

Hexavalent chromium contamination of groundwater in Bhilai City: Potential public health crisis in Central-east India

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ABSTRACT

Contamination refers to a chemical's concentration in the environment greater than would occur under natural conditions. Various anthropogenic and industrial activities can lead to a widespread chromium (Cr) contamination in soils and natural waters. This article highlights the problems arising due to improper disposal of the chromium waste in the industrial area of Bhilai city of Chhattisgarh state and the consequent translocation of the hexavalent chromium to the groundwater. This study focusing on the chemical and hydro geochemical aspects helps to create an understanding on the movement of chromium.

Key words: Hexavalent chromium, Fate of Chromium, Monsoon, Post monsoon, Ground water, Water pollution, Bhilai- Durg.

Introduction

Chromium typically occurs in two oxidation states in the natural environment, water treatment processes and water distribution systems, i.e. trivalent chromium and hexavalent chromium (Dhal *et al.*, 2013). Trivalent chromium has been considered an essential human nutrient (Fendorf *et al.*, 1995). Hexavalent chromium has been demonstrated to be a human carcinogen when inhaled (Langlois and James, 2015). Therefore the inorganic chromium contamination is a major environmental hazard (Wuana and James, 2015).

Hexavalent chromium in drinking water was first brought to the public's attention in 1993 when Erin Brockovich, a legal clerk to lawyer Edward Mastry, investigated the apparent elevated cluster of illness in the community linked to hexavalent

chromium in Hinkley, CA. further the hexavalent chromium contamination and its effect was reported in zhang's article published in Journal of occupational and environmental Medicine (JOEM) in 1997 (Hinkley Groundwater contamination). In 2010, the Environmental Working Group (EWG) USA reported trace levels of hexavalent chromium in 31 of 35 tap waters tested (EWG, 2010). In Europe the parametric value of 50 µg/L for total chromium in water intended for human consumption and a maximum limit of 50 µg/L for total chromium in natural mineral waters was laid down in the European Council Directive 98/83/EC and in Commission Directive 2003/40/EC, respectively (ECD, 2014).

When the external conditions change (eq. salinity, temperature, pH), heavy metals like chromium in sediments may be released into the water column,

causing harm to aquatic organism and further to human health (Jie Fu *et al.*, 2014). Total chromium content typically ranges from 0.1 to 0.5 $\mu\text{g/L}$ in seawater, from 0.3 to 0.6 $\mu\text{g/L}$ in non-polluted river and surface water, 5–50 $\mu\text{g/L}$ in polluted river water, whereas it can reach 200 $\mu\text{g/L}$ in severely polluted water systems (Carry and Langard, 1982). For the crops irrigation, the U.S. Environmental Agency recommended limit for chromium is 100 $\mu\text{g/L}$. With regard to drinking water, chromium(VI) is regulated under the 50 $\mu\text{g/L}$ maximum contaminant level (MCL) for total chromium (WHO, 1996; WHO, 1998).

The USEPA, 2011 regulates total chromium in drinking water and has set a Maximum Contaminant Level (MCL) of 0.1 mg/L. The World Health Organization (WHO, 1996; WHO, 1998) guideline is 0.05 mg/L for total chromium.

The major source of hexavalent chromium in drinking water is oxidation of naturally occurring chromium present in igneous geologic formations. There are locations where chromium compounds were released to the environment via leakage, poor storage, or improper industrial disposal practices. Chromium compounds in both trivalent and hexavalent chromium, are very persistent in water (USEPA, 2011).

The existence of hexavalent chromium in environment is generally associated with industrial processes or wastes. Chromium (Cr) is one of the world's most strategic and critical materials having a wide range of uses in the metals and chemical industries. Cr alloys enhance metal resistance to impact, corrosion, and oxidation. Cr is used in stainless steel and non iron alloy production for plating metals, development of pigments, leather processing, and production of catalysts, surface treatments, and in refractories.

Cr(VI) is considered as a potential soil, surface water, and groundwater contaminant. Cr(VI) may also occur in the natural environment with the level of 0.4–0.8 $\mu\text{g/L}$ in tap water and 1–10 $\mu\text{g/L}$ in rivers and lakes. But human-caused Cr(VI) contamination has recently been the focus of much scientific discussion, regulatory concern, and legal posturing (Jacobs and Testa, 2004). In July, 2011 California finalized its Public Health Goal at 0.02 $\mu\text{g/L}$ in drinking water (AWWA, 2013). The central pollution control board set a standard of 0.1ppm for industrial discharge water (CPCB, 2012).

The concentration of chromium in water varies

according to the type of the surrounding industrial sources and the nature of the underlying soils. In India, significant concentration of total and hexavalent chromium was observed in many wells located in the close vicinity of some of the industries in the industrial area of Ranipet, in Tamil Nadu (Rao *et al.*, 2011). The sources are clusters of tanneries and other industries located in the area. The concentration of total chromium in these wells varied between 3.1 to 246 mg/L whereas the concentration of hexavalent chromium varied between 2.1 to 214 mg/L which far exceed the prescribed limit of Bureau of Indian Standards (0.05 mg/L) (INSA, 2011).

In the WRF funded study, in a survey of 407 source waters, total chromium was found in both groundwater and surface waters. The range of concentrations of total chromium varied from non-detect (below the method detection level at the time of 0.2 $\mu\text{g/L}$) to 47.1 $\mu\text{g/L}$ (Parks *et al.*, 2004). The average and median concentrations were 2 $\mu\text{g/L}$ and 0.8 $\mu\text{g/L}$, respectively (Frey *et al.*, 2005). Due to open cast mining in sukinda valley, Orissa, lots of over burden are being generated and leaching from this over burden adds the hexavalent chromium to groundwater regime. Mishra and Sahu, 2013, reported most of wells and water course in sukinda valley were contaminated by Cr(VI) up to value of 3.4 mg/L in surface water and 0.6 mg/L in ground water (Mishra and Sahu, 2013).

An analysis of 3834 tap-water samples in representative cities of the United States showed a chromium concentration ranging from 0.4 to 8.0 $\mu\text{g/L}$ (Frey *et al.*, 2005). Chromium has been reported to be released to the environment via leakage, poor storage or improper disposal practices. A total number of 415 drinking water samples (Ahmadabad municipal corporation, n=125; Tube well water n=290) were analyzed for Cr (VI) reported a wide variation in the level of Cr (VI) in drinking water from tube-well bore. The average value was 14.57 $\mu\text{g/L}$ (range 0.0 - 322.64 $\mu\text{g/L}$) with a median value of 6.39 (Zaidi *et al.*, 2014).

The natural presence of elevated chromium levels in the groundwater has also been reported (Palmer and Puls, 1994). The tannery industry mushrooming in North India has converted the Ganga River into a dumping ground. As per an estimate, about 80–90% of the tanneries use chromium as a tanning agent. Analysis of upstream and downstream water and sediment revealed a 10-fold increase in the chromium level in the sediment at

downstream Jajmau area of Kanpur showing unchecked release of untreated tannery effluent (Khwaja *et al.*, 2001).

There are reports of the health effects in Chinese villagers who consumed drinking water from a well contaminated with hexavalent chromium from an alloy plant in Jinzhou (Jiandong and Xilin, 1987). The Jinzhou area is heavily industrialized and in 1965, the well water in a nearby suburban area was found to be stained yellow, presumably because of chromium contamination from a mining operation which had begun operating in 1959.

In India chromium is reported and present in both the ground and surface water in the vicinity of some designated "Industrial Estates" in the states such as Maharashtra, Tamil Nadu, West Bengal, and Uttar Pradesh (Bhagure and Mirgane, 2011).

This paper reports the case of abnormally high Cr(VI) contamination of the drinking water in and around the Industrial Estate of Bhilai city of Chhattisgarh. The investigation presents the concentration and the extent of contamination of ground water and investigates the probable reasons.

Materials and Method

Bhilai-Durg twin city lies between the latitudes 20° 23' N and 22° 02' N and Longitudes 80° 48' E and 81° 57' E. Geologically the major part of the area falls in Chhattisgarh plains. River Sheovnath drains major part of the district, which is a major tributary of the Mahanadi River. There is a large Industrial Estate in Bhilai city which comprises of both, heavy and light industries. Many of the industries situated there manufacture variety of inorganic and organic chemicals. The waste handling in most of the industries is un-scientific. In many cases the generated was found to be dumped directly onto the land or drained in unscientific manner.

The effluents from many such industries are being discharged into open drainages which ultimately join the principal geographic drainage of the area; called Samoda stream. This stream finally discharges into the Sheonath River which is a principal tributary of the Mahanadi river.

The drinking water samples were collected mainly from the bore wells of the Housing Board Colony, Amrapali Vananchhal city, Fauji Nagar and surrounding areas of the Industrial Estate Bhilai (Fig. 1). The water samples were collected from the bore wells in or around the industries located in the

area. All of the industries of this area use the bore well as the water source for drinking and industrial activities. Figure 1 depicts the sampling locations in the studied area.



Fig. 1. Sampling location in Industrial Area, Bhilai.

The sampling sites with its coordinates have been mentioned in Table 1.

The samples were collected in the fresh and cleaned plastic sampling bottles in the month of July (Monsoon) and February (Post-Monsoon). The collected samples were filtered through a 0.45 mm membrane filter to ensure the collection of only dissolved species in the sample. Samples were analyzed as soon as possible. Only in case of intended longer storage, about 250 mL of such filtered water was acidified with concentrated nitric acid to obtain pH less than 2.

Various physio-chemical parameters (viz. chromium, sodium, potassium, pH, total hardness, alkalinity, carbonates, chloride, sulphate, bicarbonate, calcium, magnesium, iron, conductivity and total dissolved solids) were analyzed using the standard methods of analysis prescribed by American Public Health Association (APHA, 1984). Spectrophotometric measurements were made in a UV-Visible

Table 1. Sampling sites coordinates

Sites	Latitude (North)	Longitude (East)
S1	21.132891	81.222377
S2	21.223227	81.373121
S3	21.223265	81.373903
S4	21.223049	81.374676
S5	21.223109	81.375362
S6	21.225209	81.374064
S7	21.225549	81.374483
S8	21.225929	81.374987
S9	21.227029	81.374579
S10	21.226669	81.377873
S11	21.226070	81.375676
F	21.225709	81.377293

spectrophotometer (Systronics). A digital pH meter (Orion) was employed for measurement of pH value. Standard 1,5 Diphenylcarbazide (DPC) spectrophotometric method was adopted for chromium determination and the results were cross-examined by atomic absorption spectrophotometer (Varian FS-240). Sodium and potassium ions were measured by using Flame photometer.

Results and Discussion

Chromium and other heavy metals have been reported at many locations in other parts of country and the reasons are mainly leakage, poor storage, improper disposal etc (Godgul and Sahu, 1995). High level of hexavalent chromium contamination in ground water near the tanneries sites were reported at Vellore (maximum 36.7 mg/L) (Rangaswamy *et al.*, 2015), Ranipet Tamilnadu (maximum 275mg/L) (Rao *et al.*, 2011), and Kanpur (maximum 6227.8 mg/L) (Gowd *et al.*, 2010). Dhakate and Singh (2008) reported ground water contamination (maximum 0.45 mg/L) at the chromite ore waste dump site in India (Dhakate and Singh, 2008).

The presence of chromium species in the natural water of Chhattisgarh has never been reported earlier. This report assumes a greater significance due to the fact that the contaminated area is heavily populated and thus there exists a great chance of the human afflictions on account of this contaminated water. The results of this paper show an alarming and consistent presence of Cr(VI) in many samples of groundwater in the Industrial Estate area of Bhilai. We have identified about eleven samples which are highly contaminated by Cr(VI).

Contrasted with the Indian standards for the drinking water (Maximum permissible 0.05 mg/L) (IS10500, 2012), the chromium levels in Bhilai city have gone to as high as 12.3 mg/L in the samples from the area (Table 2 and 3). At the eleven contaminated sampling stations the mean level of Cr(VI) was 0.99 mg/L. Smaller values of standard deviation (0.20), kurtosis (-0.80) and skewness (-0.28) indicate a uniform regime of contamination spread.

The sampled area has shown a mean pH of 6.89 with a minimum of 4.83 and maximum of 7.72 in the month of July and a mean of 8.07 with a minimum of 7.73 and maximum of 8.38 in the month of February. The low pH of 4.83 is indicative of direct contact with a probable underground acidic

leachate stream. This conclusion is derived from the fact that the geologically the rocks and soil of the area is basic in nature as it is having a limestone bedrock. Thus the inherent basic nature of groundwater is evidenced by higher total hardness, alkalinity, calcium and magnesium (mean above 456, 334,122 and 133 mg/L, respectively) in the sampled groundwater of the area. High alkalinity values (range 228 mg/L) are typically characteristic of any limestone zone groundwater.

The sudden and sharp deviations in the groundwater from the normal characteristics of an alkaline region are not possible unless there is an immediate and high volume contamination from any acidic source. In the presented study such a source is clearly discernible. A high mean TDS value (469 mg/L) associated with high value of chloride, sulphate and iron (mean 154,103, 13.09 mg/L) is indicative of extraneous acidic contamination.

To a casual observer the combined presence of both acidic and basic parameters in the analyzed samples may be baffling. However, this fact is not surprising. The concurrent presence of carbonate and bicarbonate basic anions and chloride and sulphate acidic anions only indicate that water chemistry is yet to reach at an equilibrium state. This phenomenon is possible because the underground water system requires longer period of time for chemical equilibrium to be established.

A strikingly high presence of dissolved iron (maximum and mean 130 and 13.09 mg/L respectively) in the month of July is the clinching proof of contamination by industrial leachate because iron bearing minerals are totally absent in calcareous bedrock of the studied region. This concentration decreases in the month of February (maximum and mean 0.06 and 0.05 mg/L respectively).

There are almost no reports in the literature for such high values of Cr(VI) contamination and thus the Industrial Estate of Bhilai city may get a dubious distinction of the world's most contaminated location for Cr(VI) and can be a grim reminder of the popular film "Erin Brockovich".

The most important scientific aspect of the chromium contamination at the present location is the almost exclusive presence of Cr(VI) in the samples. The ratio of Cr(VI) to Cr(III) in the samples was calculated by difference method [Total Chromium – Hexavalent Chromium] and it was obtained as 99:1 in both months (Table 4).

As such, the extensive presence of Cr in the envi-

Table 2. Statistical analysis of water quality parameters (mg/L) July.

	pH	Cond.	TDS	Cr(VI)	TH	Ca ²⁺	Mg ²⁺	Cl ⁻	Alkalinity	CO ₃ ⁻²	HCO ₃ ⁻	Na ⁺	K ⁺	Fe	SO ₄ ⁻²
Mean	6.89	0.97	486.68	0.50	455.64	333.82	121.82	153.57	133.09	24.73	108.36	10.35	0.37	13.09	102.73
Standard Error	0.27	0.10	48.48	0.24	49.84	38.88	15.72	22.85	16.28	6.69	11.96	1.14	0.13	11.73	18.53
Median	7.30	1.06	530.00	0.02	480.00	340.00	136.00	159.95	128.00	24.00	112.00	10.40	0.10	0.00	82.50
Mode	0.00	0.00	0.00	0.00	580.00	440.00	0.00	0.00	100.00	32.00	120.00	0.00	0.00	0.00	150.00
Standard Deviation	0.89	0.32	160.79	0.20	165.31	128.96	52.13	75.78	54.00	22.19	39.66	3.78	0.43	38.89	61.45
Sample Variance	0.79	0.10	25852.4	1.95	27326.25	16631.56	2717.96	5742.12	2915.49	492.22	1572.65	14.27	0.18	1512.24	3775.57
Kurtosis	1.65	-0.46	-0.46	-0.80	-0.47	-0.60	-1.17	-1.26	0.29	3.54	1.78	-0.58	-1.00	10.83	-1.27
Skewness	-1.42	-0.84	-0.84	-0.28	-0.23	-0.37	-0.07	-0.33	0.52	1.50	0.70	-0.41	0.87	3.28	0.18
Range	2.89	0.92	460.50	4.70	528.00	408.00	156.00	213.36	184.00	80.00	152.00	11.70	1.10	130.00	185.00
Minimum	4.83	0.41	204.50	0.00	200.00	124.00	40.00	33.23	44.00	0.00	44.00	4.00	0.00	0.00	17.50
Maximum	7.72	1.33	665.00	4.70	728.00	532.00	196.00	246.59	228.00	80.00	196.00	15.70	1.10	130.00	202.50

Table 3. Statistical analysis of water quality parameters (mg/L) February.

	pH	Cond	TDS	Cr(VI)	TH	Ca ²⁺	Mg ²⁺	Cl ⁻	Alakinity	CO ₃ ⁻²	HCO ₃ ⁻	Na ⁺	K ⁺	Fe	SO ₄ ⁻²
Mean	8.07	1.08	0.70	1.49	404.55	335.45	69.09	161.35	171.82	10.91	160.00	81.35	11.32	0.05	99.12
Standard Error	0.07	0.09	0.06	1.09	40.61	45.32	11.77	31.98	26.24	4.95	27.29	20.27	7.72	0.05	14.68
Median	8.08	1.13	0.73	0.50	415.00	345.00	55.00	143.00	200.00	0.00	200.00	51.70	0.00	0.00	110.00
Mode	7.84	0.00	0.73	0.50	415.00	0.00	30.00	197.00	0.00	0.00	220.00	0.00	0.00	0.00	110.00
Standard Deviation	0.23	0.29	0.19	0.52	134.69	150.32	39.04	106.06	87.04	16.40	90.50	67.23	25.61	0.18	48.68
Sample Variance	0.05	0.08	0.04	0.42	18142.27	22597.2	1524.09	11248.72	7576.36	269.09	8190.00	4519.42	655.76	0.03	2369.90
Kurtosis	-1.79	4.97	5.05	-0.12	2.53	2.01	0.40	3.00	-0.05	-0.25	-0.24	3.22	3.37	11.00	0.17
Skewness	-0.09	-1.49	-1.55	-0.24	-0.02	0.26	1.16	1.46	-0.75	1.15	-0.74	2.07	2.11	3.32	-0.76
Range	0.65	1.21	0.78	12.30	555.00	600.00	115.00	380.40	290.00	40.00	290.00	199.00	73.80	0.60	167.50
Minimum	7.73	0.34	0.22	0.00	125.00	50.00	30.00	40.00	0.00	0.00	0.00	45.40	0.00	0.00	2.50
Maximum	8.38	1.55	1.00	12.30	680.00	650.00	145.00	420.40	290.00	40.00	290.00	244.40	73.80	0.60	170.00

ronment poses a serious threat to human and animal welfare. Hexavalent chromium [Cr(VI)], which typically exists as the oxyanion chromate(CrO_4^{2-}), has a high solubility and it tends to be highly mobile in the environment. In contrast, the reduced form of chromium, Cr(III), has a limited solubility and forms strong complexes with soil minerals. While trivalent Cr is relatively harmless and immobile. Cr(VI) is rapidly reduced to Cr(III) when Fe(II) or Mn(II) occur in reduced groundwater. Hexavalent Cr is actively transported into cells by the sulphate transport system where it is capable of causing damage to DNA as well as indirectly generating oxygen radicals.

The area close to this study area contains large limestone mineralized beds which are horizontal to sub-horizontal (max. dip 10 towards North). Accordingly the area adjacent to this studied area is extensively mined for limestone mineral. As the distance between the two areas is very less, it can be presumed that the geologically a similar rock structure may be existing in the area.

The reported annual total rainfall in the studied area is 1288 mm. Over 80% of the total annual rainfall is received during the monsoon period between June to September. Hence, a huge discharge of Cr(VI) contaminated leachate takes place during the four months of rainy season. A seasonal trend in the level of Cr(VI) is clearly discernible in the results (Table 2 and 3) where the chromium levels start to rise with the onset of monsoon and peak around the post monsoon season. This establishes the ingress of water in the source of chromium which gives rise to contaminated migrating groundwater plume. The dilution effect appears to operate under subsurface due to mixing of the percolating water and existing groundwater channels that exists in limestone bedrocks.

Statistically the results are characterized by lower standard deviation, skewness and kurtosis values (Table 2), which signifies a persistent contamination

gradient across the contaminated region. This clearly indicates to the persistence of the Cr(VI) in the contaminated zone that can be an outcome of the geochemical composition of the bedrock.

The causative factor of such extensive and high chromium contamination appears to the generation of chromium-laced leachates from chromium manufacturing industrial unit/s located in the Industrial Estate. The chemical analysis of the water samples from different locations shows that most of the samples from industrial area and adjoining colonies are highly chromium contaminated. The groundwater contamination or the surface discharge of it is the likely reason of the contamination of surface water body also. Accordingly, a nearby pond water was found to contain 0.01 mg/L of Cr(VI). The other parameters of the sample were typical to that of a normal surface water (Table 5).

Based on the results and a wider area of the distribution of contamination it can be scientifically presumed that a Cr(VI) contaminated plume is ex-

Table 5. Mean results of various estimated Water Quality Parameters of Surface Water.

Water Quality Parameters	Mean of Surface Water (mg/L)
pH	8.08
Conductivity	1.05
TDS	0.68
Cr(VI)	0.05
TH	335
Ca	190
Mg	145
Cl	102
Alkalinity	65
CO_3^{2-}	40
HCO_3^-	15
Na	50
K	BDL
Fe	0.01
SO_4^{2-}	42.5

Table 4. The ratio of hexavalent chromium to trivalent chromium.

Samples	Total number of samples	Total Chromium	Hexavalent chromium Cr(VI) (Mean mg/L)	Trivalent Chromium Cr(III) (Mean mg/L) (By difference method)	Ratio Cr(VI) : Cr(III)
Month- July	11	0.51	0.5	0.01	99:1
Month- February	11	1.51	1.49	0.02	99:1

isting in the studied area. The presence of a contaminated plume is confirmed by the presence of Cr(VI) in various nearby groundwater sources. The bore well water in the surrounding colony areas were found to contain hexavalent chromium in varying degrees. Groundwater samples from colony area were also found to be chromium contaminated ranging from 0.06-4.7 mg/L. A population of about 11,000 resides in this colony called as Camp 1. The adjoining colony is called as Housing Board Colony where about 13,000 people live.

The trend of Cr(VI) contamination and its spatial distribution suggests that mobilization of chromium in the ground water is gradually towards the populated area in the colonies towards south-west direction. The exact hydrogeology of the site area is not available at the moment but the mobilization trend appears to be following the local topography and it is migrating downward.

The Bhilai Light Industrial area site is at the higher elevation topographically and the flow of the groundwater in the area is expected to move along the local stream called Samoda stream and will ultimately reach to the river Shivnath, which is the principal river draining Rajnandgaon-Durg region.

Hexavalent Cr is highly mobile in soil and no other precipitation of Cr(VI) has been observed in a pH range of 1.0-9.0 (Griffin and Shimp, 1978). In a study of the relative mobility of eleven metals for a wide range of soil Cr(VI) was found to be the only metal that was highly mobile in alkaline soils thus soluble and unabsorbed. Chromium complexes can leach from soil to ground water (Korte *et al.*, 1976). The leachability of Cr(VI) increases as soil pH in-

creases. Under this condition, it may become a contaminant of groundwater in the presence of percolating water from rain. Zachara *et al.* have reported that SO_4^{2-} and dissolved inorganic inhibited chromium VI adsorption by amorphous oxyhydroxide and subsurface soils (Zachara and Mccarthy, 1987).

The correlation analysis shows a statistically significant high positive correlation of chromium with alkalinity, iron and sulphate (Table 6). The correlation with iron is approximately 1.0 in both months i.e. July and February which is uncommon in geochemical studies under equilibrium. This is possible as the chrome products manufacturing industry uses ferrous sulphate for the reduction of Cr(VI) to Cr(III). However, it appears that the reduction process is incomplete as majority of Cr is still in (VI) oxidation state. In addition to that it correlates significantly with carbonate and sulphate and sodium potassium and iron in the month of July and February respectively (Table 6 and 7).

One industry which produces various chromium compounds such as basic chromium sulphate is located in the area. Based on the uncommon and very high presence of Cr(VI) in the samples studied it can be surmised that the source of the contamination is the same factory. The concomitant presence of Cr(VI), Fe(II), Na(I), K(I), and $\text{SO}_4(\text{II})$ can be directly attributed to the production of basic chrome compounds by the said industry. The results also show some neutralization of the attendant acidity by the alkaline bedrock but apart from that no attenuation of the chromium or sulphate is taking place in the terrestrial environment.

Table 6. Correlation matrix obtained for different water quality parameters studied (July 2015)

	pH	Cond	TDS	Cr(VI)	TH	Ca ²⁺	Mg ²⁺	Cl ⁻	Alkalinity	CO ₃ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Fe	SO ₄ ²⁻
pH	1.00														
Cond	-0.33	1.00													
TDS	-0.33	1.00	1.00												
Cr(VI)	0.23	0.26	0.26	1.00											
TH	-0.21	0.95	0.95	0.07	1.00										
Ca ²⁺	-0.06	0.95	0.95	0.29	0.97	1.00									
Mg ²⁺	-0.53	0.67	0.67	-0.48	0.78	0.59	1.00								
Cl ⁻	-0.58	0.88	0.88	0.08	0.85	0.78	0.78	1.00							
Alkalinity	0.50	-0.36	-0.36	0.50	-0.45	-0.25	-0.81	-0.45	1.00						
CO ₃ ²⁻	0.66	-0.03	-0.03	0.79	-0.11	0.14	-0.68	-0.25	0.77	1.00					
HCO ₃ ⁻	0.31	-0.47	-0.48	0.24	-0.55	-0.42	-0.72	-0.46	0.93	0.48	1.00				
Na ⁺	-0.36	0.93	0.93	0.34	0.83	0.83	0.58	0.79	-0.35	-0.06	-0.44	1.00			
K ⁺	0.49	0.13	0.13	-0.02	0.23	0.28	0.02	-0.15	0.02	0.18	-0.08	0.05	1.00		
Fe	0.34	0.18	0.18	0.99	0.01	0.24	-0.55	-0.01	0.54	0.84	0.27	0.25	0.06	1.00	
SO ₄ ²⁻	-0.14	0.69	0.69	0.56	0.57	0.65	0.18	0.49	0.08	0.29	-0.06	0.83	0.05	0.51	1.00

Table 7. Correlation matrix obtained for different water quality parameters studied (February 2016)

	pH	cond	TDS	Cr(VI)	TH	Ca ²⁺	Mg ²⁺	Cl ⁻	alkalinity	CO ₃ ²⁻	HCO ₃ ⁻	Na ⁺	K ⁺	Fe	SO ₄ ²⁻	
pH	1.00															
Cond	-0.25	1.00														
TDS	-0.23	1.00	1.00													
Cr(VI)	0.29	0.11	0.11	1.00												
TH	0.05	0.54	0.56	0.31	1.00											
Ca ²⁺	0.18	0.49	0.52	0.37	0.97	1.00										
Mg ²⁺	-0.52	-0.03	-0.05	-0.35	-0.28	-0.51	1.00									
Cl ⁻	0.17	0.40	0.39	0.22	-0.07	0.01	-0.27	1.00								
Alkalinity	0.14	0.20	0.21	0.33	0.32	0.36	-0.30	0.21	1.00							
CO ₃ ²⁻	0.42	-0.31	-0.29	0.19	0.21	0.15	0.13	-0.45	-0.02	1.00						
HCO ₃ ⁻	0.06	0.25	0.26	0.29	0.28	0.33	-0.33	0.29	0.98	-0.22	1.00					
Na ⁺	0.41	0.09	0.13	0.56	0.73	0.78	-0.47	-0.16	0.46	0.60	0.34	1.00				
K ⁺	0.43	0.05	0.07	0.84	0.60	0.66	-0.48	-0.01	0.40	0.51	0.30	0.91	1.00			
Fe	0.28	0.06	0.06	0.99	0.24	0.30	-0.33	0.25	0.26	0.18	0.22	0.50	0.81	1.00		
SO ₄ ²⁻	-0.22	0.72	0.71	0.11	0.24	0.27	-0.18	0.77	0.30	-0.74	0.43	-0.20	-0.12	0.09	1.00	

Discussion

In view of the above facts, the Bhilai city presents an extremely worrying picture from the geological and chemical composition of the contaminated plume. Hydro-geologically, the aquifers of the area are basically of fissured media type, which are discontinuous, and unconfined to semi-confined in nature. They are generally restricted to weathered mantle and fractures and are in contact with the limestone. The aquifers go as deep as about 150 M below ground level (BGL). This geology is likely to help in the almost no precipitation or adsorption of Cr(VI) by any geo-chemical process. Thus, it can be inferred that the Cr(VI) contamination can go unabated as far as the aquifer boundary.

The chromium compound responsible for the contamination of the groundwater has been identified as sodium chromate the ecological toxicity of chromic acid and its disodium salt is considered high for both animals and human beings. Chromium is only one of its kinds among regulated toxic elements in the environment to be regulated in different ways based on their differing toxicities of its species (Barnhart, 1997) All other toxic elements, such as lead, cadmium, and arsenic, are regulated based on their toxic total concentrations, irrespective of their oxidation state.

Certain Cr(VI) compounds have been found to be carcinogenic in humans. Cr(VI) can cause a wide range of other health effects. Ingestion of very high doses of Cr(VI) can cause kidney and liver damage, nausea, irritation of the gastrointestinal tract, stomach ulcers, convulsions, and death (WHO, 1988).

Dermal exposures may cause skin ulcers or allergic reactions (Nethercott *et al.*, 1994). The present location offers a large range of Cr(VI) doses in both very high to the low end.

In the example of a family consuming the contaminated water in the range of 2.3 mg/L the estimated daily dose is about 0.3 mg/kg-day. The exposed family showed the clinical symptoms of oral damage, persistent abdominal pain and indigestion. Incidences of diarrhea or vomiting were not regular but the propensity of the exposed persons to these problems was very high. Most of the exposed persons were found to be generally anemic and were having a weak constitution. We are planning to conduct a large scale epidemiological study in the matter.

Conclusion

The groundwater quality data and hydrogeological studies carried out helped to identify the chromium contaminated sites in Chhattisgarh. The high contamination of hexavalent chromium has being reported for the first time in Chhattisgarh. The range of chromium in the contaminated site is from 0.005-12.3 mg/L. The disposal of waste from the industry is major contributing factor. The migration of chromium contaminated plume and the persistence of chromium is further leading to the groundwater contamination in the studied area. So, The population residing there are at high health risk. The purpose of present study is to make aware the people of the hexavalent chromium contamination in the Light Industrial Area of Bhilai, Chhattisgarh.

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