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Comprehensive Assessment of Groundwater Quality around a Major Mining Company in Southern Sierra Leone

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Abstract

Ensuring availability and sustainable management of water and sanitation for all by 2030 is Goal 6 of the Sustainable Development Goals (SDGs). Since developing countries especially in Africa would struggle to meet this target, this study was conceived. Hence, the study was designed to assess the water quality for physiochemical parameters around a mined out site in southern Sierra Leone with the view to determine their levels, determine related associations among indicators and explore environmental forensic options. A finite population correction factor was used to identify fifty (50) groundwater sources from one hundred and fifty two (152) in nine (9) sections of Moriba Town, in Moyamba District, Sierra Leone which constitute the sample size. The study assessed sixteen (16) physical and chemical indicators across the defined boundary of the sample size. Results indicated that almost 80% of all the indicators were in good agreement with water quality standards with the exception of three. Turbidity correlated strongly with PO_4^{3-}, Al and NO_2^- and almost all other indicators did not show meaningful association. High values with significant variance of water quality indicators of physical to chemical ratio were observed for pH, temperature, electrical conductivity (EC) and total dissolved solids (TDS) but no such observation was noted for turbidity. On the whole, the water quality was judged to be good, although more pro active actions were encouraged by the local people and the mining company so as to reduce contamination in some areas.

Keywords

Groundwater, Water Quality, Physico-Chemical, Mining Area, Sierra Leone

1. Introduction

It is estimated that more than a billion people worldwide do not have access to safe drinking water with more than two million die each year of water related diseases [1] and most of these deaths occur in less developed countries. Groundwater is the main water source in rural areas of developing countries and even where there is tap water in big towns, there is always the issue of scarcity. It was recently reported that sub-Saharan Africa is characterized by one of the highest numbers of people that do not have access to clean water (319 million people in 2015) or sanitation (695 million people in 2015) [2]. With the constant rise in human population of developing countries, this fragile resource is now being confronted with several environmental issues such as waste disposal, discharge of chemicals in tailings from mining activities, agricultural runoff etc. [3].

A handful of studies on ground water quality in Africa have been reported in the wider literature [4] [5] [6] [7] [8]. Little is known about the current state of water quality indicators in Sierra Leone but two previous studies were identified. For instance, a study on water quality and associated health risks was reported in the second city Bo [9], and another assessing well waters in a district in the north of the country was reported [10]. Efforts have been made over the past decade in Sierra Leone to improve the quality and supply of drinking water as manifested in the establishment of the Sierra Leone Water Company [11]. Despite setting up this national company, the country is faced with several challenges to supply good quality drinking water and sanitation issues. For example <20% of households in the country do not have access to pipe borne water. This has resulted in hundreds of deaths during the rainy season due to the outbreak of water related diseases such as cholera and diarrhea, data not presented.

One of the corporate social responsibilities of Sierra Rutile Limited Mining Company is to ensure the provision of safe drinking water facilities for the various mining communities. The company mostly ensures that frequent awareness raising sessions are held to promote good hygiene, water and sanitation practices in order to enhance water quality and also embark on the monitoring of the sources though on a relatively small scale. Despite the gains that the company has made, monitoring was confined to few selected facilities. For this reason, the need for a much bigger monitoring scheme for groundwater sources around a mined out community was conceivable so as to complement the effort of the company in assessing their environmental performances. This project therefore seeks to holistically investigate by extending to a wider area whether or not these measures put in place by the company are sufficient enough to maintain a high water quality standard that is fit for human consumption. Monitoring water quality is essential to determine the water quality status and to improve the environmental conditions and the related public health. Hence, the main objectives of the study were to: (i) evaluate the physico-chemical indicators of groundwater drinking sources at Moriba Town; (ii) deduce the relationship among the water quality indices studied and (iii) explore baseline environmental forensic options between the physical and chemical indicators. Findings of this work would be useful to many organizations including Sierra Rutile Limited, country planners, Environmental Protection Agency Sierra Leone (EPA-SL), international and local nongovernmental organizations.

2. Materials and Method

2.1. Description of Study Area

The study area was mainly Moriba Town (See Figure 1) which is a part of Sierra Rutile Limited (SRL) mining concession area. Moriba Town is located partly in the Impere Chiefdom, Bonthe District and partly in the Lower Banta Chiefdom, Moyamba District in the Southern Region of Sierra Leone. It lies approximately 137 km southwest of the capital Freetown and approximately 30 km east of the Atlantic Ocean. The study area has populated surroundings around the mine site with a flat landscape rich in lateritic soil. Some areas are rich in silt and clay and agricultural and fishing activities are predominant. Titanium dioxide (TiO_2) commonly referred to as "Rutile" with Ilmenite and Zirconiun dioxide (ZrO_2) as major bye products is predominantly mined around the study area. Rutile is

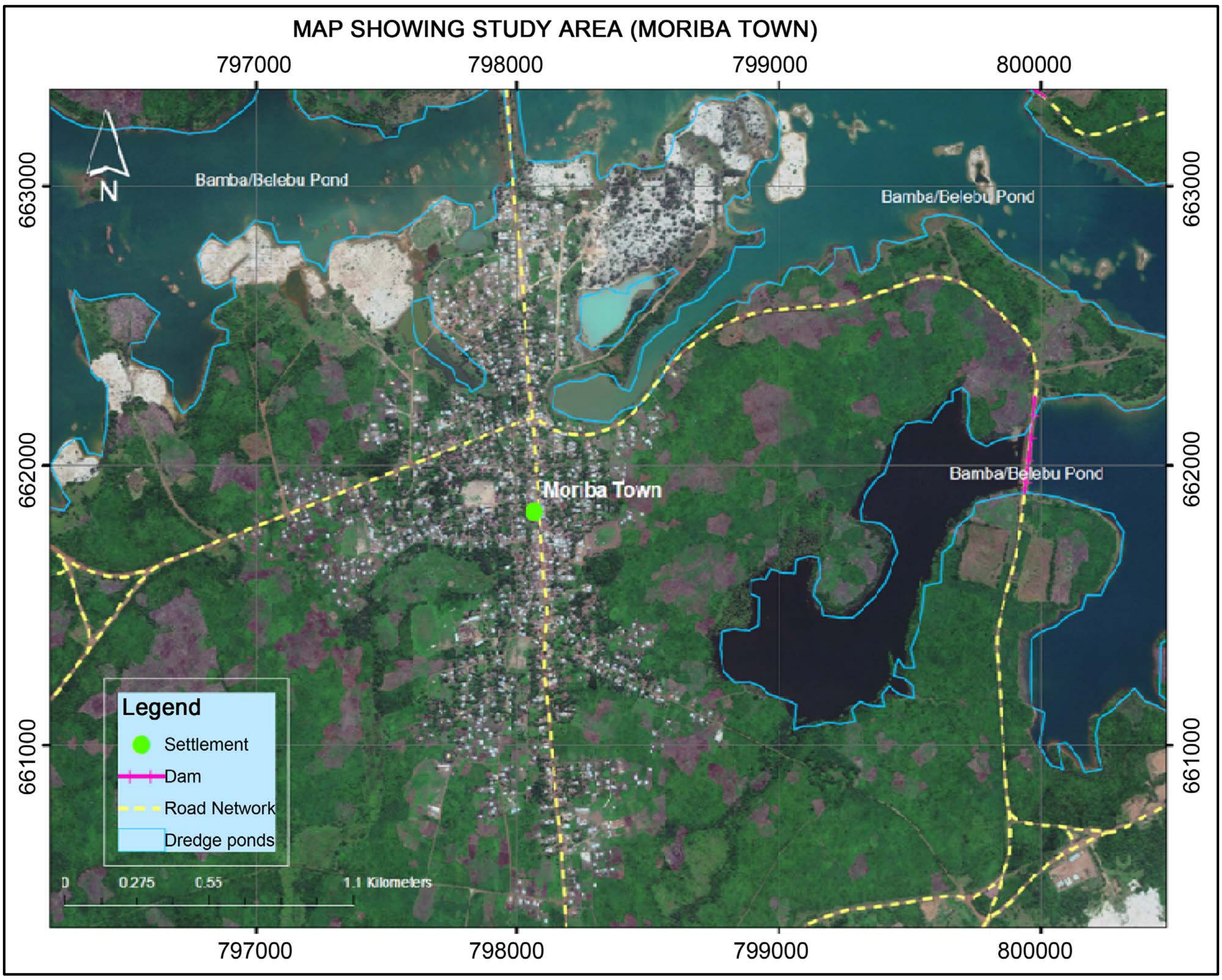

Figure 1. Map showing study area (Moriba Town) and some general physical features.

typically found in mineral deposits in coastal regions and has been mined in southwest Sierra Leone since the early 1970's. Moriba Town is partially surrounded by very large artificial lakes left behind after the dredging activity of the company. As a result, there is also a high possibility for the wells to experience intrusion in many locations.

2.2. Pre Listing Procedures/Identification of Sampling Points

Prior to embarking on the sampling, a listing exercise of all drinking water sources was identified from the various sections within Moriba Town. The study was cross-sectional in which a stratified kind of random sampling method was employed after zoning the entire township into sections or strata from which the required sample size was determined. Sectioning was according to the different settlement patterns. A total of 152 drinking water sources were identified from the listing exercise across the 9 sections, namely; New Site (NST), Zimbabwe (ZIM), Moriba Town Gbangbatoihun (MTG), Gbangbatoihun (GBA), Nyokorvulahun/On the Sand 2 (NYO), Mbelebu/Central (MBE), Tokpoi Town/On the Sand 1 (OTK), Mogbewa 2 (MOG), and Mesima (MES). Two (2) of the sources identified were later verified to be non-drinking sources and were therefore not included in the batch of samples. In determining the overall sample size (S), a sample size determination using a finite population corrector factor formulary was used. (Source: www.qualtrics.co).

$$S = Ni \cdot Nt \big/ \left\{ Ni + \left(Nt - 1 \right) \right\}$$

where; S = Overall sample size, Ni = Initial estimate (75), Nt = Total Population (152),

$$S = Nf \left(Qs/Nt \right)$$

where S = Sample size per section, Nf = Final estimated samples, Qs = Quantity per section and Nt = Total Population.

The quantity of samples to be considered for randomization per section was determined from the expression shown.

This however resulted in a net sample size of fifty (50). Hand dug well water samples were thus collected from 50 locations across the nine (9) sections or zones for the determination of physiochemical parameters. The sampling was done in the same month of July-2016 on a daily basis.

2.3. Water Sampling and Physico-Chemical Measurements

A 500 ml high density polyethylene bottle was used to collect samples. Polyethylene bottle was chosen due to its availability, resistance to breakage and light weight. The samples were collected using the local collecting containers available at each sampling point. Indigenous sample collection containers were used to fetch the water from the wells. The 500 ml high density polyethylene sample container was rinsed with the sample before pouring it into each container. Each bottle was appropriately labeled with the following information affixed location, sample code number and date. Samples were then placed in a Coleman stacked with ice packs. The process was repeated at all the sites before being transported to the laboratory where they were refrigerated until analysis using Standard Operating Procedures (SOPs). All samples were taken to the Sierra Rutile Limited laboratory for analysis.

The physical parameters investigated include pH, temperature, turbidity, electrical conductivity (EC) and total dissolved solids (TDS) and that for the chemical were chloride, fluoride, free iron, copper, phosphate, manganese, aluminum, ammonia, nitrate, nitrite and sulphate. The physical parameters were immediately measured in situ using a combined Accumet AC 85 Fischer Scientific pH, temperature and conductivity meter. The meter was calibrated before and during the field campaign using buffer solutions recommended by the manufacturer.

All of the chemical parameters were analyzed using Wagtech Potalab Photometer 9500 (brand name ECOSENSE). The standard operating procedures for all the chemical species were followed during analyses in the laboratory. For instance, the Wagtech chlorine test uses diethyl-p-pheneylenediamine (DPD) which is recognized as the standard test for chlorine and other disinfectant residuals. Free chlorine reacts with DPD in buffer solution to produce a pink coloration. The intensity of the colour is proportional to the free chlorine concentration. Subsequent additions of excess potassium iodide induce a further reaction with any combined chlorine present. In the Wagtech DPD method, the reagents are provided in tablet forms for maximum convenience and simplicity. The colour intensities are measured using a Wagtech photometer. A similar procedure was followed for all the chemical indicators and values reported in the acceptable units.

2.4. Data Analyses

The study design was purely quantitative which warranted the generation of numeric data. Data generated were subjected to descriptive statistics by summarizing the mean, standard deviation and range of values. The World Health Organization water quality standards were used to compare the threshold of values for this study and same standard values for WHO. A hypothesized threshold at a significance level of 5% was used to test the claim that the observed values were not different from WHO standards. Multivariate statistical technique in the form of Pearson correlation coefficient was used to establish relationship among the physiochemical indicators in other to ascertain whether parameters were from the same origin or having similar pathway of formation or possess the same physical or chemical transformation. A correlation coefficient of 0.5 was taken as a reasonable cut off point to depict association. Individual mean values of the physical and chemical parameters/species were subjected to physiochemical ratios in order to predict chemical species from simple inexpensive and user friendly probes of physical indicators. Reported results and figures were conducted using JMP 8 software.

3. Results and Discussion

Descriptive statistics was used to compare measured variables with WHO water quality standards. Results of the study are presented in the form of mean, standard deviation, minimum and maximum values as reflected in Table 1. From Table 2, more than 90% of all the samples showed significant and strong acid

Table 1. Site summary of physiochemical data.

		pH	Temp. (˚C)	Turb (NTU)	EC (μS/cm)	TDS (mg/L)	Cl (mg/L)	F (mg/L)	Fe (mg/L)	NH_3 (mg/L)	Cu (mg/L)	PO_4^{3-} (mg/L)	Mn (mg/L)	Al (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	SO_4^{2-} (mg/L)
NST n = 4	Avg.	4.62	28.85	1.40	31.75	15.88	0.04	1.61	0.02	0.01	0.22	0.21	0.01	0.14	0.07	26.75	5.00
	Stdev	0.17	0.42	0.54	1.58	0.82	0.03	0.04	0.01	0.00	0.15	0.08	0.00	0.03	0.06	4.27	2.45
	Max.	4.84	29.30	1.88	34.10	17.10	0.07	1.65	0.02	0.01	0.42	0.28	0.01	0.18	0.12	32.00	8.00
	Min.	4.44	28.30	0.90	30.80	15.40	0.01	1.55	0.01	N/D	0.08	0.10	0.01	0.10	0.01	22.00	2.00
ZIM n = 4	Avg.	5.17	26.98	1.04	35.25	17.49	0.02	0.46	0.02	0.03	0.05	0.29	0.02	0.14	0.09	21.97	5.75
	Stdev	0.49	1.09	0.44	14.83	7.30	0.01	0.76	0.01	0.05	0.05	0.16	0.03	0.03	0.04	14.43	4.92
	Max.	5.71	28.60	1.61	48.50	23.80	0.03	1.60	0.04	0.10	0.12	0.52	0.07	0.18	0.15	33.00	13.00
	Min.	4.54	26.30	0.64	18.19	9.07	N/D	0.01	0.01	N/D	N/D	0.18	0.01	0.11	0.05	0.90	2.00
MTG n = 5	Avg.	5.64	27.58	2.71	30.50	15.11	0.03	0.24	0.02	0.01	0.22	2.20	0.01	0.06	0.05	24.50	3.50
	Stdev	0.03	0.43	1.97	18.88	9.57	0.02	0.20	0.01	0.00	0.16	2.22	0.00	0.05	0.04	15.81	1.29
	Max.	5.67	28.10	5.36	47.00	23.50	0.04	0.48	0.02	0.01	0.40	5.50	0.01	0.10	0.08	35.00	5.00
	Min.	5.60	27.10	0.88	13.85	6.74	0.01	0.06	0.01	N/D	0.04	0.83	0.01	0.02	0.01	0.99	2.00
GBA n = 5	Avg.	4.70	35.32	3.38	22.25	12.02	0.18	1.35	0.07	0.01	0.24	0.32	0.01	0.11	0.06	31.20	4.40
	Stdev	0.16	5.53	3.36	11.08	6.45	0.29	0.75	0.10	0.00	0.16	0.07	0.00	0.05	0.04	4.21	0.55
	Max.	4.90	44.40	9.22	37.30	18.80	0.70	1.80	0.25	0.02	0.39	0.40	0.01	0.16	0.10	36.00	5.00
	Min.	4.52	30.30	1.05	9.42	4.71	0.01	0.01	0.01	N/D	0.02	0.25	0.01	0.02	0.01	25.00	4.00
NYO n = 8	Avg.	4.77	26.47	1.16	30.96	15.44	0.04	0.03	0.01	0.02	0.08	0.68	0.01	0.10	0.02	28.89	3.28
	Stdev	0.48	1.41	0.71	14.39	7.17	0.04	0.03	0.01	0.03	0.07	0.52	0.00	0.07	0.01	4.86	3.28
	Max.	5.59	28.60	2.72	56.50	28.20	0.13	0.11	0.05	0.10	0.20	1.55	0.02	0.26	0.03	36.00	10.00
	Min.	4.32	25.00	0.39	12.62	6.28	N/D	N/D	N/D	N/D	N/D	0.20	0.01	0.03	0.01	22.00	0.50
MBE n = 8	Avg.	5.59	28.06	45.34	102.90	51.28	0.73	0.02	0.76	0.02	0.31	1.23	0.01	0.22	0.11	22.65	7.50
	Stdev	0.66	1.48	121.90	114.15	56.76	1.93	0.02	2.12	0.02	0.34	2.16	0.00	0.24	0.23	14.09	8.86
	Max.	7.04	30.50	347.00	366.00	182.00	5.50	0.06	6.00	0.05	1.05	6.50	0.02	0.80	0.68	35.00	27.00
	Min.	4.76	26.00	0.53	22.10	11.00	0.01	N/D	N/D	N/D	0.04	0.20	0.01	0.06	0.01	0.06	N/D
OTK n = 8	Avg.	5.40	27.91	2.11	20.59	13.04	0.15	0.20	0.01	0.01	0.10	1.17	0.01	0.04	0.07	14.47	2.57
	Stdev	0.39	2.50	1.05	9.77	7.21	0.31	0.43	0.01	0.00	0.10	1.92	0.00	0.03	0.05	13.25	1.99
	Max.	5.99	30.40	3.72	39.50	25.70	0.84	1.18	0.02	0.01	0.28	5.50	0.01	0.10	0.12	28.00	5.00
	Min.	4.77	22.60	0.72	8.48	4.25	0.01	N/D	0.01	N/D	N/D	0.24	0.01	0.01	0.01	0.02	N/D
MOG n = 4	Avg.	4.56	27.68	0.88	42.28	21.15	0.03	1.17	0.02	0.01	0.17	0.40	0.01	0.13	0.07	27.25	3.00
	Stdev	0.08	1.61	0.54	14.16	7.05	0.02	0.75	0.01	0.00	0.11	0.08	0.00	0.07	0.04	4.35	0.82
	Max.	4.62	29.30	1.54	61.00	30.40	0.05	1.70	0.03	0.01	0.34	0.50	0.01	0.21	0.11	33.00	4.00
	Min.	4.45	26.10	0.22	29.20	14.60	0.01	0.08	0.01	N/D	0.10	0.30	0.01	0.06	0.03	23.00	2.00
MES n = 5	Avg.	5.51	29.54	1.09	106.90	53.16	0.01	0.68	0.01	0.01	0.10	0.27	0.01	0.20	0.06	26.00	5.40
	Stdev	0.58	1.35	0.78	72.68	35.55	0.00	0.92	0.01	0.00	0.07	0.10	0.00	0.16	0.05	2.92	2.79
	Max.	6.52	30.80	2.36	191.00	92.60	0.02	1.80	0.02	0.01	0.18	0.43	0.01	0.37	0.14	30.00	10.00
	Min.	5.11	27.60	0.55	31.40	15.80	N/D	N/D	N/D	N/D	0.04	0.15	0.01	0.01	0.01	22.00	3.00

Avg. = average; Stdev = standard deviation; Max. = maximum; Min. = minimum; pH = potential of hydrogen; Temp. = temperature; Turb = turbidity; EC = electrical conductivity; TDS = total dissolved solids; NST = New site; ZIM = Zimbabwe; MTG = Moriba Town Gbangbatoihun; GBA = Gbangbatoihun; NYO = Nyokorvulahun; MBE = Mbellebu; OTK = On the Sand/Tokpoi Town; MOG = Mogbewa 2; MES = Messima; N/D = Not detectable.

Table 2. Combined summary statistic for the different sites.

	Avg.	SD	Max.	Min.	P value	WHO Standard
pH	5.13	0.58	7.04	4.32	<0.001	6.5 - 8.5
Temp. (˚C)	28.53	3.21	44.4	22.6	-	-
Turb (NTU)	8.69	48.84	347	0.22	0.297	<5.0
EC (μS/cm)	49.02	59.43	366	8.48	<0.001	450
TDS (mg/L)	24.9	29.36	182	4.25	<0.001	500
Cl (mg/L)	0.17	0.78	5.5	N/D	<0.001	0.3 - 5.0
F (mg/L)	0.52	0.72	1.8	N/D	<0.001	<1.5
Fe (mg/L)	0.14	0.85	6.0	N/D	0.151	0.3
NH_3 (mg/L)	0.02	0.02	0.1	N/D	<0.001	1.5 - 35
Cu (mg/L)	0.16	0.18	1.05	N/D	<0.001	1.0 - 2.0
PO_4^{3-} (mg/L)	0.79	1.34	6.5	0.1	-	-
Mn (mg/L)	0.01	0.01	0.07	0.01	<0.001	<0.1
Al (mg/L)	0.13	0.12	0.8	0.01	<0.001	0.2
NO_2^- (mg/L)	0.06	0.1	0.68	0.01	<0.001	3
NO_3^- (mg/L)	24.61	10.54	36	0.02	<0.001	10
SO_4^{2-} (mg/L)	4.51	4.35	27	0.01	<0.001	<250.0

Avg. = average; SD = standard deviation; Max. = maximum; Min. = minimum; pH = potential of hydrogen; Temp. = temperature; Turb = turbidity; EC = electrical conductivity; TDS = total dissolved solids. (˚C) = degree Celsius; NTU = nephelometric turbidity unit; μS/cm = micro Siemens per centimeter; mg/L = milligrams per liter. There were no guideline values for indicators with blank spaces.

character with the strongest acid content of 4.32. The evidence of strong mineral acids (Cl^-, NO_3^- and SO_4^{2-}) is presumed to be dominant across the sites and a similar observation was reported in a recent study [12] where strong acids predominate over weaker acids. The strong acidity of well waters around the sites is in contrast to a previous study conducted in Guinea where the pH content was skewed to be alkaline [13]. Our findings for pH is firmly in line with a similar in Bo, Sierra Leone [9], and recently reported for ground water sources around a Dumpsite Lagos, Nigeria [14]; and in bacteriological contamination of shallow ground water in Cameroon [15]; and surface runoff even though the studies were slightly different [16]. Probable reason for such strong acid nature at these sites could be ascribed to the surrounding coastal water which is controlled by its hydrological settings [14]. It is further suggested that the soil type of the study area seems to have little carbonate and bicarbonate (CO_3^{2-} and HCO_3^-) in its aquifer [17]. The range of temperatures was relatively high and this particular indicator is a function of the amount of dissolved oxygen (DO) in water which is a pre requisite for survival of aquatic organisms. Further, >80% of the samples measured for turbidity were in good agreement with guideline standards for potable water except for site MBE but no significant difference in values was found. We share similar viewpoint from a similar study conducted earlier in southern regional headquarter town of Bo [9]. The large variance for this indicator could be strongly associated with the outlier observed for site MBE.

Site MBE is an abandoned well which has not been used over the past year and we believe that the non abstraction of water regularly might have resulted in a buildup of the levels pollutants recorded (**Table 1**), given that there is minimum room for ground water recharge. There is a significant reduction in the values of total dissolved solids and electrical conductivity with respect to their respective acceptable thresholds as manifested in **Table 1**. Our results for electrical conductivity is in agreement with previous studies in Guinea Bissau and Cameroon [8] [18] which is an indication that there is very little salt content ground water sources but in sharp contrast to the earlier study reported in Guinea even though results for turbidity appeared similar [13]. Total Dissolved Solids primarily comprises of inorganic salts with small amounts of organic matter. We share similar result with a study on quality assessment of ground water sources in Imo, Nigeria [19]; and our results are within the acceptable water standards but results of a similar study conducted in India revealed sharp contrast with this study [17].

Nearly 97% of samples exhibit good chloride content. Even though the limits of chloride have been mostly reduced to the physical approach (taste), there have been no adverse health effects on humans who are exposed to high dose of Cl^- [20]. Similarly, about 80% of all the samples had fluoride values that are within the acceptable guideline for potable water and this observable pattern was in agreement with previous studies reported [8] [12]. It was further reported in the same study that the relatively low levels of fluoride in ground water might be due to its acidic nature which renders it immobile. Even though F^- is quite essential for humans, the source of this element in ground water could be attributed to leaching from fluoride rocks and easier accessibility of weathered rocks and long term irrigation. There is significant elevation of nitrate contamination across wells of the study area (**Table 2**). For most part of the developing world, nitrate contamination is strongly associated with unsewered sanitation due to lack of proper sanitation practices and hygiene. It is probable that seepages of nitrate from local pit latrines and infiltration process due to indiscriminate practice of public urination by men in the various communities, fertilizer from agricultural runoff.

Almost all the samples (>95) for Al, Cu and Mn trace metals were in good agreement with guideline standards with few exceptions for Al. Being a mining environment for bauxite, it is unsurprising to observe levels of Al which are in excess of WHO standard. Generally, the existence of heavy metals in ground water is in the form of colloidal, particulate or dissolved phases with either natural of anthropogenic origin [21]. It should be noted that the quality of ground water sources are affected by the characteristics of the media through which water passes to the ground water zone of saturation [21] [22].

Table 3 contains Pearson correlation coefficient of the water indicators studied. Generally, there is observable pattern of relationship among the variables. For instance, temperature, pH, Mn etc. showed no relationship with most indicators. Turbidity however revealed strong association with phosphate, aluminum and nitrite, respectively. It has been reported earlier that turbidity is a good

Table 3. Pearson correlation matrix among water quality indicators.

	pH	Temp.	Turbidity	EC	TDS	Cl	F	Fe	NH_3	Cu	PO_4^{3-}	Mn	Al	NO_2^-	NO_3^-	SO_4^{2-}
pH	1.0000															
Temp.	−0.1440	1.0000														
Turbidity	0.4796	−0.1024	1.0000													
EC	0.2382	−0.0516	0.2201	1.0000												
TDS	0.2525	−0.0413	0.2201	**0.9955**	1.0000											
Cl	0.1913	−0.0265	−0.0270	0.0222	0.0193	1.0000										
F	−0.3141	**0.5576**	−0.1175	−0.2168	−0.2227	−0.1148	1.0000									
Fe	−0.0991	0.0997	−0.0293	−0.0263	−0.0295	−0.0343	−0.1172	1.0000								
NH_3	−0.1051	−0.0115	−0.0747	−0.0570	−0.0557	−0.0715	0.0995	−0.0715	1.0000							
Cu	−0.0634	−0.0221	−0.1453	0.0594	0.0482	0.0958	0.0178	0.1031	−0.2213	1.0000						
PO_4^{3-}	0.3730	−0.3006	**0.6165**	0.0844	0.0793	−0.0851	−0.2641	−0.0591	−0.0938	−0.0321	1.0000					
Mn	−0.1705	−0.0382	−0.0182	−0.0005	−0.0020	0.1402	0.1954	−0.0242	−0.0657	0.1645	−0.1027	1.0000				
Al	0.2021	−0.0217	**0.7771**	0.4781	−0.4715	−0.0598	−0.1246	0.1018	−0.1332	−0.0740	0.4216	−0.0007	1.0000			
NO_2^-	0.4522	−0.0544	**0.9025**	0.2460	0.2514	−0.0834	0.0489	−0.0833	0.0193	−0.1960	0.4817	−0.0331	**0.6826**	1.0000		
NO_3^-	−0.3181	0.1275	−0.3388	0.0325	0.0359	0.1584	−0.0635	0.0838	0.0442	0.2311	−0.2068	0.1616	−0.2148	−0.4015	1.0000	
SO_4^{2-}	0.1490	0.0679	0.1112	0.1015	0.1025	0.0067	−0.0658	−0.0626	−0.1378	0.1549	−0.0143	−0.0267	0.2074	0.0744	0.1400	1.0000

indicator to assess the presence of micro organisms in different watershed [23]. Even among the physical indicators, there was no clear trend of association and a similar pattern was noted for the chemical species. These results are consistent with similar studies that have been earlier reported [14] [24]; but such findings would suggest that the relationships among water quality indicators may be complex due to the different factors affecting the physical and chemical processes in the aquifers.

The distribution profile ratios of physical-chemical indicators are presented in Figures 2(A)-(E). All of the figures in Figure 2, showed significant variance in ratio values with the exception of Figure 2(C). Figure 2(A), Figure 2(B), Figure 2(D) and Figure 2(E) revealed extreme values which are strongly attributed to the relatively low values of most chemical species. Nonetheless, there was a consistent observable trend for pH, Temp EC and TDS ratios with NO_3^-, PO_4^{3-} and SO_4^{2-} which appeared to show minimal variation compared with the rest of chemical species. Turbidity on the other hand seems to demonstrate consistent ratios with respect to the other chemical species with one main exception Figure 2(C). Environmental forensics is a useful approach to discern commonalities among variables and such technique in the form of ratios could be used to predict results from an analysis that involves complex or laborious chemical procedure in the laboratory by using simple or less expensive method of analysis. For example, turbidity as an indicator could be used to reasonably predict most chemical species in water by using an inexpensive water probe designed to measure turbidity. Such analytical technique would greatly improve analytical skills of local researchers with little or no financial support for research and

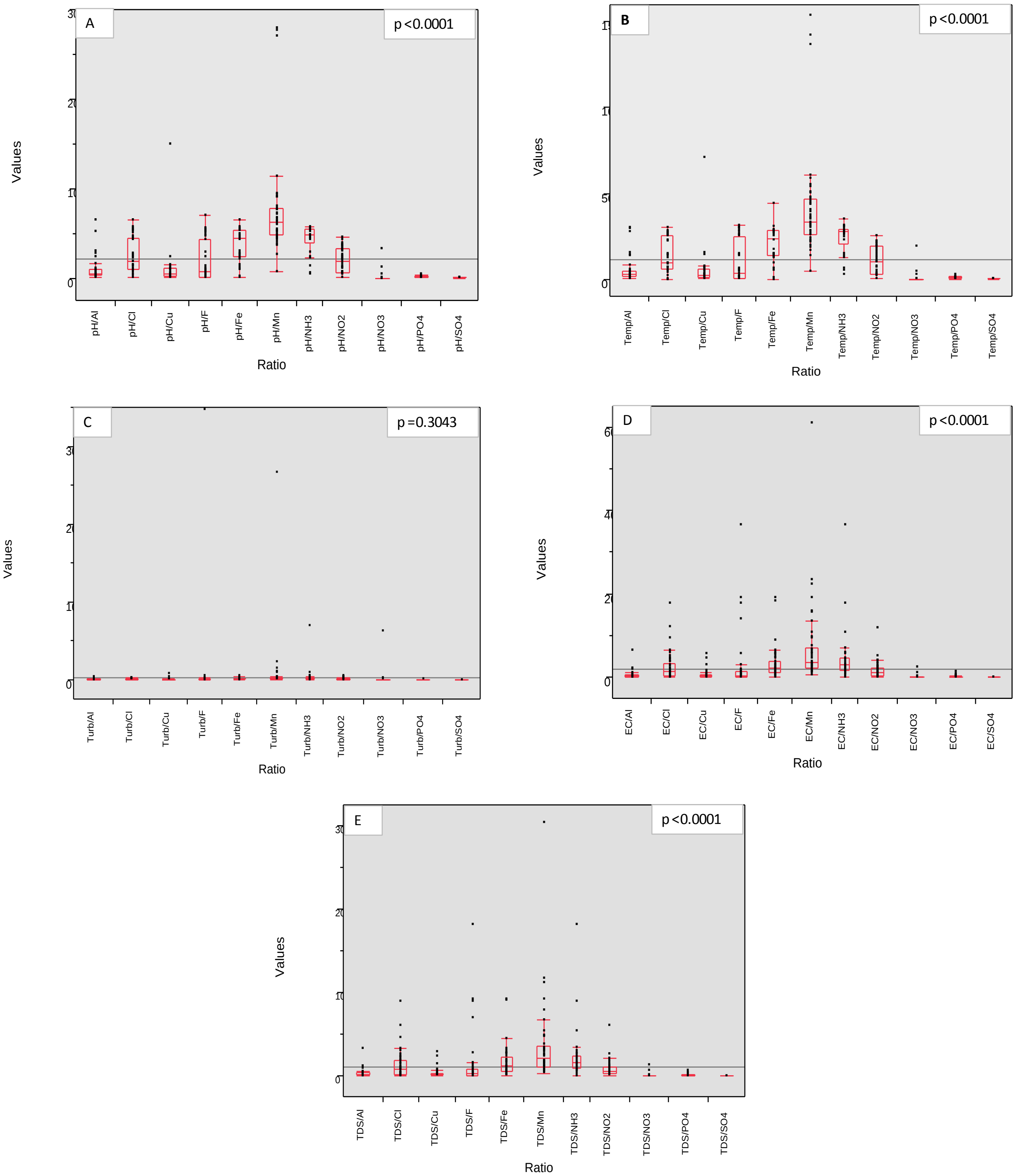

Figure 2. Distribution of physical to chemical ratios for (A) pH against all chemical species (B) temperature against all chemical species (C) turbidity against all chemical species (D) electrical conductivity against all chemical species and (E) total dissolved solids against all chemical species.

cannot compete with international scientists in generating reliable water quality data. Nonetheless, this approach needs further study which is more detailed.

The ground water sources at Moriba town are noted to contain high levels of nitrate. Evidence of higher NO_3^- levels in potable water has been reported to cause or induce methaemoglobinaemia, gastric cancer, goiter, birth malformation and hypertension. We should emphasize that the findings of this study are only generalized to one main locality around the mine site. Despite the study revealed good water parameters for most indicators, the wider areas of the mining site were not reported which is noted to be a limitation to the study. Nonetheless, this finding goes to suggest that outreach community services provided by SRL could be attributed to the acceptable state of potable water at Moriba town. For instance, SRL usually provides chlorine to disinfect or treat water wells in the various communities. Also, SRL have been supporting communities with the construction of protected wells which could have impacted positively the results of the current study. Additionally, the results generally indicate that the Moriba town community might have regenerated itself over the years which could also mean that there was no sign of disturbance from activities of company with regards to this study.

4. Conclusion

In Moriba town around Sierra Rutile Mining Company, there is no public water supply system and the communities largely depend on ground water sources for their domestic purposes. In the current study, groundwater sources were drawn from 50 wells and analyzed for physical and chemical parameters, respectively and results were referenced with WHO water quality standards for drinking purposes. Almost 80% of all the water quality indicators were in good agreement for potable water with three exceptions namely; pH, turbidity and nitrate. Greater attention should be given to these indicators which could be a public health risk. The study also revealed no consistent pattern of association among water quality indicators. Even though there were huge variances, the study provided a useful approach to predict chemical species from physical indicators. The study provided insightful information into the development of ground water sources around communities of Sierra Rutile mining concession areas considering their corporate social responsibilities and to some extent, a broader perspective of the conditions of rural water supply.

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