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Assessment of Heavy Metal Contamination in Surface and Ground Water Resources around Udege Mbeki Mining District, North-Central Nigeria

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Abstract

The study assessed the surface water and groundwater chemistry with special concern to heavy metal contaminations/pollution in Udege Mbeki mining district. A total of eight mine ponds, eight hands – dog wells, three streams and one adit water samples were analysed for their heavy metals contents. The heavy metal concentrations ranged as follows: Cd (0.000-0.110 mg/L), Cr (0.003-0.146 mg/L), Co (0.110-1.260 mg/L), Cu (0.000-0.260 mg/L), Fe (0.015-8.398 mg/L), Pb (0.0001-1.853 mg/L) and Ni (0.001.112 mg/L). Concentrations of Cr, Cu and Ni are generally within the maximum permissible limit of the WHO (2006) guideline, whereas concentrations of Fe, Co, Pb and Cd are above the maximum permissible limit. The contamination/pollution level was estimated based on the geoaccumulation index (Ige0), enrichment factor (EF) and heavy metal pollution index (HPI). Sources of the heavy metals in the waters of the area are mainly anthropogenic. The heavy metal pollution index (HPI) calculated was 559.12, which is far above the critically pollution index value of 100 and therefore depict that the waters of the area are critically polluted with regards to heavy metals.

Keywords: Heavy metals; Contamination; Enrichment factor; Heavy metal pollution index

Introduction

The T.A.M Company (a colonial company) started mining in the area over sixty (60) years ago. Different locations within the District and minerals being mine/processed are Udege Mbeki (columbite, cassiterite and zircon), Agbalande (cassiterite), and jenta (cassiterite and columbite) Rafin Gabas (cassiterite, sphalerite, galena and wolframite) and Bajari (cassiterite). In 1976, the T.A.M Company transferred the ownership to Vectis Tin Mines limited Jos due to the kind of mining policy introduced by the Nigerian Government. Ever since, the mines and/littered paddocks have been abandoned without major reclamation and/or rehabilitation.

In most mining areas surface water and groundwater are usually contaminated and/or polluted by heavy metals. Sources of the heavy metals in waters can either be natural (geogenic) or anthropogenic [1-3]. Mining and smelting plants are the main anthropogenic sources of heavy metal contaminations in any mining area. The heavy metal contaminations are important due to their potential toxicity for human being and environments [4,5]. Some of the heavy metals such as Cu, Fe, Ni and Zn are essential micronutrients for animals and plants but are dangerous at high levels, whereas Cd, Cr, Pb and Co have no known physiological functions but are detrimental at certain limits [6-10]. Furthermore Cr, Cd and Ni are carcinogenic, while Pb may cause neurological impairment and central nervous system malfunctioning.

This study assessed the surface water and groundwater chemistry with special concern to heavy metal contaminations/pollutions in Udege Mbeki mining District. It also evaluated the drinking and domestic quality of the waters as well as the possible health effects of the heavy metals on human beings in the area.

Physical Setting

The study area (Udege Mbeki Mining District) is located within Kokona and Nasarawa Local Government Area of Nasarawa State, north central Nigeria (Figure 1). It encompasses Udege Mbeki, Dogon Daji, Odu, Omadegye, Odamu, Rafin Gabas, Jenta, Agbalande and Igwo. The area lies within latitudes 080 19, 30" N to 80 30, 12" N and longitudes 7050, E to 8004, E. It covers a total area of about 400 km^2. It is accessible through Akwanga-Keffi via Mararaba-Agwada road and other major roads. The area falls within the tropical guinea-savannah and characterized by two seasons, namely: the dry season which lasts from November-March and the rainy season that lasts from April-October [11,12]. The mean annual rainfall is between 1000-1500 mm, while the mean temperature is about 25.60°C [13].

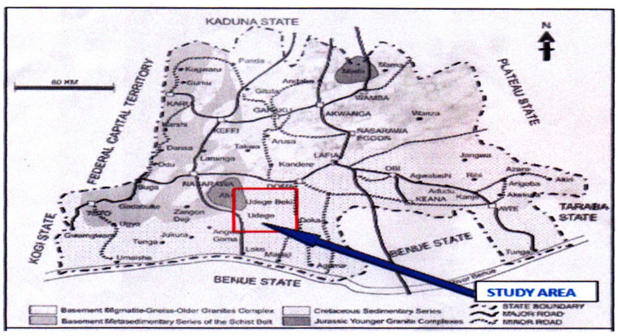

Figure 1: Map of Nasarawa State showing the location of the study area (modified after Obaje et al.) [14].

Geologically, the study area is underlain mainly by the Jurassic Younger Granites and Cretaceous sedimentary rocks of the Middle

Benue Trough (Figure 1). Common minerals in the area are cassiterite, columbite, wolframite, zircon, topaz, magnetite, beryl, sphalerite, chalcopyrite, ilmenite and galena.

Materials and Methods

Twenty (20) water samples were collected which comprise 8 mine ponds (MNP), 8 handdug wells (HDW), 3 streams (STRM) and 1 adit (ADT). These constitute the main sources of water supply for the inhabitants in and around the Udege Mbeki Mining District. Sampling was done in January 2008 at the peak of dry season to avoid the effect of dilution that may result from precipitation during rainy season.

Water samples were collected in new screwcap, highdensity polythene bottles (1.5 litres) which were first rinsed two to three times with the water to be sampled and acidified with HNO_3 at point of collection. The samples were adequately labelled and were kept at 4°C prior to analysis. Atomic absorption spectrometer (Buck scientific VGP 210 Model) was used for the analysis and the heavy metals for are cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe0), lead (Pb) and nickel (Ni). The analyses were carried out in accordance with the standard procedures specified in APHA and AWWA [15].

Results and Discussions

Heavy metal concentrations

The results of the chemical analysis of both shallow groundwater and surface water in the study area are presented in Table 1, alongside with the Mean Composition of World Rivers (MCWR) [16] and WHO [17] Guideline.

Water Sample	Description of location	Cd	Cr	Co	Cu	Fe	Pb	Ni
		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
MNP1	Udege Mbeki	0.11	0.022	0.142	0.26	0.293	1.429	0.008
HDW1	Udege Mbeki	0.002	0.146	0.314	0.06	3.3385	0.34	0.002
HDW2	Udege Mbeki	0.011	0.015	0.11	0.01	0.173	0.001	0.022
HDW3	Udege Mbeki	0	0.003	1.251	0.08	2.033	0.033	0.02
MNP2	Dogon Daji	0.014	0.03	1.061	0.09	0.619	0.008	0.034
MNP3	Dogon Daji	0.031	0.056	1.21	0.02	0.399	1.154	0.014
MNP4	Main Paddock	0.056	0.025	0.341	0.1	2.477	1.853	0.007
MNP5	Main Paddock	0.031	0.02	0.621	0.11	1.182	0.031	0.024
HDW4	Odu	0.051	0.044	0.814	0.14	2.493	1.296	0.02
HDW5	Odu	0.022	0.034	1.26	0.05	1.592	1.495	0.02
HDW6	Odu	0.011	0.017	0.211	0	6.569	0.75	0.01
HDW7	Odu	0.067	0.029	0.341	0.11	1.441	0.117	0.009
MNP6	Omadegye	0.034	0.025	0.902	0.17	1.398	0.765	0.014
ADT1	Odamu	0.031	0.021	0.164	0.19	0.842	0.976	0.024
STRM1	Rafin Gabas	0.024	0.02	0.231	0.05	1.567	0.009	0.055
STRM2	Bajari	0.019	0.016	0.16	0.05	1.027	0.032	0.015
HDW8	Jenta	0.026	0.006	1.201	0.1	0.015	0.032	0.025
MNP7	Agbalande	0.0021	0.028	1.251	0.07	0.893	0.196	0.001
MNP8	Agbalande	0.016	0.29	0.304	0.18	0.422	0.383	0.112
STRM3	Igwo	0.012	0.003	0.681	0.04	0.063	0.032	0.02
	Minimum	0	0.003	0.11	0	0.015	0.001	0.001
	Maximum	0.11	0.146	1.26	0.26	8.398	0.853	0.112
	Mean	0.03	0.0425	0.63	0.043	1.942	0.512	0.022
	World River Mean (MCWR)	0.0001	0.001	0.0002	0.007	0.5	0.003	0.0003
	WHO (2006)	0.003	0.05	0.01	0.05	0.3	0.01	0.02

	Guideline							

Table 1: Result of chemical analysis of the waters in the study area.MNP: Mine; HDW: Hand-dug well; ADIT: Adit; STRM: Stream

Concentrations of the heavy metals including Fe, in the water of the area are shown in Figure 2 The ranges of the heavy metal concentration in mg/L are as follow: Cd (0.0000.110), Cr (0.0030. 146), Co (0.1101.260), Cu (0.0000.260), Fe (0.0158.398), Pb (0.00011.853) and Ni (0.0010.112). Mean concentration of Cd, Cr, Co, Cu, Fu, Pb and Ni are 0.030, 0.0425, 0.63, 0.043, 1.942, 0.512 and 0.22mg/L. Mean concentrations of Cd, Cr, Cu and Ni are more than 100 times that of the MCWR, whereas mean concentrations of Co, Fe, and Pb are greater than 1000 times that of MCWR. Therefore, the mean (average) concentration is in the order: Fe>Co>Pb>Cu>Cr>Cd>Ni (Figure 2).

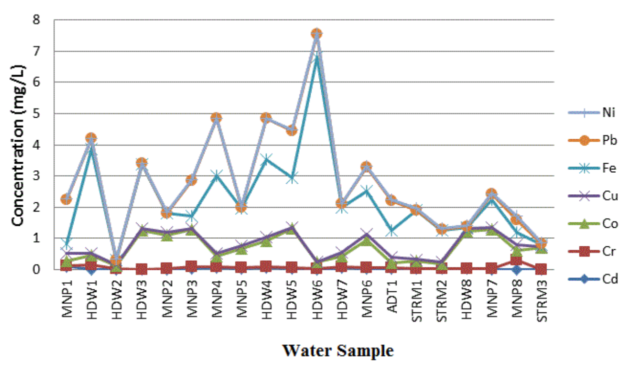

Figure 2: Heavy metal concentration in the samples of the study area.

Drinking and domestic water quality

The drinking and domestic water quality criteria for this study are based on world Health organisation (WHO) [17] Guideline for drinking water. The concentrations of Cr, Cu and Ni are generally within the maximum permissible limit (Table 2). Thus, most of the heavy metal concentrations in the waters of the area are above the WHO [17] Guideline for drinking water and thus poses a quality problem. They are unfit for drinking, domestic and agricultural use. The possible health effects of these heavy metals in humans and animals are also presented in Table 2. These effects will get to human and animal systems via water intake/uptake.

Assessment of metal contamination

In order to assess the heavy metal contamination in the shallow groundwater and surface water in the study area. Three quantitative indices namely: Geoaccumulation index [Igeo], Enrichment factor [EF] and Heavy metal pollution index [HPI] were utilised.

Index of geoaccumulation (Igeo)

Index of geoaccumulation (Igeo) as introduced by Muller [20] has been extensively used to assess the degree of metal contamination in terrestrial aquatic and marine environments [21-24]. It is expressed as; Igeo= $Log_2[(C_n)]/(1.5B_n)]$. Where, C_n is the concentration of the element in the enriched water sample and B_n is the background concentration of element either taken from the literature (average crustal abundance) or directly determined from a geologically similar area.

Heavy metals	WHO (2006) Guideline		Waters from the study area		
	Desirable Limit	Permissible Limit	Range	Mean	Evaluation for drinking and/possible health effects.
Cd (mg/L)	<0.01	<0.01	0.0-0.110	0.030	Very high. May be carcinogenic; May cause kidney damage, lung cancer, ostemalcia or osteoporosis, anaemia, teeth discolouration.
Cr (mg/L)	<0.05	<0.1	0.003-0.146	0.030	High to good. May be carcinogenic; May cause kidney damage, convulsions, dermatitis and diathasis.
Co (mg/L)		<0.1	0.110-1.260	0.63	Very high. May cause vomiting, dermatitis, asthma, skin rashes, vision and heart problem.
Cu (mg/L)	<0.05	<1.0	0.0-0.260	0.043	Excellent to good
Fe (mg/L)	<0.1	<1.0	0.015-8.398	1.942	High to good. May cause conjunctivitis, stains and taste.
Pb (mg/L)	<0.020	<0.050	0.001-1.853	0.512	Very high. May cause kidney damage, anorexia, encephalopathy (brain swelling), dizziness, digestive disorder, lung cancer, coma and death.
Ni (mg/L)		<0.02	0.001-0.112	0.022	High to good. May be carcinogenic; May cause allergies and skin problem.

Table 2: Evaluation of heavy metals in waters of the study area for drinking/domestic purposes and possible health effects (Modified after WHO, Holding, Lsevirsion) [17-19].

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The factor 1.5 is used to address possible variations in the background concentration due to lithologic differences [25]. For this study the respective values of MCWR [16] were used as background concentrations for the water (Table 1). Muller [20] proposed seven descriptive classes of geoaccumulation index (Table 3).

Class	I geo Value	Quality
0	I geo ≤ 0	Uncontaminated
1	0<Igeo <1	Uncontaminated to moderately contaminated
2	1< Igeo<2	Moderately contaminated
3	2< Igeo<3	Moderately to heavily contaminated
4	3< Igeo<4	Heavily contaminated
5	4< Igeo<5	Heavily to extremely contaminated
6	5< Igeo	Extremely contaminated

Table 3: Geoaccumulation Index (Igeo) according to Muller (1969).

The computed values of the geoaccummulation index (Igeo) of the heavy metals in the waters of the study area are presented in Table 4.

Water Sample	Cd	Cr	Co	Cu	Fe	Pb	Ni
MNP1	9.57	3.87	8.89	4.63	-1.36	8.31	4.15
HDW1	3.74	6.61	10.03	2.52	2.15	6.24	2.15
HDW2	6.20	3.32	8.52	-0.07	-2.12	-2.17	5.61
HDW3	0	1.00	12.03	2.93	1.44	2.87	5.47
MNP2	6.54	4.32	11.79	3.10	-0.28	0.83	6.24
MNP3	7.69	5.22	11.98	0.93	-0.91	8.00	4.96
MNP4	8.54	4.06	10.15	3.25	1.72	8.69	3.96
MNP5	7.69	3.74	11.02	3.39	0.66	2.78	5.74
HDW4	8.41	4.87	11.41	3.74	1.73	8.17	5.47
HDW5	7.20	4.50	12.04	2.25	1.09	8.38	5.47
HDW6	6.20	3.50	9.46	0	3.13	4.06	4.47
HDW7	8.80	4.27	10.15	3.39	0.94	4.70	4.32
MNP6	7.83	4.06	11.56	4.02	3.49	7.41	4.96
ADT1	7.69	3.81	9.10	4.18	0.17	7.76	5.74
STRM1	7.32	3.74	9.59	2.25	1.06	1.00	6.93
STRM2	6.99	3.42	8.60	2.25	0.45	2.83	5.06
HDW8	7.44	2.00	11.97	3.25	-5.64	2.83	5.80
MNP7	3.81	4.22	12.03	2.74	0.25	5.45	1.15
MNP8	6.74	7.60	9.99	4.10	-0.83	6.41	7.96
STRM3	6.32	1.00	11.15	1.93	2.03	2.83	5.47
Range	0-9.57	1-7.6 0	8.52-12. 04	-0.07-4 .63	-5.64-3. 49	-2.17-8. 69	1.15-6.9 3
Mean	6.74	3.96	10.57	2.74	0.46	4.87	5.05

Table 4: Geoaccumulation index of heavy metals in waters of the study area.

Average Igeo values are 6.74, 3.96, 10.57, 2.74, 0.46, 4.46, 4.87 and 5.05 for Cd, Cr, Co, Cu, Fe, Pb and Ni, respectively. Therefore, the degree of heavy metal contamination in the waters using geoaccumulation index (Igeo) is in the order: Co>Cd>Pb>Ni>Cr>Cu>Fe (Figure 3). The average Igeo values of 10.57, 6.74 and 5.05, for Co, Cd and Ni, respectively indicate that the waters of the area are extremely contaminated (Table 5). Also Pb and Cr have average Igeo values of 4.87 and 3.96, respectively; therefore depicting heavily to extremely contaminated waters, whereas Cu and Fe have average Igeo values of 2.74 and 0.46, respectively; thus, indicating moderately to heavily contaminated water and uncontaminated to moderately contaminated water, respectively.

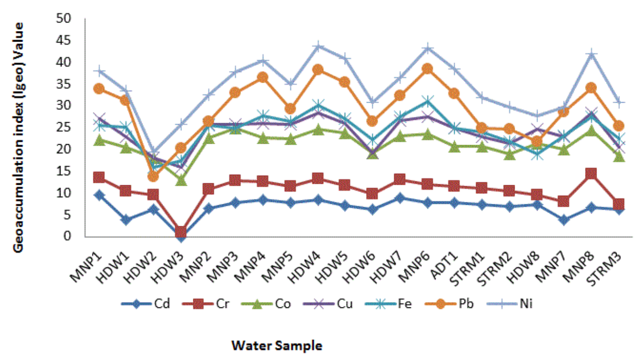

Figure 3: Profiles of the computed geoaccumulation index (Igeo) in the waters of the study area.

Metals	Igeo value		Overall heavy metal contamination level in the waters
	Range	Mean	
Cd	0-9.57	6.74	Extremely contaminate
Cr	1-7.60	3.96	Heavily contaminated
Co	8.52-12.04	10.57	Extremely contaminated
Cu	-0.07-4.63	2.74	Moderately to heavily contaminated
Fe	-5.64-3.49	0.46	Uncontaminated to moderately contaminated
Pb	-2.17-8.69	4.87	Heavily to extremely contaminated
Ni	1.15-6.93	5.05	Extremely contaminated

Table 5: Summary of geoaccumulation index (Igeo) with regards to heavy metal contamination in waters of the study area.

The relatively high Igeo values for Cd, Co, Pb, Ni, Cu and Cr in the waters could be due the mining and mineral processing activities as well as weathering of natural mineral deposits in the area.

Enrichment factor (EF)

Enrichment factor (EF) is popularly used to determine whether the sources of the metals are geogenic and/or anthropogenic as well as to assess the degree of metal contamination [26-28]. According to

Selvaraj et al. [26] EF values from 1 to 10 indicate geogenic sources (natural source), while those greater than 10 indicate anthropogenic sources. Sutherland (2000) suggested five contamination categories of enrichment factor and they are presented on Table 6.

EF Value	Quality
<2	Minimal enrichment
2-5	Moderate enrichment
5-20	Significant enrichment
20-40	Very highly enriched
>40	Extremely highly enriched

Table 6: Enrichment factor according to Sutherland (2000).

The enrichment factor (EF) originally proposed by Buat- Menard and Chesselet [29] was employed to assess the metal enrichment in the water of the study area. It is expressed as:

EF= $[(C_n/C_{ref})_{sample}]/(B_n/B_{ref})$, where $C_{n(sample)}$ is the content of the examined element, $C_{ref(sample)}$ is the content of the reference element, B_n is the background value of the examined element and $B_{ref(sample)}$ is the background value of the reference element. For this study, Fe was used as the reference element at MCWR value of 0.5mg/L [16]. The computed values of the enrichment factor (EF) of the heavy metals in the waters of the study area are presented on Table 7, while their profiles are shown in Figure 4. The computed enrichment factor (EF) values depict that the trends of metal enrichment in the waters of the area varies from one location to another.

Water Sample	Cd	Cr	Co	Cu	Pb	Ni
MNP1	1877.13	37.54	1211.60	63.38	812.86	45.51
HDW1	3.00	21.87	235.14	1.28	16.97	1.00
HDW2	317.92	43.35	1589.60	4.13	0.96	211.95
HDW3	0.00	0.74	1538.37	2.81	2.71	16.40
MNP2	113.09	24.23	4285.14	10.39	2.15	91.55
MNP3	388.47	70.18	7581.45	3.58	482.04	58.48
MNP4	113.04	5.05	344.17	2.88	124.68	4.71
MNP5	131.13	8.46	1313.45	6.65	4.37	33.84
HDW4	102.29	8.83	816.29	4.01	86.64	13.37
HDW5	69.10	10.68	1978.64	2.24	156.51	20.94
HDW6	8.37	1.29	80.30	0	1.90	2.54
HDW7	232.48	10.06	591.60	5.45	13.53	10.41
MNP6	20.24	1.49	268.52	1.45	15.81	2.78
ADT1	184.09	12.47	486.94	16.12	193.19	47.51
STRM1	76.58	6.38	368.54	2.28	0.96	58.50
STRM2	92.50	7.79	282.38	3.48	5.19	24.34
HDW8	8666.67	200.0	200166.67	476.19	155.56	2777.78
MNP7	11.76	15.68	3502.24	5.60	36.58	1.87
MNP8	189.57	343.60	1800.95	30.47	151.26	442.43
STRM3	19.59	0.49	555.83	0.93	1.74	10.88
Mean	630.85	41.51	11449.89	32.17	123.07	193.84

Table 7: Enrichment factor in waters of the study area.

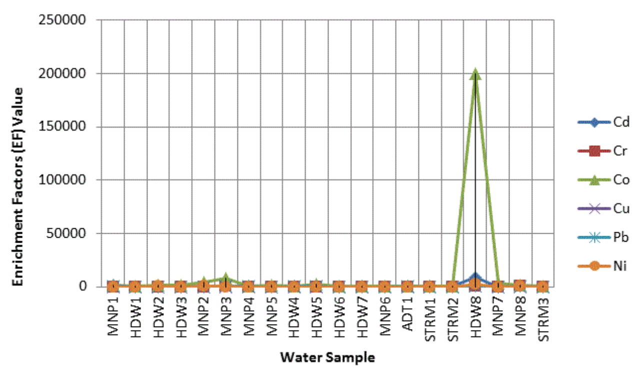

Figure 4: Profiles of the computed enrichment factor (EF) in the waters of the study area. EF values greater than 10 are indicative of anthropogenic sources.

Average values of Cd, Cr, Co, Cu, Pb and Ni are 630.85, 41.51, 11449.89, 32.17, 123.07 and 193.84, respectively (Table 7). The higher average values for Co, Cd, Ni and Pb indicate that the waters are highly enriched with these heavy metals compared to Cr and Cu (Figure 5). Therefore the mean values of the metal enrichment in the waters of the area are in the order: Co>Cd>Ni>Pb>Cr>Cu (Figure 5). Generally, using Sutherland (200) contamination categories of enrichment factor (Table 6), the waters of the study area are extremely highly enriched with Co, Cd, Ni, Pb and Cr, and highly enriched with Cu.

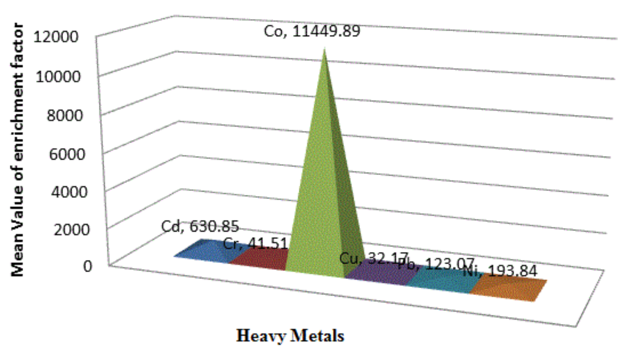

Figure 5: Profile of the mean value of enrichment factor (EF) in the waters of the study area.

The heavy metal enrichment in water samples MNPI and HDW8 show extreme high enrichment with Cd, Cr, Co, Cu, Pb and Ni (Table

7). The EF values with regards to cobalt (Co) in all the waters are greater than 40 and thus, depicts that they are extremely highly enrich in Co. The waters are also extremely highly enriched in Cd with exception of samples HDW1, HDW3, HDW6, MNP6, MNP7 and STRM3 which have minimal to significant enrichment.

Generally, the sources of these heavy metals in the waters of the study area anthropogenic since most of the computed enrichment factor (EF) values are greater than 10. Quantification of the overall heavy metal contamination in the waters shows that 100% of Co, 85% of Cd, 75% of Ni, 60% of Pb, 55% of Cr and 25% of Cu are derived from anthropogenic sources of the metals (especially Co, Cd, Pb, Ni and Cr) in the waters could be attributed to the mining and processing of cassiterite, columbite and other related or associated mineral deposits as well as lead gasoline, lubricating oil and corrosion of mining equipment around the study area.

Heavy metal pollution index (HPI)

Heavy metal pollution index (HPI) is a method of rating that shows the composite influence of individual heavy metal on the overall quality of water. It is a very useful tool in evaluating overall pollution of water bodies with respect to heavy metals [30]. It is usually computed using the formulae: HPI = $\Sigma(w_i o_i)/\Sigma w_i$. Where, w_i is the unit weight age for ith parameter, Q_i is the subindex of ith parameter. The subindex (Q_i) is given as baseline value of ith parameter and S_i is the standard or permissible limit of ith parameter. Generally, the critical pollution index value is 100 [30-32].

The parameters utilised to calculate the HPI as well as the calculated value of HPI in the waters of the study area are presented in Table 8.

Heavy Metals (mg/L)	Mean Value (Mi)	Standard Value (Si) WHO 2006	Baseline Value (Ii)	Unit Weightage (Wi)	Subindex (Qi)	Wi Qi
Cd	0.030	0.003	0.0001	333.33	195.92	65306.01
Cr	0.0425	0.05	0.001	20.00	16.95	339.00
Co	0.63	0.01	0.0002	100.00	1277.75	127775.00
Cu	0.043	1.00	0.007	1.00	1.69	1.69
Fe	1.942	0.30	0.500	3.33	144.18	480.12
Pb	0.512	0.01	0.003	100.00	1456.71	145671.00
Ni	0.022	0.02	0.0003	50.00	22.85	1142.50

Table 8: Heavy metal pollution index (HPI) calculation for the waters of the study area.

$\Sigma W_i=607.66; \Sigma (W_i O_i)=339755.08$: HPI=559.12

The heavy metal pollution index (HPI) calculated with the mean value of all the seven heavy metals is 559.12, which is above the critical pollution index value of 100. Therefore depicts that the waters of the study area are critically polluted with regards to heavy metal contents.

Conclusions

Results of this study revealed that most of the heavy metal concentration in the waters of the area are higher than the WHO (2006) Guideline for drinking water and thus pose a quality problem. The mean concentration of the heavy metals in the order: Fe>Co>Pb>Cu>Cr>Cd>Ni. The geoaccumulation index (Igeo) and enrichment factor (EF) show that the waters are moderately to extremely contaminated, and moderately to extremely highly enrich with heavy metals; whereas the heavy metal pollution index (PHI) indicates that the waters are critically polluted. Sources of the heavy metals in the waters are primarily anthropogenic and could be attributed to the mining and processing activities in the area.

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