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Effect of Acid Mine Drainage on Creeks or Streams in a Mining Community in Ghana and Treatment Options

C. Afriyie-Debrah, K. Obiri-Danso and J. H. Ephriam

Abstract—Heavy metals contamination and other physicochemical changes in underground and surface water by acid mine drainage (AMD) were determined on the impact on creeks or streams. High levels of these metals have been reported in mining areas over the years; however, investigations indicates that less monitoring has been done on water discharged as effluent for effective maintenance mechanisms to be effected. Field and laboratory studies were carried out within the mining community on Latitude S 2° 35 W and Longitude N 5° 31W to investigate the levels of heavy metals (As, Fe, Cu, Zn, Mn and Cd) and physico-chemical changes (pH, temperature, E.C, D.O, alkalinity, SO_4^{2-} , free CN) in both underground and surface water for seven sampling sites. Results from atomic absorption spectrometry (AAS) determination indicated an average concentrations of iron (6.185 mg/l) and manganese (2.271 mg/l) in both surface and underground waters which are higher than threshold limits for mining effluent. The physico-chemical changes were determined using standard methods. Results also indicated higher levels of electric conductivity (1435.0 μ s/cm) and sulphate (344.0 mg/l). Differences in pH, temperature, E.C, alkalinity, SO_4^{2-} , Fe, Cu, Zn and Mn levels in the seven water samples were statistically significant ($p \leq 0.05$). This may be attributed to the higher release of metals, relative to H⁺. Result also showed significant impact of AMD on water quality in the mining area. This effect could be attributed to the release of metals as a result of oxidation of metal-bearing sulphides in the mine dumps and pits at the selected sampling sites. The study showed that addition of lime as a treatment option has not been effective. Hence new conventional methods such as Aerobic wetland, Compost or Anaerobic Wetland, Open Limestone Channels, Diversion wells, Anoxic Limestone Drains (ALD) etc. should be considered in the treatment of acidic water (AMD) in the mining area.

Index Terms—Acid Mine drainage, Heavy Metals, Oxidation, Physico-chemical changes, Atomic Absorption Spectrometry

I. INTRODUCTION

Majority of materials and metals extracted from the earth

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by mining occur naturally as sulphide ores or are associated with sulphide minerals.

During the extraction process, those sulphides which are not part of the ore material are dumped in waste rock dumps with other rocks. Sulphides containing valuable material (either metals, or in the case of a pyrite mine, sulphide itself) are processed, and the residue dumped in slimes (tailings) dams. The tailings contain large amounts of sulphide, which are either unwanted or were not extracted [1]. This results in more of the sulphides being exposed to the surface environment, where they are unstable. Thus spontaneous chemical weathering takes place, releasing acid, metals and sulphate into surface water and groundwater [2]. This process, whereby sulphide minerals break down in the presence of oxygen and catalyzing bacteria, is known as acid mine drainage (AMD).

The oxidation of sulphidic mine waste, and the consequent release of acid drainage is one of the main strategic environmental issues facing the mining industry as it exposes large amounts of pyrite and other sulphides to the effects of water and oxygen. Mining operations can greatly accelerate the oxidation process by providing flow paths that allow the release of levels of pollutants in surface and groundwater at rates far greater than the downstream environment can sustain without significant ecological effects [3].

This study investigated the heavy metals and physicochemical changes effects of acid mine drainage on selected surface and groundwater resources in the mining community in Ghana.

II. MATERIALS AND METHODS

A. Study area

The mining community is located around 12 km from Bogoso and 9.5 km from Prestea, and in southwest Ghana approximately 200 kilometers west of the capital, Accra, and is accessible by sealed road. Bogoso/Prestea is located in the Wassa West District of the Western region of Ghana on the Latitude S 2° 35 W and Longitude N 5° 31W. The company owns 90% interest in the Prestea underground mine, including the underground mining rights for the Prestea surface concession, and a number of contiguous properties west and north of the Bogoso property known respectively as Akropong and Dunkwa. The remaining 10% interest in Bogoso/Prestea property is a carried interest owned by the Government of Ghana, with dividends payable after capital costs have been recovered [4].

B. Selection of Sampling Sites

These sampling sites were chosen because of the activities taking place around the sampling point and their effect on the water resources. A comparative test were to be done to find out the effect of acid mine drainage as it flows from the upstream and to the downstream sampling site. The five selected surface water sampling sites were located at Ajormum creek (Embankment III) (RSW-01), Apepre creek (RSW-02), Apepre creek (at Dumasi township) (RSW- 03), Chujah creek (RSW-04) and Mansi River (at Juaben) (RSW-05). The two groundwater sampling sites were located at the Adikanfo Village (Residential) (RGW- 01) and Dumasi borehole (RGW- 02) (Figure 1).

C. Sampling Collection

Water samples (surface and groundwater) were taken in duplicates from the sampling sites within six months between November, 2005 and April, 2006. Water samples were collected in 500mL sterile plastic bottles. All samples were transported to the laboratory in a cool box for analysis with the exception of pH, conductivity and temperature which were determined on site at the time of sample collection.

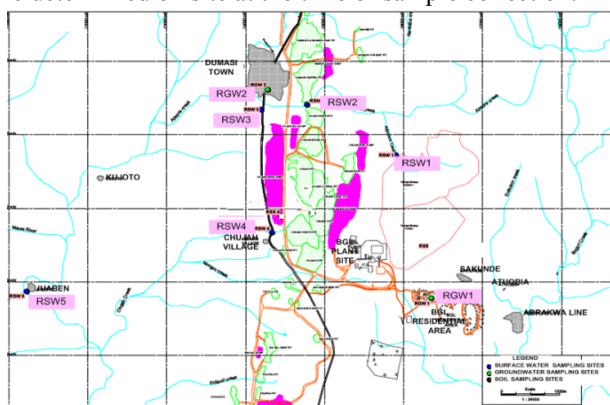


Figure 1. Map of the Mining Community are showing the sampling points(●).

1) Determination of pH, Temperature, Conductivity, Alkalinity and Dissolved Oxygen determination

pH, Temperature and Conductivity parameters were determined using by the TPS WP – 81 meter. Alkalinity and dissolved oxygen levels (No fixation) (D.O mg oxygen/l) in water samples were determined using Standard Methods [5].

2) Free Cyanide and Sulphate Determination

The Spectrophotometer HACH DR 4000 was used in the determination of free cyanide and sulphate concentrations from the water samples. Reading of the sample was done by first reading blank, standard before the water sample at a wavelength of 612 nm and 450 nm respectively after calibrations are done [5].

3) Dissolved and Total metals concentration.

The concentrations of Arsenic, Manganese, Iron, Zinc, Copper and Cadmium were determined using Varian 220 Spectra AA model of Atomic Absorption Spectrometer (AAS). The AAS was calibrated using standard solutions of the different metals under investigation. Concentrations of the total and dissolved metals were determined at the following wavelengths: As = 193.7 nm, Mn = 279.3 nm, Fe = 284.3 nm, Zn = 213.9 nm, Cu = 324.8 nm and. Cd = 228 nm [5].

D. Statistical analysis

A one-way randomized analysis of variance (ANOVA) was used for testing data between variable. Raw data for both the dissolved and total heavy metals and other parameters determined in our analysis were transformed by adding a value of one to all scores in order to eliminate zero data points. The data were tested at 95% confidence level. The statistical software package used was the SPSS (Statistical Package for Social Scientist) [6].

III. RESULTS

The mean numbers and ranges of the various parameters charactering the acid mine drainage effect at the seven sampling sites at the concession are shown in Table 1 and

Figure 2 – 6. There was a consistent decrease in heavy metals loading as the Chujah river and Chujah pits flowed upstream from source Chujah creek and Chujah pits although differences in concentrations between sites both statistically significant and insignificant ($p \leq 0.05$).

1) pH, Temperature and Conductivity in underground and surface water samples

Mean pH of underground and surface water samples from the seven sampling sites show that the groundwater values were generally low ranging between 5.54 and 5.85 compared to the surface water values which ranged between 5.75 and 6.68 as showed in Table 1.

Statistically, there were differences ($p \leq 0.050$) in pH between the underground water samples and similarly between surface water samples.

There was little variation in underground water temperatures as it varied between 26.30 and 26.40 but there was much variation in the surface waters (26.21 to 28.05) (Table 1). Differences in temperature were statistically not significant for underground water samples but there were statistically significant differences in surface water samples.

Mean Conductivity ($\mu\text{S}/\text{cm}$) of both underground and surface water samples generally varied between 95.03 and 282.17. However, mean conductivity at the Chujah creek (RSW-04) was unusually high (923.83 $\mu\text{S}/\text{cm}$) (Table 1). The underground and surface waters samples showed statistically significant difference.

2) Alkalinity and Dissolved Oxygen in underground and surface water samples

Mean levels of alkalinity (mg CaCO_3/l) in underground and surface water samples were high for all seven sampling sites (Table 1). Underground water varied between 84.50 and 84.83 compared to surface waters which were between 47.83 and 85.33 (Table 1).

There were no statistically significant differences between underground water samples but there were differences in the surface water samples.

Dissolved oxygen (mg O_2/l) were generally low in both underground and surface water samples (Table 1). The underground water samples were between 0.128 and 0.664 and surface water between 0.596 and 0.820 (Table 1). Statistically the differences in dissolved oxygen were not significant for both under ground water and surface water samples.

| Sample Type | Sampling Sites | Mean pH and Range | Temp. °C and Range | Mean Cond. µs/cm and Range | Alk. CaCO ₃ and Range | mgO ₂ /L and Range | Mean CN mg/L and Range | Mean SO ₄ ²⁻ mg/L and Range |
|---------------|----------------|---------------------|----------------------|----------------------------|----------------------------------|-------------------------------|------------------------|---|
| Groundwater | RGW-01 | 5.86 5.73 - 5.77 | 26.4 26.0 - 26.8 | 262.4 215.50 - 362.00 | 94.83 87.00 - 98.00 | 0.128 0.100 - 0.150 | 0.008 0.002 - 0.010 | 28.767 20.500 - 45.000 |
| | RGW-02 | 5.53 5.35 - 5.77 | 26.3 25.7 - 26.7 | 185.33 169.50 - 203.80 | 84.5 62.00 - 140.00 | 1.415 0.090 - 2.200 | 0.008 0.002 - 0.013 | 10.017 4.400 - 16.100 |
| | RSW-01 | 5.57 4.97 - 5.88 | 26.22 24.7 - 27.2 | 282.17 178.80 - 551.00 | 48.5 24.00 - 76.00 | 0.734 0.080 - 2.900 | 0.005 0.002 - 0.007 | 66.217 26.900 - 210.500 |
| | RSW-02 | 6.21 5.81 - 6.58 | 26.52 25.9 - 27.0 | 178.43 162.30 - 194.20 | 52.5 26.00 - 88.00 | 0.005 0.090 - 3.500 | 0.005 0.001 - 0.014 | 27.083 11.700 - 52.800 |
| | RSW-03 | 6.39 5.97 - 6.76 | 26.62 25.7 - 27.4 | 170.1 141.00 - 191.50 | 51 22.00 - 88.00 | 0.596 0.090 - 1.900 | 0.007 0.002 - 0.022 | 26.317 13.700 - 53.300 |
| Surface water | RSW-04 | 6.69 6.05 - 7.23 | 28.05 26.1 - 30.0 | 923.83 725.0 - 1435.0 | 85.33 62.0 - 113.0 | 0.82 0.120 - 3.100 | 0.015 0.004 - 0.041 | 66.217 208.00 - 344.00 |
| | RSW-05 | 6.4 6.17 - 6.55 | 28.43 26.1 - 30.0 | 95.03 39.60 - 123.50 | 47.83 32.00 - 62.00 | 0.788 0.110 - 2.800 | 0.004 0.002 - 0.007 | 6.96 0.100 - 27.600 |

3) *Sulphate and Free Cyanide underground and surface water samples*

Mean concentration of free Cyanide (mg/l) for all the seven sampling sites were generally low for both the underground water and surface water samples with the exception of values recorded a highest value of 0.146 at the Chujah creek (RSW-04) (Table 1). The underground water samples varied between 0.064 and 0.088 and surface water samples between 0.0040 and 0.0146 (Table 1).

Statistical differences in free cyanide were not significant for both groundwater and surface water. Mean sulphate (mg/l) for both the groundwater and surface water samples at the seven sampling sites were generally low, with the exception of surface water sample from Chujah creek (RSW-04) (Table 1). The surface water sample from Chujah creek recorded a high concentration value of 267.75 mg/l (Table 1). Statistically the differences in sulphate were significant ($p < 0.050$) for underground and for surface water samples.

4) *Dissolved and Total Arsenic in underground and surface water samples*

Mean dissolved and total arsenic concentration (mg/l) in the underground water samples were low and varied between 0.0045 and 0.0055 for dissolved and 0.0050 and 0.0065 for total arsenic in water samples. The concentration in surface water samples were however high and varied between 0.0043 and 0.0208 for dissolved and 0.0012 and 0.0802 for total arsenic concentration (Table 2 and Table 3).

Statistical differences were not significant ($p \leq 0.050$) for both dissolved and total arsenic concentrations for underground water samples, but there were significant differences for both dissolved and total arsenic within surface water samples.

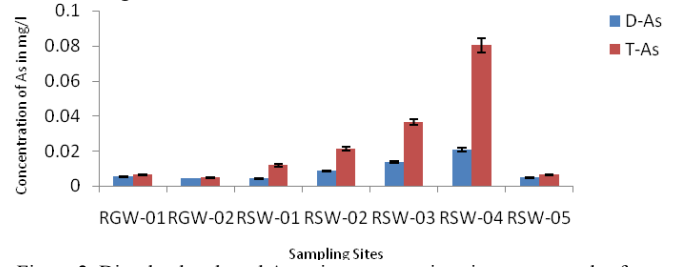


Figure 2. Dissolved and total Arsenic concentrations in water samples from seven sites.

5) *Dissolved and Total Iron in water sample in underground and surface water samples*

Mean dissolved and total iron concentration (mg/l) in the underground water samples were high, 4.4396 for dissolved and 0.6737 for total iron. The concentration in surface water samples were however low, 5.8195 for dissolved and 3.7675 for total arsenic concentration. Statistically significant differences ($p \leq 0.050$) for dissolved iron were recorded in both underground and surface water samples. There were also significant differences ($p \leq 0.050$) for total iron in surface water samples.

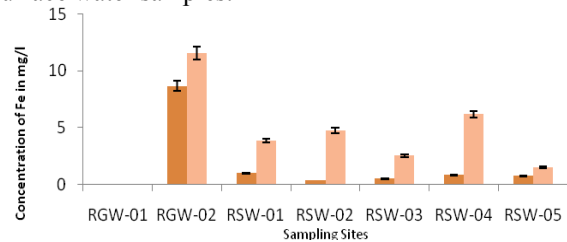


Figure 3. Dissolved and total Iron concentrations in water samples from seven sites.

6) *Dissolved and Total Copper in water sample in underground and surface water samples*

Mean dissolved and total copper concentration (mg/l) in underground water samples were general high and varied between 0.0310 and 0.2127 for dissolved and 0.1236 and 0.2116 for total copper. The concentration in surface water samples were however low and varied between 0.0200 and

0.0650 for dissolved and 0.0295 and 0.1034 for total copper concentration. There were no statistically significant differences ($p \leq 0.050$) in total copper concentration in both underground and surface water samples but there were significant differences in dissolved copper.

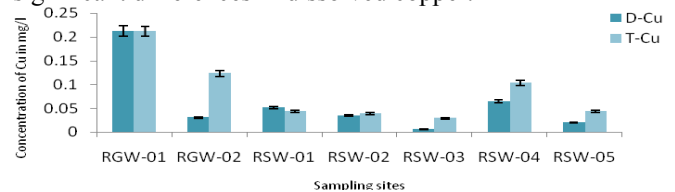


Figure 4. Dissolved and total Copper concentrations in water samples from seven sites.

7) *Dissolved and Total Zinc in water sample in underground and surface water samples*

Mean dissolved and total zinc concentration (mg/l) in underground water samples were high and varied between 0.0150 and 0.0279 for dissolved and 0.0235 and 0.0442 for

total copper. The concentration in surface water samples were however low and varied between 0.0058 and 0.0713 for dissolved and 0.0182 and 0.0777 for total zinc concentration. There were no significant differences in total zinc ($p \leq 0.05$) for both underground and surface water samples and for dissolved zinc in surface waters. However, there were significant differences ($p \leq 0.050$) for dissolved zinc in underground water samples.

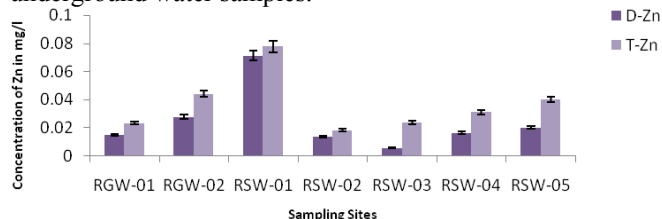


Figure 5. Dissolved and total Zinc concentrations in water samples from seven sites.

8) Dissolved and Total Manganese in water sample in underground and surface water samples

Mean dissolved and total manganese concentration (mg/l) in underground water samples were low and varied between 0.1883 and 0.2595 for dissolved and 0.2240 and 0.2802 for total copper. The concentration in surface water samples were however high and varied between 0.0992 and 2.2063 for dissolved and 0.1222 and 2.2710 for total manganese concentration. There were no significant differences in dissolved manganese in surface water samples and total manganese in underground water. Statistically significant differences ($p \leq 0.050$) were however recorded for dissolved manganese in underground and total manganese in surface water samples.

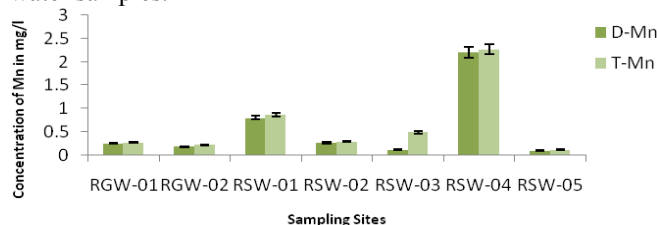


Figure 6. Dissolved and total Manganese concentrations in water samples from seven sites.

9) Dissolved and Total Cadmium in water sample in underground and surface water samples

Mean dissolved and total concentrations of cadmium in water samples were generally low (lower than the detection limit) with the exception of a few sampling sites recording significant values of cadmium. Mean levels of cadmium were 0.006 mg/l for dissolved cadmium and 0.0065 for total cadmium in underground water but the levels in surface waters were below detection.

IV. DISCUSSIONS

This study shows that acid mine drainage is occurring in the concession area investigated. This is because the main AMD indicators namely acidity, metal toxicity, metal precipitation and salinization were occurring at some sampling sites [7]. Surface water samples from the Chujah creek was extremely polluted with some of the parameters (conductivity, sulphate, iron and manganese) characterized by the acid mine drainage and that the quality improves as it flow from the dewatering process at Chujah pits (upstream)

to Chujah creek (middle) into the Mansi river (at Juaben) downstream. The Chujah creek sampling site recorded electrical conductivity range values (725.0 – 1435.0 $\mu\text{S}/\text{cm}$) exceeding GEPA permits limit 750 $\mu\text{S}/\text{cm}$. Sulphate concentration ranged (208.00 – 377.00 mg/l) exceeding compared with GEPA standard limit 250 mg/l. Sulphate is considered the best indicator of AMD as it is unaffected by neutralization [8] and has been used as the reference indicator in previous AMD impact studies [9].

Iron concentrations were high varied between (0.020 – 3.914 and 0.212 – 17.703 mg/l) for dissolved and total iron respectively exceeding standard limit 1.0 mg/l. Iron concentration was used to assess the effect of ochre formation, which was found to decrease with distance from the input of AMD in earlier studies [8] suggest that this metalloid occurs naturally in the surface waters of Golden Star Resources (Bogoso concession) mines. Concentrations of manganese were generally high in the surface water samples (0.043-4.593 mg/l and 0.050-4.655 mg/l) (Figure 6) and was above the maximum acceptable limits 0.05 mg/l for dissolved and total manganese metal by the EPA effluent standard.

No increases were noted in acidity, temperature, alkalinity, dissolved oxygen, free cyanide, arsenic, copper, zinc or cadmium in the Mansi River as it flows past the study area. The maintenance of high electrical conductivity, sulphate, iron and manganese during the entire period of field investigation suggest that H^+ generated and metals leachates from sulfide oxidation in the contamination source (i.e. the waste rock dumps upstream of the Chujah East) was readily available for discharging and the amount of ions being transported outwards depends on the volume of outflowing waters (both surface and underground runoffs). Other downstream factors change the character of the drainage by chemical reaction or dilution [10].

Underground water samples from Dumasi borehole (RGW-02) also recorded very high levels of iron and manganese concentrations exceeding maximum acceptable limits by the GEPA effluent standard. Dissolved and total iron concentration ranged (4.946 – 12.640 and 8.758 – 15.925 mg/l) (Figure 3) respectively exceeding GEPA standard limit (2.0 mg/l). Concentration of manganese concentration ranged (0.144 and 0.270 and 0.168 – 0.3131 mg/l) (Figure 6) exceeding GEPA standard limit 0.05 mg/l. This could be attributed to the rock bearing underground of the borehole at Dumasi township which is characterized by the pyrite ore and the release of metals from the oxidation of metal-bearing sulphides in the mine dumps and pits.

Concentrations of iron were within the GEPA acceptable limit (2.0 mg/l) with the exception of underground water sample from Dumasi borehole (RGW-02) and surface water sample from Chujah creek (RSW-04). High concentrations for dissolved and total iron were within the range (8.6815 and 11.5976 mg/l) for Dumasi borehole (RGW-02) underground water sample, (0.8382 and 6.1850 mg/l) for Chujah creek (RSW-04) surface water sample. Underground water concentrations could be attributed to the rock bearing underground consisting of mostly pyrite ore. Surface water effect could also be as a result of waste ore containing pyrite

ore which reacts in the pits or leachates into the environment. Mine drainage can be considered to be an unstable aqueous system undergoing continuous change. Subject to the location of the sample collection with respect to point of pyrite solubilization, such a solution has; been diluted, dissolved additional mineral components, undergone internal reaction which may have deposited ferric oxy hydroxides in its stream bed and possibly been mixed with other pollution sources; domestic, industrial, or agricultural [11].

Concentrations of manganese concentrations for underground and surface waters sampling sites in the concession fell below the GEPA acceptable concentration limit (0.05 mg/l) with the exception of values recorded from Chujah creek (RSW-04) which recorded a range (2.2063 and 2.271 mg/l) (Figure 6) for both dissolved and total manganese respectively. This could be attributed to waters pumped from the Chujah pits where dewatering processes containing elevated concentration of manganese. Manganese discharge limits have traditionally been based on the objectionable discoloration effects of manganese at concentrations as low as 0.2 mg/L in water supplies rather than effects on aquatic life [12].

However, effluent shows significant concentrations for heavy metals (iron and manganese) determined in the study with the exception of cadmium and also pH, temperature, dissolved oxygen, alkalinity, free cyanide showing insignificant and significant values for electrical conductivity, and sulphate concentrations. All parameters determined in the study showed significant and insignificant difference statistically for acid mine drainage at the Bogoso when compared with GEPA and other world international standards.

V. CONCLUSION

This study has indicated that pyrite oxide contaminated as a result of mining activities is contributing significantly to the quality of underground and surface water emanating from the Chujah environs, and is not only affecting the pH of the water, but is also contributing heavy metals to the surface aquatic environment. Local streams (creeks) are contaminated with transition metals in the vicinity of the gold mining area, but the impact is localized and does not appear to affect the chemistry of the main river system (the Mansi River).

This could be explained by low run-off volumes from the mining sites compared to the rest of the Chujah pit and Chujah creeks sub catchments. Alternatively, these data could be explained by acid mine drainage having developed only partially in the study area. The levels of irons and manganese recorded suggest that this metalloid occurs naturally in the area-and is probably leaching out of the rock formations.

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