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INTRODUCTION

Occurrence of arsenic (As) in groundwater has been a major problem worldwide for the last hundred years. Considering its toxic effects on human health, the presence of elevated levels of arsenic in groundwater resources used in drinking water supply has been an active research field throughout the world (Van Halem et al., 2009). In this regard, case studies from Bangladesh, India, Nepal, El Salvador, Ecuador, Honduras, Mexico, Chile, China, Canada, Argentina, Peru, Taiwan, United States, Bolivia and Turkey have been documented with regards to the detection of natural levels in groundwater, the occurrence and distribution mechanisms, the human health effects and the in-situ and ex-situ treatment techniques (Jean et al., 2010). In many of these locations, arsenic is naturally found in the subsurface strata within volcanic and sedimentary formations as well as in areas of geothermal systems related to tectonic activity. Western Anatolia in Turkey is one such area of complex geology with active tectonics and high geothermal potential. This natural setting serves as a suitable environment for the presence of high levels of arsenic in subsurface waters. Based on these fundamentals, this study presents a general overview of arsenic presence in western Anatolia.

GEOLOGICAL SETTING IN WESTERN ANATOLIA

Turkey is one of the most seismically active regions in the world. Its geological and tectonic evolution has been dominated by the repeated opening and closing of the Paleozoic and Mesozoic oceans (McKenzie, 1972; Dewey and Sengör, 1979; Jackson and McKenzie, 1984). It is located within the Mediterranean Earthquake Belt, whose complex deformation results from the continental collision between the African and Eurasian plates (Bozkurt, 2001). The border of these plates constitutes seismic belts marked by young volcanics and active faults, the latter allowing circulation of water as well as heat. The distribution of hot springs in Turkey roughly parallels the distribution of the fault systems, young volcanism and hydrothermally altered areas (Simsek et al., 2002). There are a total of about 1000 thermal and mineral water spring groups in the country (MTA, 1980; Simsek et al., 2002) (Fig. 1).

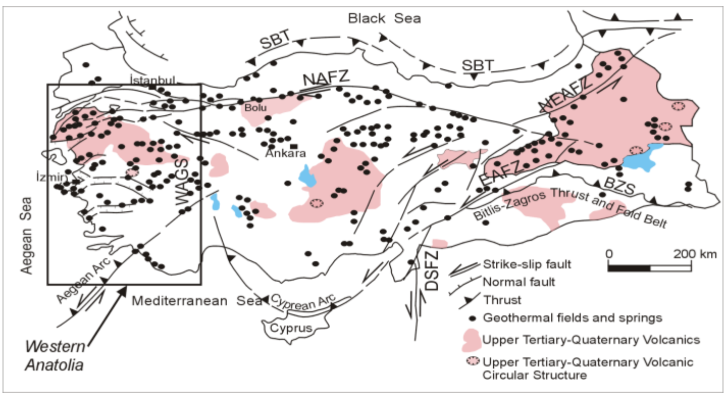

Figure 1. Tectonic map of the eastern Mediterranean region showing structures developed during the Miocene to Holocene time and distribution of geothermal areas around Turkey (compiled from; Simsek et al, 2002 and Yigitbas et al, 2004). (SBT, Southern Black Sea Thrust; NAFZ, North Anatolian Fault Zone; NEAFZ, Northeast Anatolian Fault Zone; EAFZ, Eastern Anatolian Fault Zone; WAGS, Western Anatolian Graben System; DSF, Dead Sea Fault Zone; BZS, Bitlis-Zagros Suture) (Baba and Armannsson, 2006).

The activity of Western Anatolia is believed to be a result of tensional forces that resulted from rigid behavior during the Neogene and Quaternary and the development of extended near-coastal graben areas (Baba and Ármannsson, 2006).

ARSENIC LEVELS IN WESTERN ANATOLIA

The volcanic structure that is dominant in the geological formation of Turkey and particularly western Anatolia is the primary mechanism for the presence of numerous trace elements in earth's crust including but not limited to arsenic, antimony, boron, nickel, lead and zinc. They are also found as impurities in the ores of other minerals including coal (Karayigit et al., 2000; Baba et al., 2009) reaching to levels as high as 6413 ppm as in the case of arsenic. Consequently, these trace elements are dissolved in all geothermal waters and in some cold groundwater resources in many locales in western Anatolia. The concentrations of arsenic in rocks and ores of westerns Anatolia are given in Table 1. Accordingly, arsenic levels as high as 4% are observed in mineral deposits particularly in Kutahya-Emet area, which is known to contain the world's largest boron deposits. In this area, arsenic is typically found in numerous boron minerals as discussed by Helvacı (1986), Helvacı and Orti (1998) and Helvacı and Alonso (2000).

Table 1. Arsenic concentrations in rocks in Western Anatolia.

Site	Province	Type	Maximum level recorded (ppm)	Reference
Halıköy Hg-Sb Mine	İzmir	Ore	8900	Akar (1981)
Kalecik Hg Mine	İzmir	Sediment	9660	Gemici and Oyman (2003)
Bayındır-Sarıyurt	İzmir	Ore	200	Bulut and Filiz (2005)
Balya Pb-Zn Mine	Balıkesir	Ore	1000	Wagner et al (1984)
Kızıldere	Denizli	Rock	268	Ozgur (2002)
Etili	Çanakkale	Rock	700	Unpublished data from Alper Baba
Doğancılar	Çanakkale	Rock	3000	Wagner et al (1984)
Soğukpınar	Çanakkale	Rock	6000	Wagner et al (1984)
Çan	Çanakkale	Coal	6413	Baba et al (2009)
Emet	Kütahya	Rock	500	Aydın et al (2003)
Gökler coal mine	Kütahya	Coal	3854	Karayigit et al (2000)
Emet	Kütahya	Rock	3900	Dogan and Dogan (2007)
Igdekoy-Emet	Kütahya	Ore	40000	Colak et al (2003)
Simav Sb Mine	Kütahya	Ore	660	Gunduz et al (2010)
Dulkadir	Kütahya	Rock	4197	Atabey (2009)
Emet	Kütahya	Rock	19487	Atabey (2009)
Kırka Borate Mine	Kütahya	Ore	>2000	Helvacı and Alonso (2000)
Alaşehir Hg Mine	Manisa	Waste rock	1164	Gemici (2008)

The high levels in Table 1 are mostly related to the alterations in volcanic formations. Typically, arsenic is observed in the alteration zones of volcanic formations as well as in some sedimentary rocks. Based on the tectonic characteristics (see Fig. 1) and the geological structure, many parts of Turkey are likely to have arsenic containing geological formations within which groundwater is also likely to contain high arsenic levels. Most of these rocks are altered and fractured due to the effects of active faults. Basement rocks are composed of Oligocene aged volcanic rocks such as andesite, dacite, rhyodacite, basalt, tuff and agglomerate. Several mineral deposits including numerous industrial metals as well as some precious metals have been found in the alteration zones or fractured parts of these volcanic rocks where arsenic is typically seen as an impurity (Baba, 2010).

Due to the neotectonic structure and volcanism, various altered rock types which may affect the quality of water resources. Thus, arsenic found in groundwaters is typically geogenic in origin and has strong links to the local regional geology. In particular, arsenic is an indicator parameter for hot water reserves of Western Anatolia. It is found in almost all geothermal waters and is used as a tracer (together with lithium and boron) for the detection of contamination in surface and subsurface waters with geothermal fluid (Gunduz et al, 2010). Arsenic levels in geothermal waters of Western Anatolia are presented in Table 2.

Table 2. Arsenic concentrations in geothermal fields in Western Anatolia.

Geothermal Field	Province	Maximum level recorded (ppb)	Reference
Heybeli	Afyon	1249	Gemici and Tarcan (2004)
Çan	Çanakkale	100	Baba and Deniz (2008)
Tuzla	Çanakkale	136	Baba et al (2009)
Karaılıca	Çanakkale	88	Baba and Deniz (2008)
Kestanbol	Çanakkale	100	Baba and Ertekin (2007)
Alibeyköy	Çanakkale	290	Yılmaz et al (2009)
Kızıldere	Denizli	1500	Ozgur (2007)
Balçova-Narlıdere	İzmir	1420	Aksoy et al (2009)
Seferihisar	İzmir	172	Tarcan and Gemici (2003)
Dikili	İzmir	480	Personal comm. with Alper Baba
Simav	Kütahya	594	Gunduz et al (2010)
Gediz	Kütahya	300	Dogan and Dogan (2007)
Yoncalı	Kütahya	950	Dogan and Dogan (2007)
Salihli	Manisa	315	Tarcan et al (2005)
Alaşehir	Manisa	939	Bulbul (2009)
Sart	Manisa	198	Ozen (2009)
Kurşunlu	Manisa	3455	Ozen (2009)
Hamambogazi	Uşak	6936	Davraz (2008)

As seen from the table, arsenic levels are extremely high in many geothermal fields such as Hamamboğazı in Uşak, Kızıldere in Denizli and Balçova-Narlıdere in İzmir. Although ingestion of geothermal waters is not a typical practice in Turkey as it is in some other parts of the world, these high levels serve as potential contamination sources for local cold groundwater and surface waters that are used for drinking water purposes as discussed in details by Aksoy et al. (2009) and Gunduz et al. (2010). These levels are two-to-three orders of magnitude higher than the levels depicted in national (ITASHY, 2005) and international standards (EPA, 2003; WHO, 2004).

Table 3. Arsenic concentrations in groundwater resources in Western Anatolia.

Site	Province	Source	Maximum level recorded (ppb)	Reference
Bigadiç	Balıkesir	Spring	337	Gemici et al (2008)
Ayvacık	Çanakkale	Well	282	Baba (2010)
Çan	Çanakkale	Spring	71	Baba et al (2009)
Etili	Çanakkale	Well	150	Unpublished data Alper Baba
Menderes plain	İzmir	Well	463	Simsek et al (2008)
Nif mountain	İzmir	Spring	294	Simsek et al (2008)
Balçova	İzmir	Well	170	Aksoy et al (2009)
Aliaga	İzmir	Spring	120	Unpublished data Orhan Gunduz
Simav plain	Kütahya	Well	562	Gunduz et al (2010)
Hisarcık	Kütahya	Spring	152	Atabey (2009)
Emet	Kütahya	Spring	634	Oruc (2004)
Igdekoy	Kütahya	Spring	9300	Dogan et al (2005)
Göksu-Sarıkız	Manisa	Well	59	Personal comm. with IZSU* officials
Eşme	Uşak	Well	50	Local newspaper article (2006)

* İzmir Municipality Water and Sewerage Administration.

Similar to geothermal waters, arsenic levels are also high in many locales in western Anatolia as shown in Table 3. Accordingly, high arsenic levels exceeding the standards are observed in provinces such as Balıkesir, Çanakkale, İzmir and Kütahya. Majority of these high levels are from spring and shallow groundwater samples that are in direct contact with alteration zones, which also contain high arsenic levels or that are under the influence of geothermal fluids. It should also be noted that these high levels demonstrate carcinogenic risks on people who ingest these resources for domestic water supply. Furthermore, although there are reports of arsenic occurrence in water resources of many other settlements in western Anatolia other than the ones reported in Table 3, there are unfortunately very few examples of reported and published case studies. Majority of these occurrences are based on sporadic measurements from water supply networks in local laboratories and predominantly find space in newspaper articles. Data published in peer-reviewed journals are rather limited. Thus, there is a need for a state-wide arsenic survey to be conducted on hot and cold water samples taken from surface and subsurface water resources. Such an inventory will provide the necessary spatial and temporal extent required for a detailed review.

CONCLUSIONS

Due to its neotectonic structure and the influence of volcanism, Anatolian Plate contains various altered rock types that contain elevated levels of arsenic and other trace elements. These rocks demonstrate a strong potential to influence the quality of water resources as a result of rock-water interaction in geological formations. Thus, high arsenic levels of geogenic origin are observed in wide spatial extent in Western Anatolia. Values in the order of milligrams per liter are common in some parts of Western Anatolia. These values are several orders of magnitude larger than the national and international standard values and demonstrate a significant health risk for people consuming these waters.

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