exposed to a substance that has a toxic effect throughout their lives. Therefore, tolerable risk values for toxic substances were determined by experts and legal regulators. Accordingly, the tolerable risk values determined for arsenic are between 10^{-6} and 10^{-4} (Varol & Şekerçi 2018). Also, 1–2 out of 10 healthy adults or children in the study area are more likely to develop cancer. In addition, arsenic has high non-carcinogenic and carcinogenic potentially harmful effects. According to drinking water guidelines,

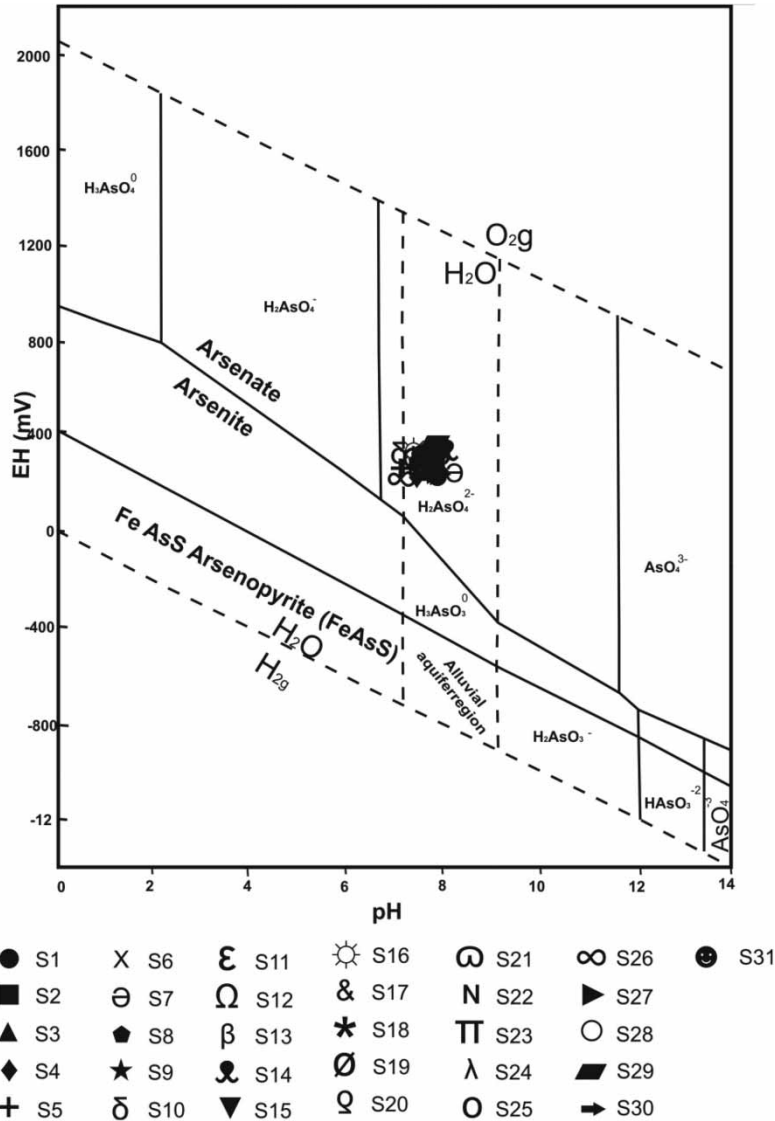


Figure 3 | Eh-pH diagram for arsenic species.

concentrations of As_T in water exceeded the limit values. This also supports the health risk assessment results. These results show that local people living in the study area are at high risk for cancer.

CONCLUSION

In the Akşehir district and surroundings, hydrochemical properties and arsenic pollution in groundwater were examined in terms of effects on human health. In this study, a total of 31

water samples taken from well waters were analyzed in October 2018. In the study, physicochemical, major ion and trace element concentrations of water samples were evaluated separately according to drinking water guidelines. Accordingly, samples were not suitable for use as drinking water in the area as follows: S19, S21, S23, S24, S25, S26, S28, S29, S30 and S31 for TDS, seven samples (S5, S19, S21, S23, S25, S29 and S31) for Mg, three samples (S24, S25 and S29) for Na, five samples (S23, S24, S25, S29 and S31) for SO_4 and five samples (S23, S24, S25, S29 and S31) for Cl. When trace element concentrations are evaluated according to

Table 2 | Reference doses (RfD) and slope factors (SF) of As_T with accepted values for drinking water and ADD, Rc and HQ values for arsenic (adult and child)

| Substance | Water sample number | IR (L/day) | ED (years) | EF (days/years) | BW (kg) | AT (days) | *RfD (mg/kg/day) | *SF (mg/kg/day) ⁻¹ |
|-----------------|---------------------|------------|------------|-----------------|---------|-------------|----------------------|-------------------------------|
| As _T | Adult | 2 | 15 | 350 | 70 | 30/70 × 365 | 3 × 10 ⁻⁴ | 1.5 |
| | Child | 1 | 3 | 350 | 15 | 30/70 × 365 | 3 × 10 ⁻⁴ | 1.5 |

| Samples | Adult | | | Child | | |
|---------|--------|--------|-------------------------|--------|--------|-------------------------|
| | ADD | Rc | HQ _{noncancer} | ADD | Rc | HQ _{noncancer} |
| S1 | 0.0011 | 0.0017 | 3.7042 | 0.0052 | 0.0078 | 17.2863 |
| S2 | 0.0004 | 0.0006 | 1.3196 | 0.0018 | 0.0028 | 6.1583 |
| S3 | 0.0002 | 0.0002 | 0.5327 | 0.0007 | 0.0011 | 2.4860 |
| S4 | 0.0006 | 0.0010 | 2.1512 | 0.0030 | 0.0045 | 10.0389 |
| S5 | 0.0008 | 0.0012 | 2.5642 | 0.0036 | 0.0054 | 11.9662 |
| S6 | 0.0015 | 0.0023 | 5.1299 | 0.0072 | 0.0108 | 23.9395 |
| S7 | 0.0005 | 0.0008 | 1.6763 | 0.0023 | 0.0035 | 7.8228 |
| S8 | 0.0005 | 0.0007 | 1.6032 | 0.0022 | 0.0034 | 7.4818 |
| S9 | 0.0004 | 0.0006 | 1.4176 | 0.0020 | 0.0030 | 6.6153 |
| S10 | 0.0009 | 0.0013 | 2.9477 | 0.0041 | 0.0062 | 13.7561 |
| S11 | 0.0009 | 0.0013 | 2.8432 | 0.0040 | 0.0060 | 13.2684 |
| S12 | 0.0004 | 0.0005 | 1.1963 | 0.0017 | 0.0025 | 5.5830 |
| S13 | 0.0009 | 0.0013 | 2.9234 | 0.0041 | 0.0061 | 13.6425 |
| S14 | 0.0001 | 0.0002 | 0.4840 | 0.0007 | 0.0010 | 2.2588 |
| S15 | 0.0003 | 0.0004 | 0.9924 | 0.0014 | 0.0021 | 4.6312 |
| S16 | 0.0004 | 0.0006 | 1.4358 | 0.0020 | 0.0030 | 6.7005 |
| S17 | 0.0008 | 0.0011 | 2.5053 | 0.0035 | 0.0053 | 11.6915 |
| S18 | 0.0004 | 0.0006 | 1.4384 | 0.0020 | 0.0030 | 6.7123 |
| S19 | 0.0005 | 0.0007 | 1.5728 | 0.0022 | 0.0033 | 7.3398 |
| S20 | 0.0006 | 0.0009 | 1.9280 | 0.0027 | 0.0040 | 8.9971 |
| S21 | 0.0004 | 0.0006 | 1.2288 | 0.0017 | 0.0026 | 5.7345 |
| S22 | 0.0005 | 0.0007 | 1.6063 | 0.0022 | 0.0034 | 7.4960 |
| S23 | 0.0010 | 0.0015 | 3.2694 | 0.0046 | 0.0069 | 15.2572 |
| S24 | 0.0007 | 0.0011 | 2.4160 | 0.0034 | 0.0051 | 11.2748 |
| S25 | 0.0004 | 0.0006 | 1.3167 | 0.0018 | 0.0028 | 6.1446 |
| S26 | 0.0003 | 0.0004 | 0.8635 | 0.0012 | 0.0018 | 4.0298 |
| S27 | 0.0007 | 0.0011 | 2.4992 | 0.0035 | 0.0052 | 11.6631 |
| S28 | 0.0006 | 0.0008 | 1.8620 | 0.0026 | 0.0039 | 8.6893 |
| S29 | 0.0002 | 0.0003 | 0.7121 | 0.0010 | 0.0015 | 3.3230 |
| S30 | 0.0007 | 0.0011 | 2.4049 | 0.0034 | 0.0051 | 11.2227 |
| S31 | 0.0008 | 0.0011 | 2.5495 | 0.0036 | 0.0054 | 11.8975 |

Bold entries indicate HQ value exceeds 1, indicating potential non-carcinogenic but harmful effects.

drinking water guidelines, all groundwater in the study area exceeded limit values in terms of Fe_T, As_T and Pb_T. According to Piper (1944), Ca–Mg–HCO₃ and Ca–HCO₃ were

determined as the water facies in the study area. This shows that water–rock interaction is a powerful factor in the formation of the chemical composition of water samples.

Clay units around the alluvium were found to be the main source of natural arsenic pollution in the area. However, the excessive application of pesticides and fertilizers appears to have greater contribution to arsenic pollution of underground water resources. A health risk assessment was carried out since groundwater is used for drinking purposes in the area. The results indicate that arsenic levels in groundwater constituted an unacceptable carcinogenic and non-carcinogenic health risk to both adults and children. Consequently, groundwater in the study area, which includes Akşehir and surroundings, exceeds maximum acceptable limits for arsenic in drinking water.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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