



Impact of Tailings on Surrounding Streams at a Mining Area in Sierra Leone

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Abstract: Access to clean water and sanitation is the centerpiece of Africa water vision 2025 and Goal six (6) of the 2030 UN agenda for Sustainable Development. Considering the current national WASH regulatory structures in Sierra Leone, meeting these targets enshrined in the policy documents would be a critical challenge for the government. The overarching objectives sought by the study were to determine the available composition of physio-chemical parameters and evaluate impact of mine tailings on nearby water bodies within the operational areas of Sierra Rutile Mining Company Limited. Twenty-four (24) water samples obtained from six (6) streams were tested for seventeen (17) physical and chemical parameters. About 30% of the indicators were noted to be above the permissible limit of water quality standard in almost all of the sampling sites. A pattern of decrease concentration downstream for Zn, Pb and Cu was observed but those at the tailing points were noted otherwise. The results revealed that mining activities have to an extent negative impact on the local water sources. Consequently, certain indicators were considered to be of public health concern considering their baseline levels. It would be necessary for the company to examine the mechanism of discharge of tailings and strengthen the environmental surveillance within its concessionary areas to enhance sustainability with the ultimate goal to improve environmental performance.

Keywords: Tailing, Water Quality, Physico-Chemical, Impact, Chemicals

1. Introduction

Ensuring availability, accessibility and sustainable management of water has been the centrality of multiple policy forums [1]. In spite of this, it has been recently reported that 844 million people still have no access to a basic drinking water facility and 159 million of them are directly dependent on surface water, 58% of which are in sub-Saharan Africa [2]. It is likely that the current estimate reported by WHO and UNICEF would increase over time given the trends in global population growth rate. However, the issue of water quality is more severe in the areas where excessive mining operations and related processes are present [3]. Report from studies have shown that various forms of contaminants are continually introduced into water bodies mainly due to mining activities [4-6]. This consequently would have the propensity of severe ecotoxicological threats

to human and other living organisms that rely on water bodies [7, 8].

There is a wide array of studies on surface water quality in mining environments worldwide [8-13]. Also, in Africa several studies on surface water in mining areas were reported [14-16]. But in Sierra Leone, studies on water quality have focused on different aspects of water. For example, a study on the physical and biological parameters of an entire water supply network was reported [17]. Another study have investigated the quality of 60 groundwater from wells [18]; while an earlier study that looked at the public health risk related to water quality [19] was reported. One of the few studies identified in the literature relating to water quality from mining environment in Sierra Leone was from groundwater sources [20].

Notably, there is no information on surface water quality particularly in mined out areas that has been reported in Sierra Leone to the best of the authors’ knowledge. Against such a backdrop, this study attempt to assess the impact of tailings from mining activities on streams; measure physiochemical parameters and compare the levels with WHO guideline 2011; examine degree of variation in concentration between the background site and all other sites to draw conclusion on downstream impact. Finding of this study would be very instrumental to decision makers and key stakeholders.

2. Materials and Method

2.1. Description of Study Area

Sierra Rutile Company Limited is a mineral sands company operating in Moyamba and Bonthe Districts in the Southern Province of Sierra Leone. The company’s area of operation which is also the study area is politically divided into four chiefdoms: Upper Banta Chiefdom, Lower Banta Chiefdom, Imperi Chiefdom and Jong Chiefdom respectively from which the mines are located as represented in Figure 1. The most important town in the study area is Moriba town. Details of its physical and Climatic features, geology and socioeconomic characteristics has been described in an earlier study [20].

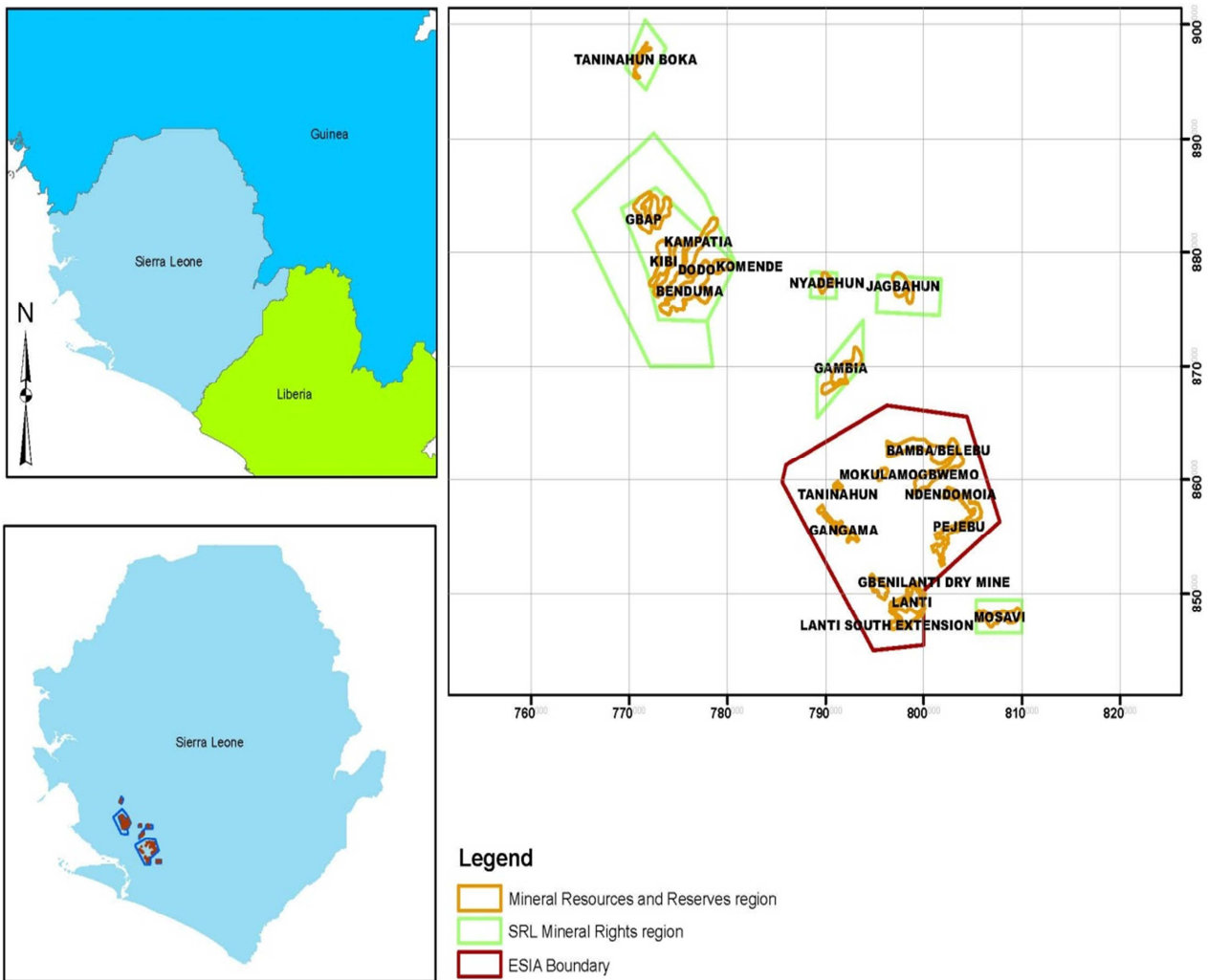


Figure 1. Location of Study Area.

2.2. Description of Study Sites

The study sites were coded as Gondama Stream (GS), Dry mill tailings (DMT) stream, Gangama Dry Mining Tailings (GDMT) stream, Lanti Dry Mining Tailings (LDMT) pond, Dredge Tailings (DT) stream, and Wet Plant Tailings (WPT) Stream; in that order.

Gondama Stream is far away from the tailings and there

are no reported mining related activities in the area. It passes through a village that abounds in rich vegetation. GS therefore provides excellent conditions for a background site for comparing downstream impact of tailings in the area based on the principle of the distance from mining regions. Inhabitant in this area practiced farming and fishing activities. Situated in the south end of the main plant is the DMT stream which is approximately three miles. It drain two

villages characterized primarily by hilly landscape. The activities around the stream are same as in GS. The GDMT stream runs parallel to and within the Gangama dry mining plant. The stream is about two miles long stream and has three villages along it course with steep slope topography. The LDMT stream which is about half a mile lies in close proximity to Lanti dry mining fleet which is located adjacent to the concentrator plant. Likewise, GDMT, the dominant topography along the LDMT stream is primarily steep slopes. There are two villages along the course of the stream. The DT stream flows north-west to the processing plant which lie close to the dredge. The stream is about two miles long. The WPT stream is located adjacent to the wet plant, with a length of about three miles. The dominant physical features are hills and three villages are found along its path of flow.

2.3. Water Sampling Procedures

Field work was carried out from January 24th to February 7th 2018. Water samples were collected at four sites from each location using 500 mL high density polyethylene-terephthalate (PET) bottles. Each plastic bottle was thoroughly inspected to ascertain that it was not visibly contaminated, leaking or damage. A rope was tied at the top of the plastic bottles to collect samples at a depth of approximately 20 cm below the water surface. Each plastic bottle was pre-cleaned, and properly rinsed thrice with the water to be sampled prior to filling with the actual sample. This was done to avoid nonconformities in the samples. Each plastic bottle was tightly recapped with the screw cover. Water samples were collected from four sites per location (i.e. Upstream, at the tailings, at a village and downstream) in order to be able to assess concentration trends in each of the locations. Twenty-four water samples were collected in total and each plastic bottle was legibly labelled using an insoluble ink with sufficient information on coded identifier (i.e. location and sampling site), and date of collection so as to meet the samples acceptance criteria of the laboratory. Collected samples were temporarily stored in a cooler containing ice packs for indicators to be measured in the Lab. Subsequently, samples were then transported to the Sierra Rutile Limited Quality Laboratory and were preserved in refrigerator within 24-hours period after collection before chemical analyses. Sample were accompanied by test request (requisition) indicating which investigations are required.

Both in-situ and ex-situ analytical techniques were used to test for the various physical and chemical parameters respectively. The physical indicators mentioned in the following list: pH, Temperature, turbidity, electrical conductivity and total dissolved solids were measured on site using a portable combined Accumet AC85 Fischer scientific pH/temperature/ conductivity meter. The instrument was calibrated before and during sampling in accordance with directives by the Manufacturer.

For ex-situ analysis, water samples were tested for chemical indicators at the Sierra Rutile Limited Quality Laboratory within 24 hours of sample collection. The following chemical indicators Chloride, Fluoride, Free iron,

Copper, Phosphate, Magnesium, Aluminium, Ammonia, Nitrate, Calcium hardness, Potassium, Lead and Zinc were analyzed using Wagtech Potalab Photometer 9500 (model ECOSENSE). To ensure the veracity of the result produced by the laboratory, the Standard Operating Procedures (SOP) for chemical analysis were strictly followed. Details of this analytical procedures were being reported earlier [20].

2.4. Data Analyses

The study design was quantitative in nature hence data were subjected to descriptive statistics. All statistical analyses were conducted using Microsoft Excel 2016. The mean and standard deviation values of the various locations were used to describe the concentration trend of the indicators measured. T-test was used to compare concentrations for parameters between locations. Significant variation (p value) in mean values was considered to be at $p < 0.05$ from which all statistical interpretations were made. The values of measured parameters were compared with Physical and chemical guideline standards of WHO (2011) for drinking water quality. Results for each indicator among locations were also compared with background site to draw conclusion on concentration trends of tailings downstream.

3. Results and Discussion

The summary statistics of the physio-chemical parameters in the study area are given in Tables 1 and 2 respectively. Descriptive statistics was used to compare the mean values of measured parameters with World Health Organization (WHO) water quality guidelines 2011 where applicable as presented in Table 3.

From Table 1, the results show that there is no significant variation in mean temperature values across sampling locations. The temperature values recorded for all the sampling locations in this study is firmly in line with those obtained for one of the investigated lakes in a previous study on Impact of coal mining on water quality in Brazil [13] and another study of surface water from major mining areas in Ghana [16] even though the mean values of the latter were slightly above those recorded in this current study. However, the temperature values reported in this work are in sharp contrast with those determined for water values in a tin mining area in Malaysia [21]. The aggregate pH values of the sampling site from four locations indicate acidity, with the strongest average concentration being 4.6 at the dredge tailing. Most sampling sites across tailings areas showed a high concentration of acidity in the study area. Acid generation is the main issue related to pollution from mining activities [22]. The high pH values ranging between 3.2 - 4.6 has been attributed to pyrite oxidation in the vicinity of a mining site [11]. However, the high acidic properties in three of the locations sampled in this study shared similar characteristics with an assessment of Surface Water Quality of a gold mining area in eastern Cameroon [14] even though the study design was slightly different.

Table 1. Sites summary statistic of results of physical parameters.

Site Name		Temp. (°C)	pH	Turb (NTU)	EC (µs/cm)	TDS (ppm)
GS n=4	Avg.	24.6	6.38	3.27	33.3	16.6
	Stdev	1.09	0.5	0.31	2.33	1.16
	Max.	26.1	6.79	3.57	36.7	18.3
	Min.	23.5	5.65	2.88	31.6	15.8
DMT n=4	Avg.	23.68	4.82	28.08	44.5	22.2
	Stdev	0.31	0.72	1.27	0.14	0.08
	Max.	24.1	5.68	28.9	44.6	22.3
	Min.	23.4	4.03	26.2	44.3	22.1
GDMT n=4	Avg.	23.93	4.705	40.55	20.09	9.57
	Stdev	0.64	0.51	9.03	14.40	8.10
	Max.	24.6	5.16	49.6	41.6	21.7
	Min.	23.1	4.02	28.9	11.55	5.09
LDMT n=4	Avg.	21.15	5.43	43.75	14.53	8.14
	Stdev	1.3	0.39	10.95	1.94	1.9
	Max.	22.5	5.86	58.6	16.9	10.9
	Min.	19.6	5.02	32.4	12.5	6.84
DT n=4	Avg.	24.5	4.64	41.73	20.9	14.9
	Stdev	0.66	0.32	5.62	1.12	1.09
	Max.	25.2	4.96	49.8	22.1	16.3
	Min.	23.6	4.24	36.8	19.8	13.9
WPT n=4	Avg.	23.45	4.71	36.48	23.15	23.7
	Stdev	1.19	0.3	21.97	3.14	1.66
	Max.	24.8	5.01	69.4	25.6	25.3
	Min.	21.9	4.32	24.2	18.6	21.5

Table 2. Sites summary statistic of results of chemical parameters.

		Cl (mg/L)	Al (mg/L)	NH3 (mg/L)	Ca (mg/L)	Cu (mg/L)	F (mg/L)	Fe (mg/L)	Mg (mg/L)	NO ₃ ⁻ (mg/L)	k (mg/L)	Pb (mg/L)	Zn (mg/L)
GS n=4	Avg.	0.51	0.02	N/D	N/D	0.06	N/D	0.04	1.83	N/D	1.25	0.02	0.02
	Stdev	0.06	0.01	N/D	N/D	0.01	N/D	0.01	0.24	N/D	0.13	0.01	0.01
	Max.	0.58	0.03	N/D	N/D	0.07	N/D	0.05	2	N/D	1.4	0.04	0.01
	Min.	0.45	0.01	N/D	N/D	0.04	N/D	0.02	1.5	N/D	1.1	0.01	0
DMT n=4	Avg.	0.89	0.11	0.21	3.25	1.7	N/D	0.5	4.5	0.15	3.23	0.07	0.04
	Stdev	0.33	0.02	0.41	2.22	0.19	N/D	0.48	2.65	0.03	0.26	0.05	0.04
	Max.	1.26	0.14	0.82	6	1.96	N/D	1.2	8	0.19	3.6	0.13	0.09
	Min.	0.46	0.09	0.01	1	1.5	N/D	0.12	2	0.11	3	0.02	0.01
GDMT n=4	Avg.	0.35	0.30	0.17	3.5	1.29	0.33	0.63	3.1	0.23	2.25	0.04	0.03
	Stdev	0.08	0.36	0.16	3.11	0.84	0.25	0.4	2.39	0.10	1.17	0.04	0.03
	Max.	0.46	0.83	0.4	7	1.98	0.6	1.2	6	0.32	3.6	0.1	0.07
	Min.	0.3	0.03	0.06	0	0.06	0.01	0.3	0.6	0.14	1	0.01	0.01
LDMT n=4	Avg.	0.51	0.34	0.03	2.5	1	0.2	0.24	2.67	0.42	1.65	0.06	0.04
	Stdev	0.09	0.40	#DIV/0!	2.08	0.65	#DIV/0!	0.21	2.08	0.16	0.93	0.05	0.04
	Max.	0.63	0.93	0.03	5	1.86	0.2	0.5	5	0.63	2.8	0.13	0.1
	Min.	0.42	0.1	-	0	0.4	-	0.04	1	0.26	0.6	0.02	0.01
DT n=4	Avg.	0.46	0.62	0.26	4.5	0.45	N/D	0.2	6.25	0.57	1.55	0.06	0.04
	Stdev	0.12	0.48	0.22	2.65	0.25	N/D	0.2	4.99	0.3	0.93	0.04	0.03
	Max.	0.55	1.21	0.56	8	0.8	N/D	0.5	11	0.97	2.7	0.11	0.09
	Min.	0.29	0.05	0.09	2	0.2	N/D	0.1	1	0.26	0.5	0.02	0.01
WPT n=4	Avg.	0.33	0.66	0.36	4.5	1.13	N/D	0.68	0.35	0.50	0.28	0.08	0.05
	Stdev	0.22	0.43	0.24	3.32	0.39	N/D	0.64	0.21	0.28	0.17	0.06	0.05
	Max.	0.63	1.26	0.69	9	1.58	N/D	1.6	0.6	0.86	0.5	0.16	0.12
	Min.	0.12	0.3	0.12	2	0.65	N/D	0.2	0.1	0.19	0.1	0.01	0.02

Table 3. Comparison of the mean values of Physiochemical indicators with the WHO guideline standard.

PARAMETERS	WHO STANDARDS 2011	AVERAGE VALUES OF THE SAMPLING LOCATIONS					
		GS	DMT	GDMT	LDMT	DT	WPT
Temp. (°C)	-	24.6	23.68	23.93	21.15	24.5	23.45
pH	6.5 - 8.5	6.38	4.82	4.71	5.43	4.64	4.71
Turb. (NTU)	5	3.27	28.08	40.55	43.75	41.73	36.48
EC (µs/cm)	1400	33.3	44.5	20.09	14.53	20.9	23.15
TDS (ppm)	1000	16.6	22.2	9.57	8.14	14.9	23.7
Cl ⁻ (mg/L)	250	0.51	0.89	0.35	0.51	0.46	0.33
Al (mg/L)	0.10	0.02	0.11	0.30	0.34	0.62	0.66

PARAMETERS	WHO STANDARDS 2011	AVERAGE VALUES OF THE SAMPLING LOCATIONS					
		GS	DMT	GDMT	LDMT	DT	WPT
NH ₃ (mg/L)	1.5 - 35	N/D	0.21	0.17	0.03	0.26	0.36
Ca ²⁺ (mg/L)	75	N/D	3.25	3.5	2.5	4.5	4.5
Cu (mg/L)	2	0.06	1.70	1.29	1.00	0.45	1.13
F ⁻ (mg/L)	1.5	N/D	N/D	0.33	0.2	N/D	N/D
Fe (mg/L)	0.3	0.04	0.50	0.63	0.24	0.2	0.68
Mg ²⁺ (mg/L)	125	1.83	4.5	3.1	2.67	6.25	0.35
NO ₃ ⁻ (mg/L)	50	N/D	0.15	0.23	0.42	0.57	0.50
K ⁺ (mg/L)	10 - 12	1.25	3.23	2.25	1.65	1.55	0.28
Pb (mg/L)	0.01	0.02	0.07	0.04	0.08	0.06	0.08
Zn (mg/L)	3	0.02	0.04	0.03	0.04	0.04	0.05

Temp. = temperature; pH = potential of hydrogen; Turb = turbidity; EC = electrical conductivity; TDS = total dissolved solids. Cl = Chlorine; Al = Aluminum; NH₃ = Ammonia; Ca = Calcium; Cu = Copper; F = Fluoride; Fe = Iron; Mg = Magnesium; NO₃⁻ = Nitrate; K = Potassium; Pb = Lead; Zn = Zinc; (°C) = degree Celsius; NTU = nephelometric turbidity unit; $\mu\text{S}/\text{cm}$ = micro Siemens per centimeter; mg/L = milligrams per liter; PPM = parts per million; GS = Gondama Stream; DMT = Dry Mill Tailings; GDMT = Gangama Dry Mining Tailings; LDMT = Lanti Dry Mining Tailings; DT = Dredge Tailings; WPT = Wet plant Tailings. There were no guideline values for indicator (s) with blank spaces.

From Table 1, there is significant variation in turbidity values across some of the sampling stations. It was observed that the mean concentration of DMT, GDMT, LDMT, DT, and WPT locations as well as the individual site values, lie above the acceptable WHO limit for turbidity. The LDMT location showed the highest mean turbidity value 43.75 NTU on the whole. It was only samples from GS that showed low turbidity values in line with WHO permissible value. A plausible explanation for low turbidity values in GS apparently could be as a result of serial dilution [14] along the stream given that location GS is far from the tailing areas. In addition, it has been reported that variance in turbidity values along a surface water is strongly associated with stream hydrology and land use pattern [23]. The findings for this indicator is in disagreement with a recent study on ground water quality conducted in the same area where more than 80% of values were in conformity with WHO value [20]. However, the pattern of turbidity values across locations in the study area of this current study is in agreement with an earlier study on turbidity in different watersheds in New Mexico, USA [23].

For Electrical conductivity (EC), significant variations were noticed across locations but the individual site values, as well as mean concentration values, represent a firm agreement with the guideline standard. It was observed that EC values at the four sites (DMT1 – DMT4) along DMT followed a consistent pattern (44.6 $\mu\text{S}/\text{cm}$, 44.6 $\mu\text{S}/\text{cm}$, 44.5 $\mu\text{S}/\text{cm}$, 44.3 $\mu\text{S}/\text{cm}$) with DMT recorded the highest mean concentration of 44.5 $\mu\text{S}/\text{cm}$ for EC. The findings for EC, however, are in contrast, with a previous study in Namibia that generally reported high electrical conductivity (EC) values even though the design were different [24]. There was a significant difference between mean concentration values of Total Dissolved Solids (TDS) across locations. Again, observably, the four sampling sites in DMT showed the same consistent trend of values (22.3 ppm, 22.2 ppm, 22.2 ppm, 22.1 ppm) for TDS and this pattern is similar to that seen for EC. However, despite the variation amongst locations, both individual sites and mean concentration of locations were lower than the threshold value of the Guideline standard.

From Table 2, there was a high mean concentration of Pb across locations except in GS where concentration is moderate

but the mean concentrations of all sampling locations including GS were above the (WHO 2011) guideline standard of 0.01mg/l for water quality. The presence of traces of Pb in surface water constitute a growing concern [10] because human exposure to high Pb levels have considerable cumulative effects that would result in fatal health consequences [4]. The average concentration values were high for Pb obtained in this study but are lower than the peak values obtained in another study in Nigeria [25]. In agreement with our findings for Pb, surface water from Enyigba and Ameka streams, in Ebonyi state, Nigeria; reported values were 70 and 30 times in excess of WHO prescribed value for water quality [26].

Elevated mean concentrations of Fe were noticed in water samples from BDMT, GDMT, and WPT. On the other hand, water samples from GS, LDMT, DT showed low mean concentrations for Fe and which is in agreement with a recent study in Nigeria [25]. Even at low concentration heavy metals impact negatively on living organisms [4]. It is worthy to note that water samples were collected during the dry season. In view of the aforesaid, an earlier study on stream water of gold mining areas of southwestern Nigeria, have shown that lower mean concentrations were recorded for Fe especially during the dry seasons. And this could be associated with a sharp decline in entry rate of oxide and clay minerals [15]. However, the study revealed that important increases of iron contents are registered at sites two (2) (i.e. close to the mine tailing discharge) from DMT (1.2 mg/L), GDMT (1.2 mg/L), and WPT (1.6 mg/L) locations respectively, and are above the acceptable limit of the guideline standard of WHO for iron contents. A similar observation for Fe was reported for the Toka stream in Gyöngyösorszsi, North Hungary [27]. The high concentration of Fe at sites 2 (i.e. in the tailings) might also be influenced by the dry season. In support of this, a previous study conducted in Romania by [12] established that during the dry season, the concentration of heavy metals released in aquatic ecosystem increase in the surrounding area of mining waste heaps or tailing dams. The high Fe concentration revealed in this study, is in line [though with lower peak values] with a previous study in Southern Brazil [11].

Water samples tested for Cu showed values that are within

the allowable limit by the guideline standard of WHO 2011. Result for Cu in the study is in contrast to a previous study on surface water in a former mining area of Rudnany, in Slovakia where Cu values were reported to be above the accepted limit [28]. Further, water samples measured for Aluminum from LDMT, DT, and WPT yield high mean concentration values that are far above the allowable standard for surface water. Emphasis must be drawn to a key observation that samples which were taken at site 2 (i.e. close to the tailings) from GDMT, LDMT, DT, WPT showed very high levels of Al. This study shared similar high Al values with a recent study on water quality in an abandoned mining site in Pahang in Malaysia [9] but the peak values reported in the current study were higher than those obtained in [9].

This study has shown that the metal concentrations of Cu, marked a wide variation between sampling locations and a similar observation was noted in a previous study in Iran [29]. From all sampling locations, it was observed that the concentration trend of trace metals Zn, Pb, Cu decreased at sampling sites downstream which could be associated with distance away from tailings. The same pattern was observed for Calcium. In like manners, decrease in metals and ions content downstream has been reported in an earlier study at Otjihase mine in Namibia [24] and in the Linglong gold mining area, Shandong Province, China [5]. The downstream decrease of some metals has been earlier argued that aqueous dilution lowers contaminant concentrations downstream [30]. Further, the phenomenon of downstream decrease of heavy metals received emphasis in a slightly different study of the Gan River, in China where abundant concentrations of heavy metals in surface water were found only in the upstream and midstream sections and not in the downstream [31]. A study in southern Brazil by [11] concludes that the [high or low] presence of Zn, Pb, Cu and Ca is largely due to leaching minerals.

Of the six locations investigated, the samples from five locations showed Nitrate levels that is within range of the accepted values except for GS where Nitrate was not detected. Findings for NO_3^- in this study is in sharp contrast with a similar study in Koira-Joda mining area in India where all water samples were highly contaminated with Nitrate even though their analysis was based on the Indian standard (IS) 10500 (2012) [32]. This observable pattern was different for a recent study in the same area that considered ground water quality which reported elevated levels of nitrate across sampling locations [20]. In the case of fluoride, there was a low detection of this indicator in water samples from GS, DMT, DT, WPT, and at three sampling sites from LDMT. The low detection of fluoride in surface water for >90% of the sampling locations is contrary to a previous study reported on the groundwater where about 80% of samples measured for fluoride showed concentrations that were within the permissible limit [20]. There is paucity of literature on low detection of fluoride in surface water in mining environment but a recent study asserted that divergent fluoride concentrations are because of variations in the local hydrological conditions as well as differences in rocks distribution with readily leachable fluoride [33].

For Ammonia, all locations show low concentration below

the regulatory limit of WHO except in one location-GS where this indicator species was not detected. The results showed that the mean value for ammonia is in contrast to a study in Romania despite variance in the study design [12].

4. Conclusion

In the current study, surface water samples across streams that drain through mining tailing sites were measured to ascertain the impact of mining activities on the water quality. This study revealed that most of the indicators among the studied sites were relatively higher than those observed at the background site with the exception of pH, turbidity and Pb. It was observed that pH and Pb were well above the acceptable limit at the background site contrary to the other physical and chemical indicators among the sites. Elevated levels of Zn, Pb and Cu were recorded at all of the tailing points but decrease concentration was observed downstream. Turbidity, pH, Pb, Fe, and Al were observed to be a public health concern for local inhabitants considering WHO guideline values. Even though most indicators were in agreement with water potability, this study has shown that tailings due to mining operations impacts nearby streams negatively and could have general implications for surrounding water bodies. In spite of the continual efforts by Sierra Rutile Mining Company Limited to improve on their environmental performance in relations to improve water quality, our finding has pointed to the fact that more environmental management actions should be strengthened.

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