Physico-Chemical Quality of Water in the Gold Mining areas of Bibiani, Ghana

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Abstract
Physico-chemical quality of waters sources from Bibiani and its environs was conducted between November, 2009 and April, 2010. This study was undertaken to determine whether physical, chemical and trace metal contamination of water sources in Bibiani is as a result of mining or geochemical and biochemical processes within the environment. Levels of trace metals (Arsenic (As), Iron (Fe), Manganese (Mn), and Copper (Cu)), physical parameters (pH, Total Dissolved Solids (TDS), Electrical Conductivity and Temperature) and chemical parameters (Alkalinity, Hardness, Phosphate and Cyanide) in water sources were determined. Water samples were collected from ten sampling points: four surface waters (SW1, SW2, SW3, and SW4) and six groundwater points (GW1, GW 2, GW3, GW4, GW5 and GW6). Mining related contaminants detected in water samples were As (<0.001 to 0.002 mg/l), CN (0.002 to 0.036 mg/l), Mn (0.1 to 0.72 mg/l) and Fe (0.32 to 3.035 mg/l). Groundwater (GW3 and GW4 samples had more Mn with concentrations of 0.72 and 0.5 mg/l, respectively). Surface water contained more As (SW2 recorded 0.02 mg/l) and Fe (between 1.246 and 3.035 mg/l) contaminants. Compared to WHO / EPA guidelines, few water sources had levels outside limits acceptable for drinking.

Keywords: Physico-chemical quality, water sources, gold mining, Bibiani.

1. INTRODUCTION
The environment is the most important asset for man. It is therefore prudent to protect it from pollution. The development of every nation depends largely on its well-managed environment. In Ghana surface gold mining operations generate substantial revenue for the nation. However, if its activities are not well monitored and proper measures put in place, it will be a major cause of environmental degradation. Many of the residents in the Sefwi-Bibiani belt, within which Bibiani falls, depend on ground and surface waters for drinking and domestic purposes [16]. However, effluents from the mining industry may pollute some of these water bodies and make them unsafe.

Gold mining has been the most important industry in Ghana for a long time and the country is one of the major gold producing countries in the world today. Surface gold mining involves the extraction and exploitation of gold minerals from the ore in the earth’s crust by surface mining operation. CAG in Bibiani like any other surface gold mining can be a major source of pollution to the surrounding water bodies. The major chemical used in extracting gold in CAG is mainly sodium cyanide solution in the Cyanide Inland Leach (CIL) plants. This chemical used in the gold extraction and the leachate from the waste and / or ore dumps turns to affect the hydrology, physical and chemical nature of the environment such as water bodies, air and land. Besides, spillage from the tailing may have adverse effect on man and the ecological life due to poisoning (e.g. Cyanide poisoning). It is thus essential to identify the water sources within the Bibiani gold mining area and determine the actual sources of impact on the quality of water in relation to the geochemistry or mining activity.

Bibiani is a town in Ghana where the indigenous population in the town as well as surrounding communities use groundwater, rivers and streams as their sources of drinking water. The qualities of these water supplies vary naturally and widely dependent on climate, season, and the geology of the bedrock, as well as anthropogenic activities. This study is thus focused on the water sources of Bibiani where gold mining activities occur. There are fears among residents that the operations of the mining company (Central African Gold) in the area are causing serious contamination of the water sources. Arsenic, copper, iron, manganese, and cyanide are among the contaminants likely to be released from mining operations [2]. Water is affected by mining through heavy use of water in processing the ore, and through water pollution from discharged mine effluent and seepage from tailings and waste rock impoundments. Water has been called “mining’s most common casualty” [3].
It has been anticipated that metal levels in ground and surface water may exceed WHO guidelines for drinking water in many mining areas in Ghana. This has been confirmed by earlier studies in areas like Obuasi, Tarkwa and Prestea [3]. For instance, a study conducted by Friends of the Earth-Ghana in Obuasi and its surrounding settlements in 1996, showed that the Kwabrafo River at Obuasi in the Ashanti region, had 38 times more arsenic than World Health Organization (WHO) permissible levels whilst the Jimi River at Akrofrom also in the Ashanti region had 36 times more arsenic [1]. This study thus seeks to determine the quality of water sources in the Bibiani gold mining area in order to evaluate their suitability for drinking and domestic purposes.

2. MATERIALS AND METHODS

2.1 Selection of study area
The study area, Bibiani was selected for this study because surface and ground water sources are extensively used for drinking and domestic purposes. Most of these are easily accessible and there is a mine operation in the area.

2.2 Location and access
Bibiani is located in the Western Region of Ghana. It has a population of about 19,076 [16]. Bibiani is located at latitude 6.47°N and longitude -2.33°W at an altitude of 250 meters [16]. The Bibiani gold mine is located in Western Ghana. The mine lies within the Sefwi-Bibiani belt, host to over 17 million ounces of gold mineral resources, and the second-most significant gold-bearing belt in Ghana after the Ashanti belt to the east. The mining concession area of approximately 49km² is closely adjoined to the town of Bibiani, approximately 80km southwest of the Ashanti capital, Kumasi. The most practicable access to the area is from the east on the Kumasi road.

2.3 Sampling points and location
Sampling points were carefully chosen in order to assess the general characteristics of ground and surface water quality in Bibiani and its environs. Ten (10) sampling points; four surface water bodies (SW1, SW2, SW3 and SW4) and six groundwater samples (GW1, GW 2, GW3, GW4, GW5 and GW6) were chosen for this investigation. Factors considered in choosing the sampling points include: proximity, purpose and population, (Fig. 1).

![Diagram of the sampling area showing the sampling points.](image)

**Fig. 1:** Diagram of the sampling area showing the sampling points.
2.4 Sampling and Sample preparation

Sampling was done between November, 2009 and April, 2010. Samples were collected at one month interval from ten (10) sampling points. To obtain reliable results, sample procedures which eliminate or minimise potential contaminants were adopted. This was achieved by soaking sample containers in nitric acid solution overnight and thoroughly flushing the container with distilled water and finally rinsing them with de-ionized water and dried in a drying cabinet. Water sample for physico-chemical analysis were collected with 500ml plastic containers. Samples were transported (stored in an ice chest containing ice) to the laboratory, stored in a refrigerator and analysed within 12 hours. Samples for trace metal analysis were also collected with 500ml container but were acidified with concentrated nitric acid. This was done to ensure a low pH value which helps to prevent or reduce precipitation and limit sorption to the bottle walls. It was also to preserve sample(s) for about six months if the need arose (low pH keeps the metals in solution). In sampling surface water, bottles were held near the base and its neck was plunged downward below the surface of the water body. Bottle was turned until the neck pointed slightly upwards, the mouth being directed towards the current of the water body. Bottles were filled directly from the water body without further rinsing and cap replaced immediately. In the case of SW 1 sampling was done with the aid of a bailer. In sampling groundwater stagnant water was remove from the bore casing before a sample was taken. This is called purging. About three casing volumes of water were removed before sampling (pumping of bore continued even after three casing volumes had been removed until such time as the pH, electrical conductivity and temperature of the discharged water were observed to remain constant (stabilised) for at least five minutes). Steadied temperature, conductivity and pH levels indicate that GW quality has stabilised. Purging all stagnant water ensured that only GW from the in-situ aquifer was collected (i.e. GW representative of the geologic material under investigation). All samples were kept in an ice-chest and transported to the Health Safety and Environment laboratory of CAG, stored in a refrigerator at a temperature < 4 °C and analysed within 12 hours. Temperature, pH, TDS and electrical conductivity were measured on site.

3. RESULTS
3.1 Water quality results
A summary of results recorded for physico-chemical parameters and trace metals analyses have been presented in figures 1 to 6. Where possible, these values have been placed alongside WHO and / or EPA (Ghana) guidelines for surface and ground waters.

3.2 pH

Fig. 2: Mean pH values recorded for ground and surface water bodies. The lines indicate the pH range stipulated by the WHO, [20].

pH values ranged from 5.77 to 7.14 pH units (Fig. 2). This gives the general indication that the water bodies under study ranges from being acidic to neutral. The highest desirable level for pH stipulated for drinking and domestic purposes is within the range of 6.5 to 8.5 (EPA, [11]; WHO, [21]). The pH value of surface water varied from a minimum of 6.57 to maximum of 7.14 whereas ground water pH was from 5.77 to 6.56 (Fig. 2). Minimum and maximum surface water pH values were recorded at SW1 (within mine concession) and SW4 (outside mine concession) and those of ground water were obtained at GW1 and GW4 both of which are outside mine concession and processing facilities. There was a significant difference between the pH values for ground and surface water bodies (P = 0.00418) (Table 1).

3.3 TOTAL DISSOLVED SOLIDS (TDS)
TDS concentrations for water samples ranged from 162.45 to 552.38 mg/l (mg/l). Surface water TDS concentration ranged from a minimum of 208.12 to a maximum of 552.38 mg/l. Groundwater concentration values ranged from 162.45 to 524 mg/l.
3.4 TEMPERATURE
The mean temperature value of all the water samples analysed ranged from 27.57 to 29.8°C. Surface water temperature ranged from the minimum value of 27.57 to a maximum of 28.13°C occurring at SW4 and SW3 (outside the mines). Groundwater recorded values ranging from 27.87 to 29.08°C which occurred at GW1 and GW2 respectively.

3.5 ELECTRICAL CONDUCTIVITY (E.C)
Recorded E.C. values for water in the study area varied between 360.167 and 957.12 µS/cm. These values are within the WHO guideline limit of 1000 µS/cm [21] stipulated for drinking and domestic water. The conductivity values for groundwater ranged between 360.16 ? to 957.12 µS/cm whereas surface water values were from 451.67 µS/cm to 774.72 µS/cm. Conductivity values for ground and surface water bodies were observed to be statistically insignificant (P = 0.25) (Table 1).

3.6 PHOSPHATE
Phosphate concentrations for the water samples varied between 1.067 and 2.13 mg/l. Phosphate concentrations for groundwater ranged from 1.067 to 2.03 mg/l. Surface water concentrations from the study area ranged from 1.25 to 2.13 mg/l. The recorded phosphate concentrations (Table 1) for ground and surface water bodies were not significantly different (P = 0.47).

3.7 TOTAL ALKALINITY
Alkaline concentration ranged from 270 to 385 mgCaCO₃/l for both water sources. Recorded alkalinity values for surface water bodies ranged from 295 to 378.33 mgCaCO₃/l. Groundwater concentrations were from 270 to 385 mgCaCO₃/l. Groundwater alkalinity values did not differ significantly from that of surface water sources (P = 0.84) (Table 1).

3.8 TOTAL HARDNESS
Total hardness concentrations recorded during the study ranged from 320 to 458.3 mgCaCO₃/l. The hardness value for groundwater ranged between 351.67 to 458.3 mgCaCO₃/l whereas surface water values were from 320 to 405 mgCaCO₃/l.

3.9 ARSENIC
As concentration for the water samples in Bibiani ranges from values < 0.001 to 0.02 mg/l (Fig. 3). Surface water As concentration ranged from 0.002 to 0.02 mg/l whereas groundwater recorded concentrations from values <0.001 to 0.0017 mg/l (Fig. 3). Minimum and maximum surface water As concentrations were recorded at SW4 (outside the mines) and SW2 (within the mines) whiles the highest groundwater As concentration was recorded at GW4 (outside the mines). The concentration of As is generally very low (below detection limit) almost throughout the study. However at SW2 As concentrations exceeded the WHO guideline limit of 0.01 mg/l (Fig. 3). The concentration of As in groundwater varied significantly from that of surface water (P =0.009) (Table 1).
3.10 TOTAL CYANIDE

Fig. 4: Mean cyanide values (mg/l) recorded for ground and surface water bodies

CN concentrations for the water samples understudy varied between 0.002 and 0.036 mg/l (Fig.4). This falls within the WHO and EPA guideline limit of 0.07 and 0.1 mg/l ([21]; [11]) (Fig.4). The level of concentration of CN in groundwater ranged from 0.002 to 0.036 mg/l whiles surface water recorded values from 0.008 to 0.02 mg/l. These values were recorded at GW6 and GW3 for groundwater; SW1, SW2 and SW4 for surface water. The sampling points GW6, GW3, SW1, and SW2 are located within the mines whereas SW4 is not. Cyanide levels in surface water bodies showed significant variations (P = 0.7) from that of groundwater (Table 1).

3.11 MANGANESE

Fig. 5: Mean manganese values (mg/l) recorded for ground and surface water bodies.

Values recorded for water samples were between 0.1 and 0.72 mg/l. Groundwater Mn concentration ranged from 0.1 to 0.72 mg/l at GW6 and GW3 (Fig.5). Mn concentrations for surface water were between 0.22 and 0.23 mg/l occurring at the sampling points SW1 and SW3 for the minimum and SW2 and SW4 for maximum (Fig. 5). These concentrations fall within the WHO guideline limit of 0.5mg/l. At GW3 (located within the mines) Mn concentration exceeded the WHO guideline limit of 0.5 mg/l stipulated for drinking and domestic purposes. Variations between Mn concentrations in surface and ground water samples were statistically insignificant (P = 0.3) (Table 1).

3.12 TOTAL IRON

Fig. 6: Mean iron values (mg/l) recorded for ground and surface water bodies.

Iron (Fe) values for both ground and surface waters ranged from 0.32 to 3.04 mg/l (Fig.6). Concentrations obtained for groundwater varied between 0.32 and 1.47 mg/l occurring at GW2 (located outside the mines) and GW3 (located within the mines) (Fig.6). Fe concentrations recorded for surface water sources ranges from 1.246 to 3.035 mg/l at the sampling points SW2 and SW1 both of which are located within the Bibiani mines (Fig.6). Fe concentrations recorded at all the sampling points are clearly in excess of the WHO and EPA guideline limit of 0.3mg/l [21]; [11], (Fig.6). From Table 1, the variations of Fe concentrations between ground and surface water bodies were statistically significant (P = 0.008).
Table 1: ANOVA for Ground and Surface Water Sources

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<th>Source of Variation</th>
<th>ss</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
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Cell contents:
- Temp. - Temperature
- Mn - Manganese
- Fe - Iron
- pH - Potential of Hydrogen
- TDS - Total Dissolved Solids
- Grp. - Group
- CN - Cyanide
- Phos - Phosphorus
- Alk - Alkalinity
- Hard - Hardness
- As - Arsenic

4. DISCUSSION

4.1 Water Quality

**pH:** Surface water pH values fell within the 6 – 9 pH range of natural waters [18]. With the exception of SW1, all the surface water bodies can be described as being neutral (pH range 7.03-7.14). These pH values also fell within the range of 6.5 to 8.5 stipulated for drinking and domestic purposes by the WHO, [21]. The EU also sets protection limits of pH from 6 to 9 for fisheries and aquatic life [7]. The pH obtained in the surface water bodies were within these ranges. Based on these guidelines, the pH of surface water sources from Bibiani would not adversely affect its suitability for drinking, domestic and recreational purposes as well as aquatic ecosystem.
Groundwater pH recordings were generally low except at GW 1 which recorded a pH value of 6.56 (Fig.2), and which is within the WHO limit of 6.5 to 8.5 [21]. The highest desirable level for pH stipulated for drinking and domestic purposes is within the range of 6.5 to 8.5 [11; 21]. Groundwater pH was below this limit suggesting possible acidity. The low pH in groundwater may be due to natural geochemical and biochemical processes within the aquifers [9]. This is due to the fact that, the presence of sulphides and carbonaceous matter in the ore formations means that natural geochemical and biochemical degradation (oxidation) of these rocks may occur, when in contact with oxygen gas containing water, leading to increased hydrogen ion activity in the waters with which they are in contact. Acidity in some groundwater sources in Bibiani may be attributed either to mining activity (seepage of effluent discharge or old tailing dams) or to natural geochemical and biochemical processes within the aquifers especially at sampling points outside mining concession, activities and processing facilities (GW 1, GW 2, GW 4, and GW 5). Acidity gives sour taste to water. It is for this reason of taste that the EPA, [11] and WHO, [21] limit the pH range for water potability from 6.5 to 8.5. Consequently, pH values for most of the groundwater sources in the study area were lower than the WHO and EPA limits which suggests a potential taste problem.

**Total Dissolved Solids (TDS):** TDS values recorded for ground and surface water sources were within the WHO limit of 1,000 mg/l. This indicates that the water bodies in the study area are generally fresh [20]. Davis and DeWiest, [8], regard water as fresh if the TDS value is less than 1,000 mg/l. The palatability of water with TDS level less than 600 mg/l is generally considered to be good whereas water with TDS above 1,200 mg/l becomes increasingly unpalatable [14].

**Temperature:** There was a significant difference in temperature variation between water bodies in the study. Minimum and maximum temperature values for ground and surface water bodies were both recorded at sampling points outside concession of the mines and processing activities and facilities. The EPA, Ghana [11], stipulates that water for drinking and domestic purposes should have a temperature not exceeding 30 °C. The temperature values recorded for water in the study area were within the EPA limit of 30°C. Thus quality of water in Bibiani with respect to temperature may be suitable for drinking as well as for domestic uses.

**Electrical Conductivity:** Conductivity values were all within the WHO, [21] guideline limit of 1,000 μS/cm for drinking water, it could be concluded that no adverse health effects associated with the electrical conductivity of water bodies in Bibiani and its environs were expected.

**Phosphate:** There was no WHO guideline value to compare with the recorded values. However, comparing these values with the natural phosphate range of 0.005 to 0.020 mg/l [6], it could be concluded that groundwater phosphate concentrations were high. This might be a result of eroded materials from waste rock dumpsites and old tailings coming in contact with the water table via seepage. Phosphate loads in surface water samples exceeded the natural phosphate range of 0.005 to 0.020 mg/l [6]. This could be attributed to industrial (inflows from eroded materials carried from waste rock dumpsite and old tailing dams) and domestic activities (e.g. detergents from washing and bathing and refuse).

**Total Alkalinity:** Alkalinity concentrations less than 1,000 mgCaCO$_3$/l are desirable for domestic water supplies [13]. There was no WHO/EPA guideline to compare with the recorded values from the study area. However, the Illinois Department of Public Health, [13] recommends 300 to 400 mgCaCO$_3$/l as the range for drinking water. Alkaline concentration recorded from the study area for most of the ground and surface water sources fell within the 300 to 400 mgCaCO$_3$/l range. It can thus be inferred that the water sources in Bibiani per this parameter are suitable for drinking purposes. A minimum level of alkalinity is however desirable because it is considered a “buffer” that prevents large variations in pH. Alkalinity is not detrimental to humans. Moderately alkaline water (less than 350 mgCaCO$_3$/l) in combination with hardness forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. Many public water utilities employ this practice to reduce pipe corrosion and to increase the useful life of the water distribution system [13].

**Total Hardness:** Hardness of water for domestic use relates mainly to its reaction with soap. Since soap is precipitated principally by Ca$^{2+}$ and Mg$^{2+}$; hardness is defined as the sum of the concentrations of these ions expressed as mg/l of CaCO$_3$. Water with hardness in the range 0–60 mgCaCO$_3$/l, 61 – 120 mgCaCO$_3$/l, 121 – 180 mgCaCO$_3$/l and > 180 mgCaCO$_3$/l are regarded as soft, moderately hard, hard and very hard, respectively [12; 17].
There was no WHO / EPA guideline to compare with groundwater values obtained from the study. However, comparing the recorded values with The British Columbia Groundwater Association, [17] and Hem, [12] guidelines it could be deduced that groundwater in Bibiani were generally very hard. This might have resulted from weathering of limestone, sedimentary rock and calcium bearing minerals largely facilitated by mining activities; as well as effluent discharges from the mines that seeped underground. Other sources such as excessive application of lime to the soil in agricultural areas might have contributed to the high hardness values in this study.

Surface water recorded varying levels of hardness between 320 and 465 mgCaCO₃/l. Comparing the recorded values with the range provided by Hem [12] and The British Columbia Groundwater Association, [17], surface water bodies in Bibiani could be described generally as being very hard. This means usage of surface waters for domestic purposes could lead to more soap requirement for washing.

**Arsenic (As):** The variations of As concentrations between ground and surface waters were statistically significant (P = 0.009) (Table 1) As was detected in all surface water bodies in the study at concentrations within the WHO [21] guideline of 0.01 mg/l. However at SW2, As concentrations were slightly in excess of the WHO [21] guideline of 0.01 mg/l (Fig. 3). This could be due to mineral dissolutions such as pyrite oxidation. The generally low As concentrations detected in surface water in Bibiani, suggests As could poses limited potential physiological problem to the use of these water bodies for drinking purposes. The very low concentrations in groundwater, in spite of the high presence of pyrite and arsenopyrite in association with the gold ore, suggests there might be a level of co-precipitation of As with ferric oxyhydroxide in the creeks before possible infiltration into the aquifer [15].

**Cyanide (CN):** CN was detected in all the water bodies in Bibiani (Fig.4). The levels detected were however, less than the 0.1 and 0.07 mg/l guideline limits set by the WHO, [21] and EPA, [11] respectively indicating low CN contamination levels (Fig.4). The low levels detected provide a useful early warning of potential problems. Chronic low exposure to hydrogen cyanide causes neurological, respiratory, cardiovascular and thyroid effects [4; 5; 10]. It is therefore important to constantly monitor CN levels in water bodies (drinking water in particular) in Bibiani and its environs. CN variations between ground and surface water bodies were statistically insignificant (P = 0.7) (Table 1).

**Manganese (Mn):** Mn was detected in all water samples. Variations in Mn concentrations between surface and ground water samples were statistically insignificant (P =0.3) (Table 1). This implies the rate at which Mn contaminates groundwater does not differ significantly from that of surface water. Surface water bodies investigated in this study had Mn concentrations below the WHO guideline value of 0.5 mg/l [21] stipulated for drinking and domestic purposes (Fig.5).

Ground water sources sampled in the study area also recorded Mn concentrations within WHO guideline. GW3 was most affected by Mn contamination with a recorded value of 0.72 mg/l in excess of the WHO guideline of 0.5 mg/l (Fig.5). The high Mn concentration level detected at GW3 (within the mines) could be attributed to anthropogenic sources such as effluent discharges and acid-mine drainage from mining activities. It could also be as a result of natural geochemical and biochemical processes such as weathering of manganese bearing minerals and rocks within the aquifers.

**Iron (Fe):** From Table 1, the variations of Fe concentrations between ground and surface water bodies were statistically significant at P = 0.008. Surface water bodies in Bibiani were more contamination by iron than groundwater bodies (Fig.6). Fe concentration in the water samples exceeded the 0.3 mg/l guideline set by the WHO, [21] and EPA, [11]. The major minerals found in igneous rocks; amphiboles, ferromagnesian micas, ferrous sulphide (FeS), ferric sulphide or iron pyrite (FeS₂), and magnetite (Fe₃O₄) form the natural sources of iron in ground water [19]. The geology of the Bibiani area is such that rock mineral types present include arsenopyrites (FeAsS), magnetite, pyrite (FeS₂), (PbS) and iron-rich carbonates. The presence of these minerals in the study area is major natural sources of iron in water. The high Fe concentrations found in surface water samples compared to that of groundwater (Fig.6) might be suggestive of the mineral-water interactions and oxidation-reduction reactions taking place in such systems. Mine activity possibly resulting to effluent discharges as well as leachate from waste rock dump and tailing dams might also have contributed to the high Fe levels in surface water. The high levels of Fe in the surface waters indicate possible contamination from inflows of waste rock dumpsites and old tailing dams.
Copper (Cu): Levels of Cu in ground and surface water sources investigated in Bibiani and its surrounding communities were all below the WHO threshold of 1.00 mg/l [21]. This suggests that any adverse health effects arising from domestic use of the water are not expected as far as this parameter is concerned.

5. CONCLUSION

Groundwater had lower pH ranging from 5.77 to 6.56 pH units than surface water ranging from 6.57 to 7.14. The differences in pH between ground and surface waters may be due to natural geochemical and biochemical processes within the aquifers. Ground waters had higher concentrations of dissolved ions (ranging from 360.167 to 957.12 µS/cm) and so more mineralized than surface waters (ranging from 451.67 to 774.72 µS/cm).

Mining related contaminants detected were As, CN, Mn and Fe. Groundwater in the study area was established to be contaminated by Mn and Fe. Mn contamination may be due to natural geochemical and biochemical processes within the aquifer. Anthropogenic sources such as effluent discharge and acid-mine drainage from mining activities might also have contributed to the high Mn concentration in groundwater. High Fe concentrations may also be attributed to mineral water and oxidation-reduction reactions taking place in the system. Effluent discharges as well as leachate from waste rock dumpsite and tailing dams may also contribute to the excessive Fe level in groundwater.

Surface water bodies were found to be contaminated by As and Fe. As contamination may be due to the high presence of arsenopyrite in association with the gold ore. Fe levels in all the surface water bodies exceeded WHO / EPA guidelines. Fe contamination in surface water sources like groundwater may also be attributed to mineral-water and oxidation-reduction reactions taking place in the system. Inflows from waste rock dumpsites and old tailing dams might also have contributed to the increased Fe level. Compared to WHO / EPA guideline, few of the ground and surface water supplies had one or more trace metal (Fe, As and Mn) levels outside acceptable limits set for drinking water. Most of them however have levels safe for human consumption.

REFERENCES


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