An integrated assessment of water quality in an arsenic containing aquifer: milestones from hydrogeology to public health

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ABSTRACT:

A multi-disciplinary research is being conducted in Simav Plain, Turkey where an arsenic containing aquifer is at the center of attention. The study is not only aimed to understand the sources and mechanisms of the presence of high arsenic levels in groundwater but also to determine the associated consequences with regards to human health. The high arsenic levels in most groundwater (N=33, avg. 162 ppb), surface water (N=9, avg. 76.6 ppb) and geothermal water (N=3, avg. 406 ppb) samples are strongly related to high occurrences of arsenic in rocks and soils of the plain, which range between 7.1 and 833.9 ppm with an average of 49 ppm. These values correspond to several orders of magnitude higher than international standards and world averages in water and soil, respectively. With this motivation, this research also focuses on human health in the study area associated with exposure to these high arsenic levels via numerous pathways. Consequently, more than 1000 individuals were personally surveyed by public health specialists to determine an inventory of diseases in the area. Furthermore, a verbal autopsy study was also conducted with relatives of the deceased, which were further verified with hospital records, to understand the underlying death cause. As a result, certain cancer rates were found to exceed national averages and the results statistically demonstrated a potential link with high arsenic levels mainly through oral exposure.

KEYWORDS: arsenic, hydrogeology, water quality, public health, Turkey

INTRODUCTION

Water quality is directly related to human health. Many chemical constituents found in surface and subsurface waters can influence the quality of these resources, which in turn can affect the well-being of populations that depend on them for domestic water supply purposes. Typically, ingestion and dermal contact are the two major routes of exposure to these chemicals. Of the many contaminants that cause degradation in human health status, inorganic chemicals such as arsenic, antimony, boron, chromium, selenium, etc. and organic compounds such as phenols, polyaromatic hydrocarbons, trihalomethanes, etc. are of primary concern in many water quality monitoring activities and are listed high on the research agenda.

Arsenic is a chemical of concern for public health and its occurrence in water resources impacts millions of individuals' worldwide including but not limited to Bangladesh, India, Nepal, El Salvador, Honduras, Mexico, Chile, China, Argentina, Peru, Taiwan, United States and Turkey (Bundschuh *et al.,* 2010). Western Anatolia in Turkey is one such area of interest for the presence of high arsenic levels in groundwater reserves due to its complex geology with active tectonics and high geothermal potential (Gunduz *et al*., 2010a). Being situated in Western Anatolia, the Simav Plain is the primary focus of this research due to the presence of high arsenic levels in surface and groundwater resources as well as many complaints from local inhabitants regarding deteriorating health conditions and increased cases of cancer related deaths. Thus, this study has originated from the necessity to identify the reason for above average internal cancer occurrences within the plain and to assess the potential link between human health and water quality.

PROJECT AREA

The project area is situated near the district of Simav in Kutahya Province, Western Anatolia, Turkey. Simav Plain is a graben region surrounded with an area of complex geology and forms the central focus of this study (Fig. 1). The graben plain is composed of the alluvial deposits that originated from the surrounding terrain and provides groundwater for domestic, agricultural and industrial consumption. Previous studies in the project area has revealed the presence of arsenic in surface and groundwater resources (Simsek and Gunduz, 2007; Gunduz *et al*., 2010b). The project area demonstrates some unique characteristics, one of which is the shallow Simav Lake that was drained in mid 1960s in order to gain land for agricultural production. From a hydrological viewpoint, the lake acts as an intermittent wetland where a shallow lake re-forms during winter and dries during summer. A regulator structure near the village of Bogazkoy controls the outflow from the plain (Fig. 1). The area is also unique with regards to geothermal reserves. Currently, there are three geothermal fields (i.e., Eynal, Nasa and Citgol) within the project area (Fig. 1).

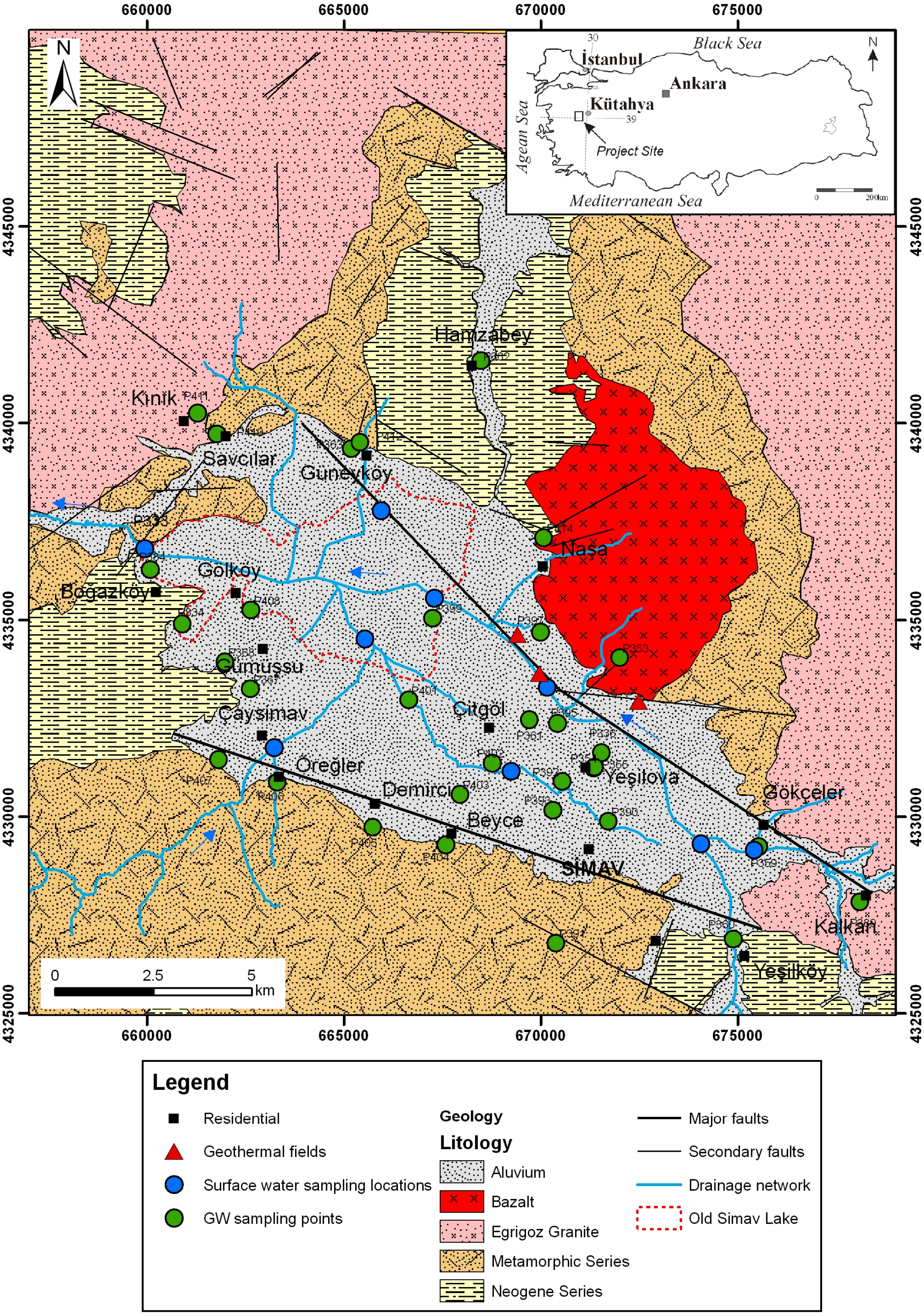

Figure 1. Project area and its environs

GEOLOGICAL AND HYDROGEOLOGICAL STUDIES

Five major geological units define the regional geology of the study area (Fig 1). Paleozoic-aged Menderes Metamorphics form the base rock, which is overlaid in sequence by Paleocene-aged Egrigoz granite; Neogene-aged complex Kizilbuk formation that contains claystone, conglomerate, sandstone, agglomerate and tuff; Lower Quaternary basalt and Quaternary alluvium (Gunduz *et al*., 2010b). The project site is an area of complex tectonic structure with the presence of numerous active fault lines that also resulted in three geothermal fields (i.e., Eynal, Nasa and Citgol). Geothermal fluid extracted from these fields is used in domestic and green house heating, in thermal spas and in wool cleansing and treatment. The waste geothermal fluid from these uses is discharged into the surface water drainage network in an uncontrolled manner.

The project area is characterized by two major aquifer systems; (i) an unconfined aquifer from which domestic, industrial and agricultural water demand is satisfied, and (ii) a deep confined aquifer, which typically provides the geothermal fluid. The alluvial aquifer has a variable thickness and locally reaches to 150 m in central parts of the plain. The alluvial aquifer is mostly formed from varying sizes of silt, sand and clay and is formed as a result of the deposited material originating from the slopes surrounding the graben area.

To better quantify and understand the hydrogeology and hydrogeochemistry of this area, more than 800 m of new boreholes were drilled to different levels at 15 different locations (Fig 2). Core samples were obtained from these boreholes, which were later converted to water quality monitoring wells. The results from core samples revealed arsenic levels ranging between 7.1 to 833.9 ppm with an average and standard deviation of 49 ppm and 80.2 ppm, respectively. The spatial distribution of average arsenic levels along the vertical profile are presented in Fig 2. When compared with the average earth crust arsenic content of 1.5 ppm (URL1), samples from the project area demonstrate levels that are 2 to 3 orders of magnitude higher than the world average. The water quality monitoring from these new wells is currently in progress and provide data similar to the screening level monitoring campaign. Considering the relation between iron and arsenic in water samples, the spatial distribution of iron oxide levels in core samples is shown in Fig 3. The iron levels in these samples ranged between 1.49% to 13.34% with an average and standard deviation of 4.77% and 1.90%, respectively. The iron levels in Simav Plain samples were mostly close to the world average of 6.7% (URL1).

WATER QUALITY ASSESSMENT

A water quality monitoring campaign of surface and subsurface water resources within the plain was conducted to determine the general water quality of surface and subsurface water resources. As a part of this screening level monitoring activity, groundwater (N=33), surface water (N=9) and geothermal (N=3) samples were collected from an area of about 200 km^2 (Fig. 1).

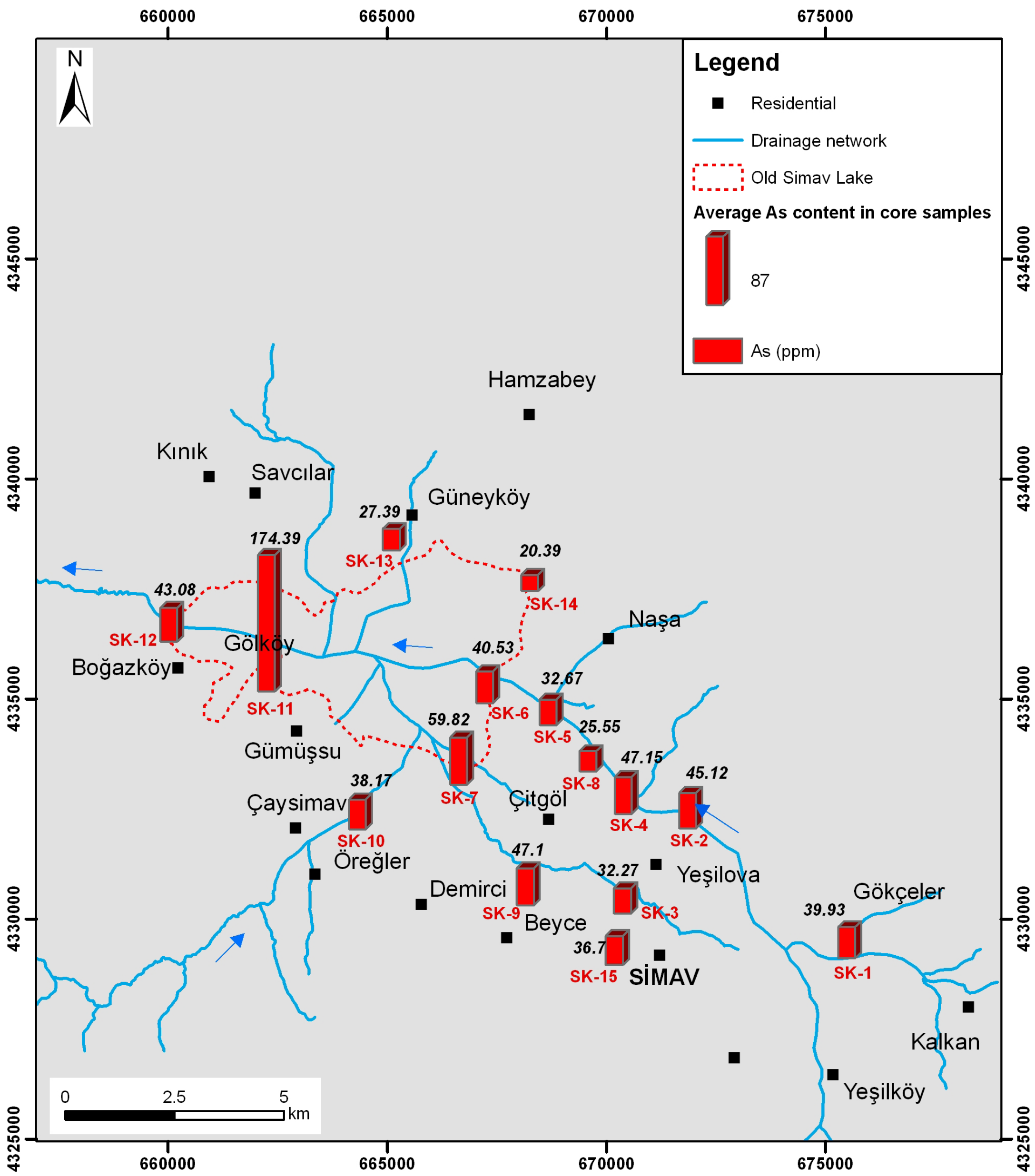

Figure 2. Depth averaged soil arsenic content of core samples in 15 monitoring well locations

These samples were then analyzed for physical parameters, major anions/cations and heavy metals and trace elements. The statistical summary of this monitoring activity is presented in Table 1. The primary finding of this activity was the presence of arsenic in most groundwater (avg. 162.6 ppb) and surface water (avg. 76.6 ppb) and in all geothermal (avg. 406 ppb) samples. These values were found to be several orders of magnitude above the national (ITASHY, 2005) and international (EPA, 2006) standard limit of 10 ppb.

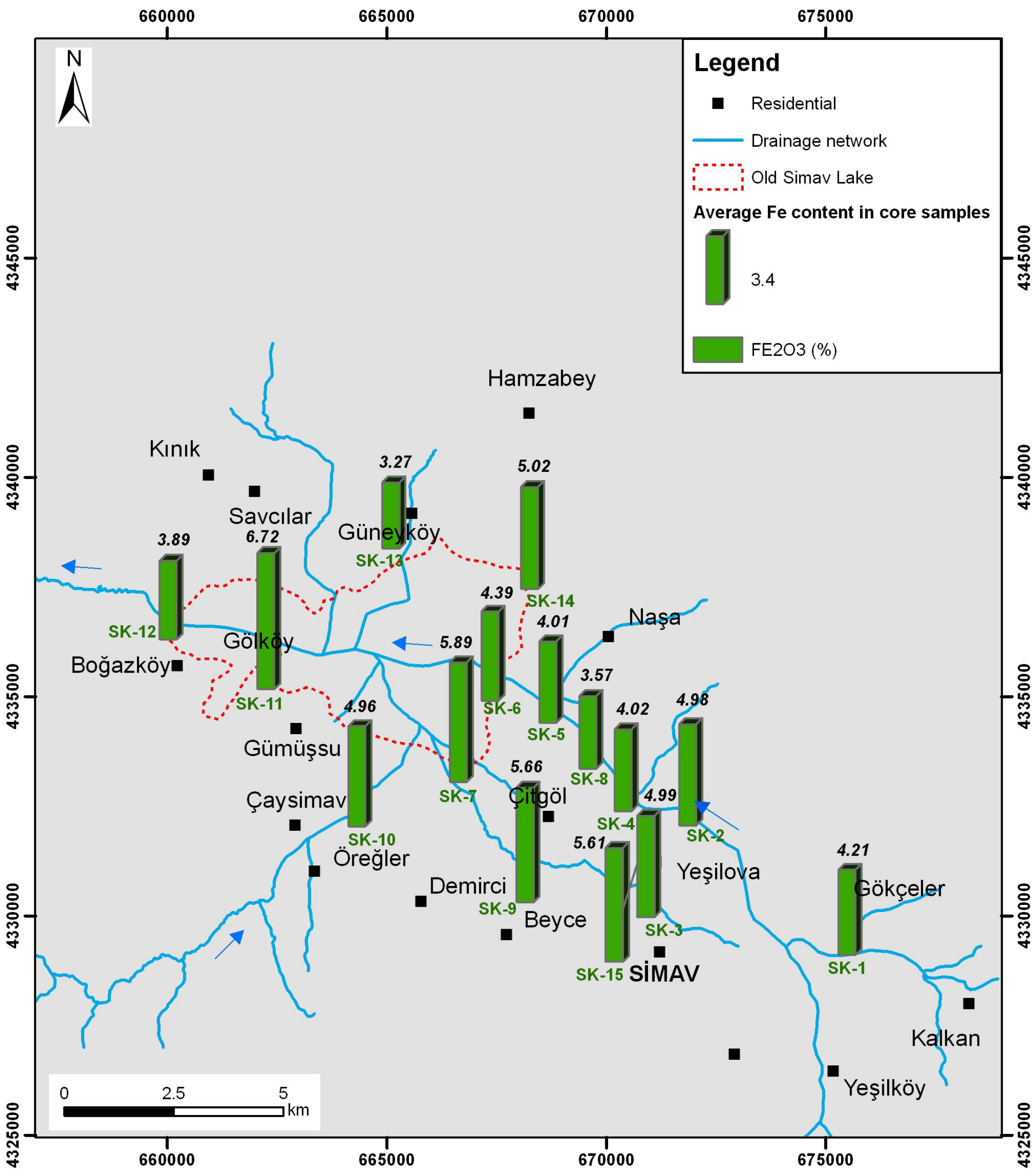

Figure 3. Depth averaged soil iron content of core samples in 15 monitoring well locations

High arsenic level in geothermal waters was associated with water-rock interactions under high temperature and pressure conditions in deep aquifer conditions. Without proper re-injection activities, the extracted geothermal fluid is discharged to surface waters creating significant increases from their associated background levels detected in upstream reaches from the plain (Fig 4). In groundwater, on the other hand, arsenic levels ranged between 0.5 ppb and 1851 ppb, with an average value of 162.6 ppb. The spatial distribution of these values pointed out the fact that the majority of samples from drinking water supplies of villages located near the mountain ridges had arsenic levels below the standard limit of 10 ppb.

Table 1. Statistical summary of water quality monitoring activities in Simav plain

Parameter	Unit	Minimum			Maximum			Average*		Standard Deviation*		ITASHY (2005)	EPA (2006)
		Surface Water	Ground Water	Geothermal Waters	Surface Water	Ground Water	Geothermal Waters	Surface Water	Ground Water	Surface Water	Ground Water		
Temp.	ºC	15.60	12.40	90.00	25.00	23.40	160.00	21.02	17.13	2.98	2.49	25	-
pH	-	7.66	6.72	7.35	8.68	7.90	8.92	8.17	7.35	0.40	0.27	6.5-9.5	6.5-8.5
ORP	mV	-1.00	-123.00	-75.00	135.00	192.00	217.00	72.67	53.95	43.22	87.97	-	-
E.C.	µS/cm	356.00	37.90	1633.00	3310.00	2127.00	2490.00	1006.67	574.60	890.87	405.88	2500	
D.O.	mg/L	0.60	1.08	3.50	11.79	10.40	4.65	5.66	5.23	4.30	3.23	-	-
TOC	mg/L	3.68	2.05	3.35	113.00	15.12	4.62	24.30	3.98	34.30	2.84	-	-
HCO_3^-	mg/L	207.40	14.64	585.60	907.44	800.32	744.20	428.33	320.82	198.64	183.50	-	-
Li^+	mg/L	0.09	0.07	0.97	0.28	1.32	2.09	0.15	0.35	0.07	0.55	-	-
Na^+	mg/L	3.95	2.51	296.99	156.32	290.80	531.63	52.29	26.04	50.18	49.76	200	-
NH_4^+	mg/L	0.35	0.16	0.09	10.80	6.08	0.09	3.18	2.19	3.67	2.16	0.5	-
K^+	mg/L	2.08	1.23	31.04	36.14	39.58	60.56	15.75	4.55	12.20	7.72	-	-
Mg^{+2}	mg/L	16.74	6.66	10.61	42.29	42.66	10.61	28.82	24.13	7.67	9.93	50	-
Ca^{+2}	mg/L	54.10	24.24	38.17	112.57	256.35	65.22	76.48	91.58	18.82	48.21	200	-
F^-	mg/L	0.22	0.19	5.05	1.95	4.08	19.31	0.77	0.47	0.58	0.75	1.5	4
Cl^-	mg/L	3.26	2.12	46.39	101.52	76.61	76.77	24.80	11.21	30.65	15.95	250	250
SO_4^{-2}	mg/L	36.53	0.95	347.16	2527.30	726.71	525.12	357.84	61.86	815.34	134.32	250	250
NO_2^-	mg/L	0.15		0.38	0.36		0.78	0.23		0.11		0.5	3.3
Br^-	mg/L	0.03	0.02	0.14	0.08	0.16	0.35	0.05	0.05	0.02	0.04	-	-
NO_3^-	mg/L	0.28	0.22	0.23	3.31	20.09	2.87	1.74	2.80	1.61	4.59	50	44.3
PO_4^{-2}	mg/L	0.10	0.08	0.10	8.38	1.65	13.33	1.98	0.37	3.04	0.43	-	-
Al	µg/L	18.00	1.00	4.00	2896.00	1114.00	188.00	508.89	84.84	923.35	229.63	200	200
As	µg/L	4.60	0.50	311.60	402.80	1851.00	542.90	76.56	162.64	124.66	372.33	10	10
B	µg/L	6.00	6.00	2667.00	758.00	2170.00	3784.00	294.44	130.33	269.66	412.59	1000	-
Ba	µg/L	36.78	13.23	66.40	149.82	421.03	101.92	100.22	136.84	39.16	122.97	-	2000
Co	µg/L	0.09	0.03	0.02	10.63	2.32	0.08	1.79	0.44	3.37	0.70	-	-
Cs	µg/L	0.05	0.01	164.36	50.33	7.45	270.86	11.76	0.82	16.05	1.64	-	-
Cu	µg/L	1.00	0.10	1.40	21.40	8.20	3.10	4.66	1.74	6.50	1.79	2000	1300
Fe	µg/L	51.00	15.00	20.00	7315.00	22211.00	410.00	1398.63	3300.83	2414.38	6293.54	200	300
Mn	µg/L	16.34	0.29	34.93	3027.32	2937.77	547.16	564.44	632.41	962.52	967.30	50	50
Pb	µg/L	0.20	0.10	0.30	19.20	25.60	0.40	3.29	2.28	6.08	5.80	10	15
Sb	µg/L	0.25	0.05	23.49	6.55	2.01	41.87	1.73	0.43	1.89	0.53	5	6
Se	µg/L	0.50	0.50	0.50	5.40	1.00	1.00	2.95	0.77	3.46	0.18	10	50
Sr	µg/L	111.88	31.17	418.23	3022.15	1578.49	896.32	643.33	375.27	900.03	352.50	-	-
Zn	µg/L	1.50	0.50	5.50	39.20	101.70	36.10	12.98	9.26	13.91	18.61	5000	5000

* Since there are only three geothermal water samples, average and standard deviation are not calculated.

On the contrary, almost all samples collected within the plain boundaries had higher arsenic levels. Thus, arsenic is said to dominate the alluvial deposits within the plain (Fig 4). When the oxidation-reduction potentials (ORPs) of these samples are assessed, it was observed that the samples from the plain were under reductive conditions, which is known to favor the presence of more toxic arsenite (As+3) form. Similarly, high correlations of arsenic with iron and manganese in plain samples are consistent with its preference to adsorb on iron and manganese precipitates.

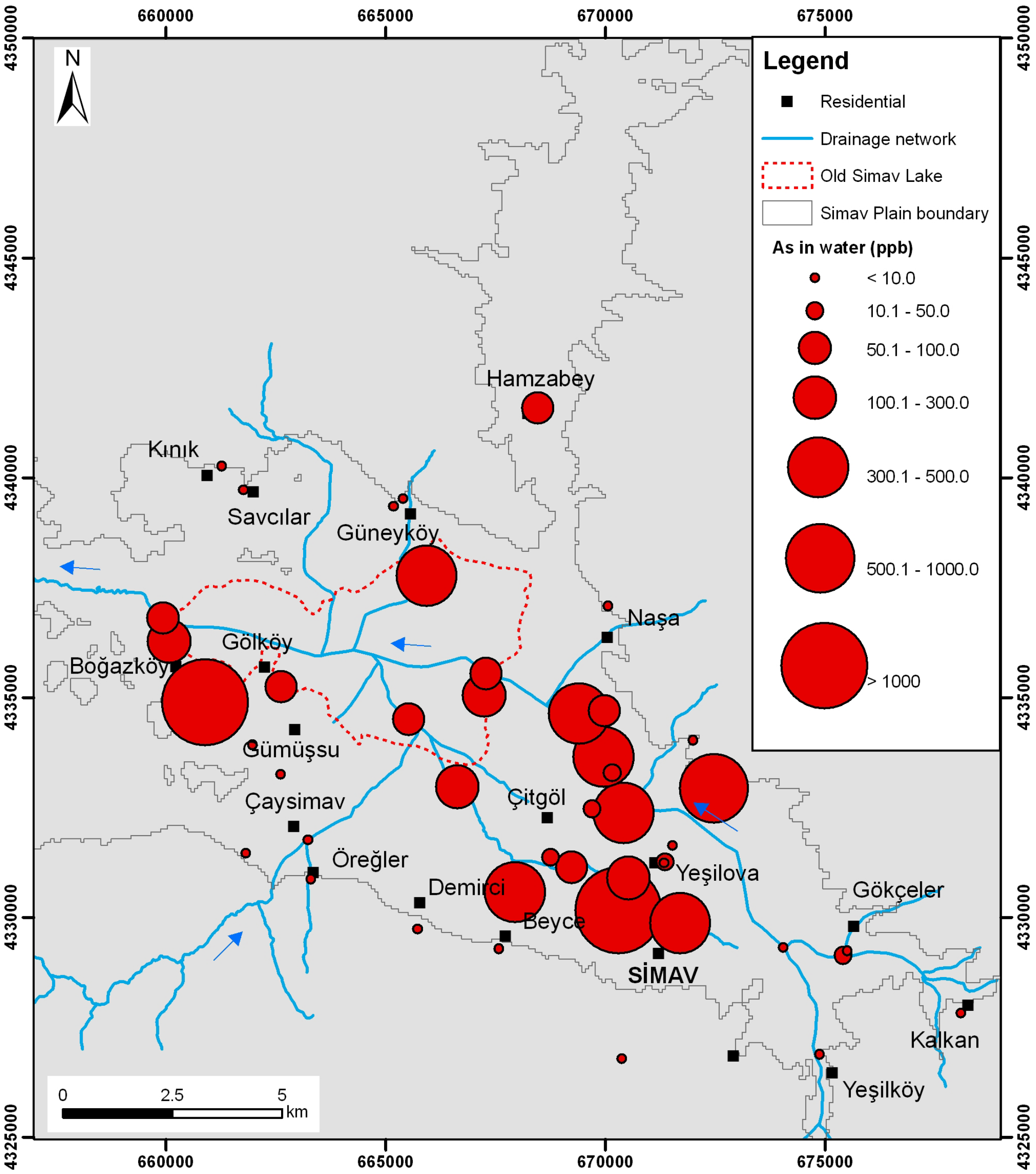

Figure 4. Total dissolved arsenic values obtained from water quality monitoring

The preliminary results obtained from two new sets of water quality monitoring in the observation wells shown in Fig 2 further support these findings (Gunduz *et al*., 2011). Higher levels of arsenic were obtained in boreholes situated in central parts of the plain and particularly in wells that are drilled in the confined aquifer. The reductive conditions and the dominance of arsenite in the confined aquifer point out the fact that a vast volume of subsurface underneath the plain is affected by elevated dissolved arsenic concentrations. In essence, this region coincides with the area where Citgol, Bogazkoy and Golkoy have provided groundwater for more than two decades.

PUBLIC HEALTH STUDIES

Finally, a public health study was undertaken in the study area with particular emphasis on settlements that supply their drinking water requirements from this high arsenic containing aquifer (i.e., Bogazkoy, Golkoy, Citgol, Oregler and Demircikoy). Of these five villages, Oregler and Demircikoy were selected as control villages that had below standard arsenic in their drinking water, while the others all had higher levels of arsenic in their water supply for at least 20+ years. The public health studies were conducted as in two phases. In first phase, a public health survey was conducted with 1003 people living in these five villages to determine an inventory of diseases. In the second phase, oral autopsy surveys were conducted with the relatives of deceased during 2005-2010 period to determine the cause of death. For all other cases of death where no relative was found, official death records were used to identify the death cause.

A total of 402 death cases were found in these five villages during the aforementioned period where 171 of them were analyzed with oral autopsy surveys and the remaining 231 were determined from official death statistics records. Accordingly, it was found that about 53% of all deaths were male and 81% were above the age of 65. The crude death rate was computed to be 8.3‰. Of all cases, 44% was related to cardiovascular system diseases and 15.2% was due to cancers. Cancer was determined to be the second important cause of death in the project area. When compared to Demircikoy and Oreyler, total number of cancers were seen in higher numbers in the villages of Golkoy, Bogazkoy and Citgol. The number of bronchi and lung cancers were highest among other cancer types in all villages with a relative total percentage exceeding 44%. Prostate, colon and stomach cancers were other predominant cancer types with percentages of 9.8%, 9.8% and 8.2%, respectively. The deaths related to liver, stomach, bladder and prostate cancers were all detected in the three villages with high arsenic levels in their drinking water supply. The deaths related to bronchi, lung and colon cancers were observed in similar ratios in all villages. Although no statistically significant differences were detected in cancer related death causes between the villages, it was important to find out the fact that all cases of liver, bladder and stomach cancers were observed in villages with high arsenic levels in drinking water supply.

CONCLUSIONS

The influence of water quality on human health is a complicated topic that requires a comprehensive multi-disciplinary research approach. A wide array of experts from hydrogeology to public health must work in harmony to achieve results, which could eventually improve the quality of life. The research conducted in Simav Plain, Turkey aims to shed light to the above average occurrences of some internal cancer types, in an area where high arsenic levels are detected in soil and in surface and groundwater resources. The results revealed very high arsenic content in plain soil/rock samples. Although water quality monitoring activity is still underway in 20 new boreholes drilled in different layers of the unconfined and confined aquifers, preliminary findings demonstrated a trend parallel to soil/rock samples where dissolved arsenic levels were also found to exceed the national and international standards several orders of magnitude. Residential areas found in central parts of the plain used these waters for domestic water supply purposes for varying periods and have experienced higher occurrences of certain cancer types.

ACKNOWLEDGEMENTS

This research is funded by the Scientific and Technological Research Council of Turkey (TUBITAK) through project 109Y029.

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