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Research Article

ARSENIC CONTAMINATION IN GROUNDWATER OF THE AREAS SURROUNDING INGALDHAL, CHITRADURGA DISTRICT, KARNATAKA STATE

Annapoorna Hebbar[1] and *Janardhana M.R.[2]
[1]*Department of Studies in Earth Science, University of Mysore, Manasagangotri, Mysore.570006*
[2]*Department of Geology, Yuvaraja's College, University of Mysore, Mysore. 570005*
**Author for Correspondence*

ABSTRACT
Elevated concentration of arsenic in drinking water is a major health hazard. Arsenic contamination of the groundwater by natural and anthropogenic sources is a serious problem faced by developing countries. The present study focuses on the qualitative assessment of groundwater of Ingaldhal and surrounding villages of Chitradurga district, Karnataka state, India, with an emphasis on arsenic contamination. An objectionable level of arsenic concentration ranging from 0.104 mg/l to 0.235 mg/l has been detected in the groundwater samples collected from the bore wells and hand pumps located in the rural areas surrounding a defunct copper mine at Ingaldhal in Chitradurga district of Karnataka state. According to the standards prescribed by WHO (2008) and BIS (1991), groundwater of the Ingaldhal region is unfit for drinking purpose. The study reveals that the source of contamination of arsenic in groundwater of the study region is both natural and anthropogenic as the area is known for base metal sulphide mineralization and the mining activity.

Keywords: *Groundwater, Arsenic Contamination, Health Hazard, Ingaldhal, Chitradurga, India*

INTRODUCTION

Arsenic is a naturally occurring chemical in the environment. Potable water is a major carrier of arsenic into the food chains and thus, elevated concentration of arsenic in water is a major health hazard. Arsenic-containing groundwater is the primary medium of exposure in many areas of the world influencing large populations (Arsenic Project, 2008). Cancer is the most striking long term effect of chronic exposure to inorganic arsenic (Armlenta *et al.,* 1997). Natural arsenic content in groundwater at concentrations above the permissible drinking water limit of 0.1 mg/l (WHO, 2008) is not uncommon. Man-made sources of arsenic, such as mineral extraction and processing wastes, poultry and swine feed additives, pesticides, and highly soluble arsenic trioxide stockpiles are also not uncommon and have caused the contamination of soils and ground waters (Nordstrom, 2002). Rama Mohan *et al.*, (2012) recorded the occurrence and distribution of arsenic in and around Nuggihalli chromite mining areas, situated in Hassan district of Karnataka state, India. The study demonstrated that almost 79% of examined water samples exhibit arsenic concentration higher than the maximum permissible concentration limit of WHO specifications (0.01mg/l) for drinking waters.

Arsenic is commonly concentrated in sulfide-bearing mineral deposits, especially those associated with gold mineralization (Nordstrom, 2002) and it has a strong affinity for pyrite (Kolker *et al.,* 1998). Wastes produced during mining and beneficiation processes of sulphidic ores and protores, if left on the ground, acts as a potential source of arsenic contamination of groundwater. High arsenic levels in sulphide-bearing parent rocks are also responsible for high concentrations in groundwater. When found in levels exceeding 10 μg/l in water and 90 μg/kg in soils, arsenic is proven to demonstrate toxic effects to human health (WHO, 2001; EA, 2002).

India is one among the countries in Asia, severely affected by arsenic contamination in drinking water. Mukherjee *et al.,* (2006) attempted to summarize the incidents of arsenic contamination in groundwater around the world emphasizing the recent finding in Asian countries. Further, they inferred that there are areas where this problem still remains to be recognized and called for the early identification of the affected areas. Perhaps owing to several factors ranging from ignorance of severe health hazard of As contaminated water to paucity of resources and technical know-how for identification of regions of taxing water resources and negligence of concerned authorities to bright to the notice of the end users. In this direction, the present study has been undertaken with an aim to assess the arsenic concentration and possible concentration in groundwater of the Ingaldhal area and its spatial distribution along with the other quality parameters.

Study Area

Ingaldhal is a small village on the outskirts of Chitradurga town of Karnataka state. It is located at about 8 km southeast of Chitradurga town and is well connected to National Highway-4. The study area encompassing Ingaldhal lies within 76° 25’: 76° 30’ E longitudes and 14° 08’: 14° 12’ N latitudes (Figure 1) and covers a geographical area of about 61. 47 sq. km. The study area and its surrounding villages lack any major surface water resources and the population is entirely dependent on groundwater for their drinking and agricultural purposes. In the Karnataka state, the areas surrounding the Belligudda Hill in the Chitradurga district gained prominence owing to the occurrence of commercial grade copper and gold ores which were recovered by underground mining. The Ingaldhal Copper Mine (named after Ingaldhal Village) is located in Belligudda Hill and the mining activity was in operation during the period from 1966 to 1995. The mining of the copper and gold ores was abandoned now due to low recovery of copper and other base metals. The study area falls in the middle of the well-known Chitradurga schist belt of Dharwar Craton, exposing volcano-sedimentary rocks.

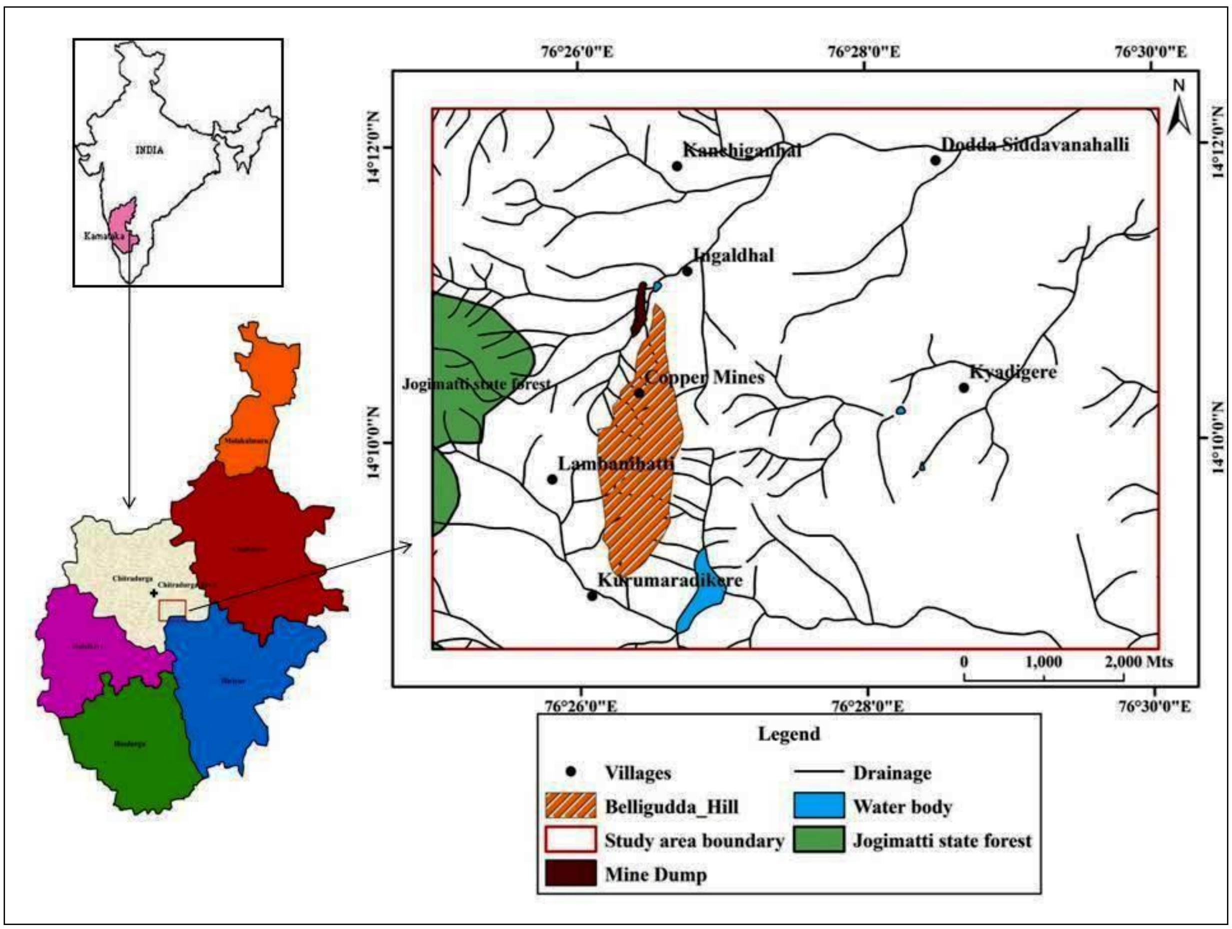

Figure 1: Location Map of the Study Area

Geomorphologically, the area represents an undulating plain with linear structural hills and valleys (1150 – 600 m above m.s.l), and the supracrustal rocks of the terrain is composed of volcano-sedimentary rocks of Precambrian age (older than 2600 m.y). The study area is characterized by flat lying shallow pediplains which are used extensively for agricultural purpose. It is relatively a hot place in Karnataka state with annual temperature ranging from 17° to 41°C. The study area is a drought prone area where normal annual rainfall ranges between 100 and 200 mm. The area is located in Krishna drainage basin. The drainage is mainly of ephermal type; pattern is largely dendritic over undulating and plain terrains and trellis between the ridges of the structural hills. Major soil classes found in the study area are shallow black soil, mixed red and black soil, red loamy and sandy soil.

Mineralization

Ingaldhal in Chitradurga greenstone belt of Dharwar craton has been known for copper±gold mineralization since over sixty years. The mineralized area (with over one million tons of copper ore grading 1% Cu) supported a copper mine which was active for over 25 years, producing copper concentrates containing 25% Cu, 4gm/t gold and 40gm/t silver (Vasudev, 2009). The host rocks for copper mineralization are pillow metabasalt and bedded epiclastic volcaniclastites (identified as agglomerates), bedded tuffs and banded sulphidic cherts, the latter representing volcanic exhalites. The sulphide ore comprises an assemblage of chalcopyrite ($CuFeS_2$), pyrite (FeS_2), pyrrhotite (FeS_{1-x}), arsenopyrite (FeAsS), tennantite [$(CuFe)_{12}As_4S_{13}$], sphalerite, galena, cobaltite, linneaite, tetrahedrite, minor bornite, chalcocite, argentite and arsenopyrite, in that order of abundance. Geochemical data of ore-bearing metavolcaanics and ore zone of Ingaldhal reveal an average of arsenic concentration at 300- 400 ppm (Antony, 1999).

Vidyavathi *et al.*, (2008) reported the presence of arsenic content in mine waste generated from the concentrator plant is ~ 0.041 mg/kg.

MATERIALS AND METHODS

Groundwater samples from 21 deep bore wells and 1 open dug well (sample ID w12) (Table 1) of the unconfined aquifer of the Ingaldhal area were collected in duplicate in new pre-cleaned polypropylene bottles (1L capacity) in the month of October 2013 (post-monsoon season). Before collecting the water samples, the water was pumped out from bore wells for about 10 min to remove stagnant groundwater. Prior to sampling, water was filtered through 0.45 Millipore membrane. The physical parameters measured and recorded in the field are colour, taste, odour, temperature, EC (using conductivity meter) and pH (using pH meter).

Water samples were acidified with 1% HNO_3. Calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and chloride (Cl^-) were analyzed by volumetric titration methods; sodium (Na^+) and potassium (K^+) were measured using the flame photometer; sulphate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-) were determined by spectrophotometric technique as per the methods described by the American Public Health Association (APHA, 1995). Arsenic concentration in the groundwater samples is measured using Jobin-Yvon ICP Spectrometer, by following standard procedure.

RESULTS AND DISCUSSION

Physico-Chemical Characteristics

The results of the general investigations of the physico-chemical parameters are presented in table 1. The arsenic contaminated groundwater of the study area in terms of me/l, are characterized by $Mg^+ > Na^+ > Ca^{2+} > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^- > CO_3^-$. Hydrochemically the groundwater contains higher concentrations of TDS, Mg^{2+} and HCO_3^-, moderate concentrations of Ca^+, Na^+ and Cl^-, and lower concentrations of K^+, SO_4^{2-} , F and NO_3^-.

Assessment of the quality of the groundwater of the study area indicate that the groundwater belong to hard to very hard category and based on the major ion concentration in the groundwater from majority of the bore wells of the study region is unfit for drinking purposes (Annapoorna and Janardhana, 2015).

Natural Mechanisms Controlling Groundwater

Plots of Gibbs ratios of groundwater samples on Gibbs diagrams (Gibbs, 1970) can provide information on the relative importance of three major natural mechanisms controlling water chemistry: (1)

atmospheric precipitation (2) mineral weathering, and (3) evaporation and fractional crystallization. Gibbs diagram (TDS versus $Na^{+}+K^{+}$ / $Na^{+}+K^{+}+Ca^{2+}$) drawn for the groundwater samples of the study area indicate rock weathering and evapo-concentration of solutes. In addition, samples which fall on outside the designated fields in the Gibbs' diagram indicate the role of anthropogenic activities in altering the chemistry of the groundwater (Figure 2a) (Annapoorna and Janardhana, 2015).

Hydrochemical Facies

Hydrochemical facies of groundwater can be evaluated based on the plots of hydrochemical data (in meq/l) on Piper's trilinear diagram (Piper, 1944, 1953). The plots indicate that the groundwater samples, hydrochemical facies-wise, belong to $CaMgHCO_3$ (n = 9), $CaMgSO_4$ (n = 6), NaCl (n = 1) types. Groundwater samples from five bore wells reveal the signature of mixed type hydrochemical facies (Figure 2b) (Annapoorna and Janardhana, 2015).

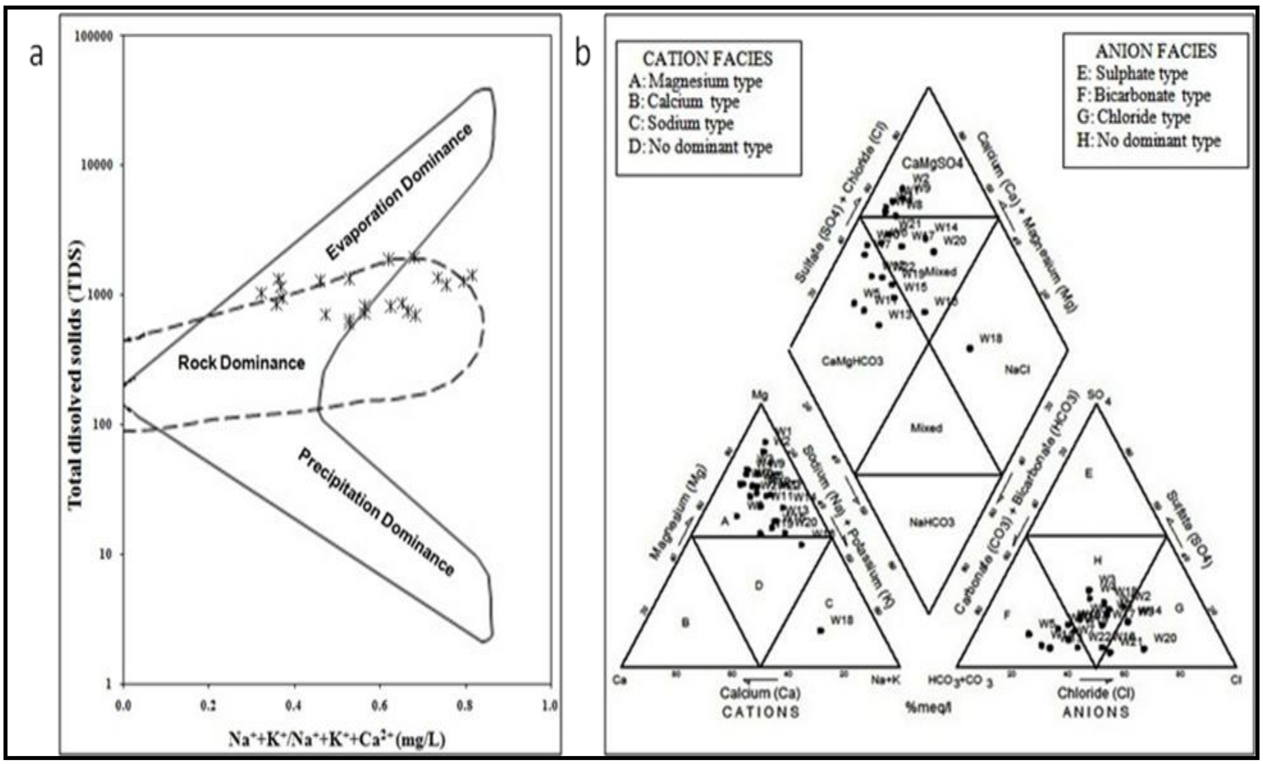

Figure 2: Plots of the Hydrochemical Composition of the Groundwater Samples (n=22) of the Study Area on (a) Gibbs Diagram (b) Piper Tri-Linear Diagram (Source: Annapoorna and Janardhana, 2015)

Arsenic Concentration in the Groundwater of the Study Area

Arsenic in drinking water can impact human health and is considered as one of the prominent environmental causes of cancer mortality in the world (Smith *et al.*, 1992). The study area is located in a semi-arid region wherein the people of the terrain are entirely dependent on the groundwater for their domestic needs. In the groundwater samples collected from 21 deep bore wells and 1 open dug well located in the study area, arsenic concentration varies from 0.104 mg/l to 0.235 mg/l (Table 1). Spatial distribution of arsenic in the study area is shown in the Figure 3. The maximum arsenic concentration was found in the groundwater of the well W1 located inside Ingaldhal Village. Groundwater from a shallow dug well (W12) has lowest arsenic concentration of 0.104 mg/l (Table 1).

According to the standards given by WHO (2008), the maximum permissible limit for arsenic concentration in drinking water is 0.01 mg/l. Indian Standard 10500 – 1991 BIS, (1991) has restricted the maximum permissible limit of arsenic concentration in drinking water to 0.05 mg/l.

Table 1: Physico-Chemical Parameters and Arsenic Concentration (in mg/l) of the Groundwater Samples (n=22) of the Ingaldhal Area, Chitradurga District, Karnataka

Sl. No	Sample ID.	TDS	EC	TH	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	F^-	NO_3^-	SO_4^{2-}	As
1	W1	1937	3489	1440	7.43	56	325	120	6	877	372	0.19	170	350	0.235
2	W2	1882	3253	1320	7.71	75	283	123	6	724	412	0.18	154	364	0.151
3	W4	1154	2002	860	7.55	96	155	56	2	586	171	0.18	51	280	0.131
4	W5	946	1686	720	7.43	86	126	51	0	481	143	0.2	50	200	0.137
5	W6	597	1059	356	7.55	42	63	47	1	431	42	0.16	106	51	0.118
6	W7	697	1235	480	7.48	61	84	55	1	386	98	0.24	80	95	0.128
7	W8	844	1613	688	7.58	93	112	52	1	623	134	0.24	36	75	0.142
8	W10	1317	2316	1000	7.42	112	80	64	0	623	255	0.13	80	215	0.153
9	W11	1336	2316	916	7.68	91	172	102	2	536	316	0.18	95	190	0.146
10	W12	1032	1928	828	7.24	117	134	56	0	715	148	0.14	30	140	0.104
11	W13	720	1325	468	7.48	66	76	86	0	563	76	0.09	60	45	0.144
12	W14	638	1170	440	7.71	56	75	63	0	451	78	0.12	41	75	0.139
13	W15	693	1219	368	7.55	50	61	108	0	544	87	0.17	45	40	0.146
14	W16	1407	2440	548	7.28	67	95	299	9	833	308	0.18	13	90	0.167
15	W17	743	1307	444	7.58	46	82	92	1	367	137	0.11	80	92	0.146
16	W18	1263	2126	588	7.62	54	13	212	2	573	224	0.13	20	252	0.158
17	W19	815	1408	460	7.68	83	63	108	2	461	109	0.06	110	80	0.160
18	W20	1355	2246	560	7.24	83	100	231	2	500	364	0.08	150	75	0.154
19	W21	1279	2265	884	6.84	126	142	108	0	707	294	0.07	96	60	0.159
20	W22	815	1467	508	7.35	58	91	97	3	510	129	0.2	105	47	0.161
21	W23	857	1553	472	7.58	72	73	135	2	578	118	0.18	28	110	0.189
22	W24	1196	2025	600	7.43	59	113	183	2	485	288	0.2	33	176	0.158

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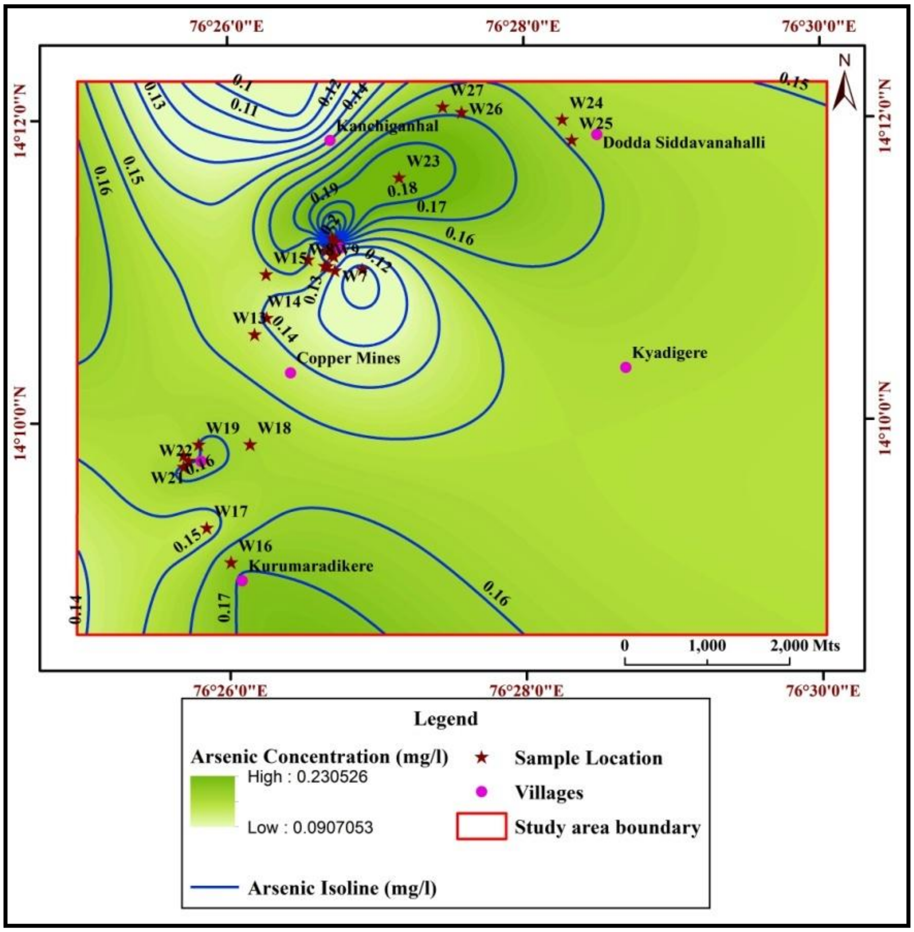

Figure 3: Spatial Distribution Map Showing Arsenic Concentration in the Groundwater Samples of the Ingaldhal Area

Summary and Conclusion

Arsenic content in 22 groundwater samples of the Ingaldhal area range from 0.104 mg/l to 0.235mg/l (Av. 0.151 mg/l). As per the WHO (2008) and BIS (1991), the arsenic content in all the groundwater samples exceed maximum permissible limit and desirable limit. The primary sources of arsenic in the groundwater of the Ingaldhal area is the metavolcanics which host sulphide mineralization and abandoned tailing dumps generated from the mining activity during the period from 1966 to 1995. The occurrence of arsenic-bearing minerals and their leaching due to accelerated oxidation rate upon their exposure have contributed for the elevated concentration of arsenic in the groundwater. Gibbs plots also indicate the role of anthropogenic activities and under the present circumstances dissolution of the arsenic-bearing mine tailings may be major source of arsenic in the groundwater. Cation facies-wise, dominance of Mg type, anion facies-wise dominance of SO_4 type and hydrochemical facies-wise $CaMgHCO_3$ and $CaMgSO_4$ facies indicate both carbonic and sulphuric acid-aided weathering of the source rocks and mine wastes (insitu sulphide-bearing metavolcanics and mine tailings). High arsenic concentration of the groundwater of the shallow dug well (W 12) may probably be due to the leaching of arsenic from mine tailings as the well is located close to the mine waste site. Relatively very high concentration of arsenic found in the groundwater of this part of the study area supports this view. Hence, it may be concluded that the exposure of As-bearing sulphide ore bodies, host rocks and mine wastes to the oxygenated environment and the activities of sulphur oxidizing and reducing bacteria have obviously played a significant role in the leaching of arsenic from volcanic rocks and mine waste dumps leading to arsenic contamination of the groundwater of the study area.

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