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Impact of mining activities on water quality status at Wolfram Mining and Processing (WMP), Burera, Rwanda

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Abstract
The mining industry is one of the important economic sector, which has potential contribution to the economic development and environmental issues at the same time. This research intended to assess the impact of mining activities on water quality status at WMP sites at Gifurwe, Burera, Rwanda. Water samples were randomly collected in seven (7) points of the study area. The physico-chemical parameters such as temperature, pH, EC, TDS, Fe^{2+}, Mn^{2+}, Mg^{2+}, Al^{3+}, Ca^{2+}, K^{+} and Na^{+} have been analyzed. The findings were compared to the National Standards for Drinking Water (RS EAS 12:2014), National Tolerance Limits for Discharged Wastewater (RS110:2009) and World Health Organization (WHO: 2011) guidelines for potable water. The mean level of parameters examined were temperature (21.6^{0}C), pH (6.14), electrical conductivity (42.57µScm^{-1}), total dissolved solids (85.14mgL^{-1}), Iron (0.20 mgL^{-1}), Manganese (0.15 mgL^{-1}), Magnesium (1.07mgL^{-1}), Aluminium (0.11mgL^{-1}), Calcium (2.80mgL^{-1}), Potassium (1.13 mgL^{-1}) and Sodium (1.41mgL^{-1}). It is recommended to treat the effluent of the control tailing ponds by precipitating out metals.

1. Introduction
Mining is the process of extracting a naturally occurring material from the earth to derive a profit. Mining has five stages which are the prospecting, exploration, development, exploitation, and reclamation. It is also defined as the process or business of working mines [17]. However, water is a liquid which forms rain, rivers, lakes and the sea and which makes up a large part of the bodies of organisms [2]. Water is vital for the operation of the mining industry. It is used for operating equipment (e.g. drilling, milling, flotation, smelting) and for health and safety (dust suppression, hydration) and can have a significant demand on a local resource [16]. The deterioration of water quality is becoming increasingly important in the world. This phenomenon is due to the human activities which have contributed to their increasing [3, 4]. Water pollution can take many forms: the most common are discharges from industrial processes like mining activities, household sewage and the runoff of chemicals used in agriculture [2]. The main sources of wastewater from mine sites can be broadly classified into mine water; process wastewater; domestic wastewater and surface runoff [8]. Mining activities generate effluent containing a number of chemical pollutants, which adversely alter the quality of both surface and groundwater resources that often cause significant pollution [10].
According to [6] indicated that the effect of degraded water quality is not only felt in the local area of the mine, but often felt downstream of the mine far away from the source of pollution. The impacts of mining activities for instance, can create problems for ecosystems functioning [14]. Koryak [10] argues that the effluent produced from waste rock dumps has a potential to cause Acid Rain Drainage (ARD) into stream and river waters. [11] reported the non-survival of fish in Ely Brook River-USA due to extremely poor survival and growth conditions resulted from mine effluent.

Furthermore, the tailings in mining areas are usually in the form of fine slurry, which are managed in ponds. Both the chemical and physical stability of tailings management facilities are of high importance, since they can also have an ARD potential. The amount of tailings generated depends on the content of the desirable mineral(s) in the ore, its grade, and the efficiency of the mineral processing stage in the recovering process. The United States Environmental Programme (USEP) affirms that mine tailings contain residual minerals and potentially toxic chemicals [21]. This study is mainly focused on the impact of mining activities on water quality status at WMP sites at Gifurwe, Burera, Rwanda. It determined the level of Iron, Manganese, Aluminium, Magnesium, Calcium, Potassium and Sodium and different physical parameters. This research will therefore provide an understanding on existing baseline for evaluating the impact of mining activities on water quality in mining areas of Rwanda. It will also ensure the sustainable mining management in Rwanda.

2. Materials and Methods

2.1. Study area

The study was conducted in Gifurwe WMP area in Burera District, Rwanda. The location is situated at -1^0.556850 of latitude and 29^0.809940 of longitude in central Rwanda. It forms part of the NW to SE oriented Bugarama-Gifurwe-Nyakabingo zone also known as the tungsten belt. The tungsten belt comprises silica-clastic rocks with composition ranging from black shales to quartz-phyllites to quartzites, which have undergone green schist metamorphism [5].

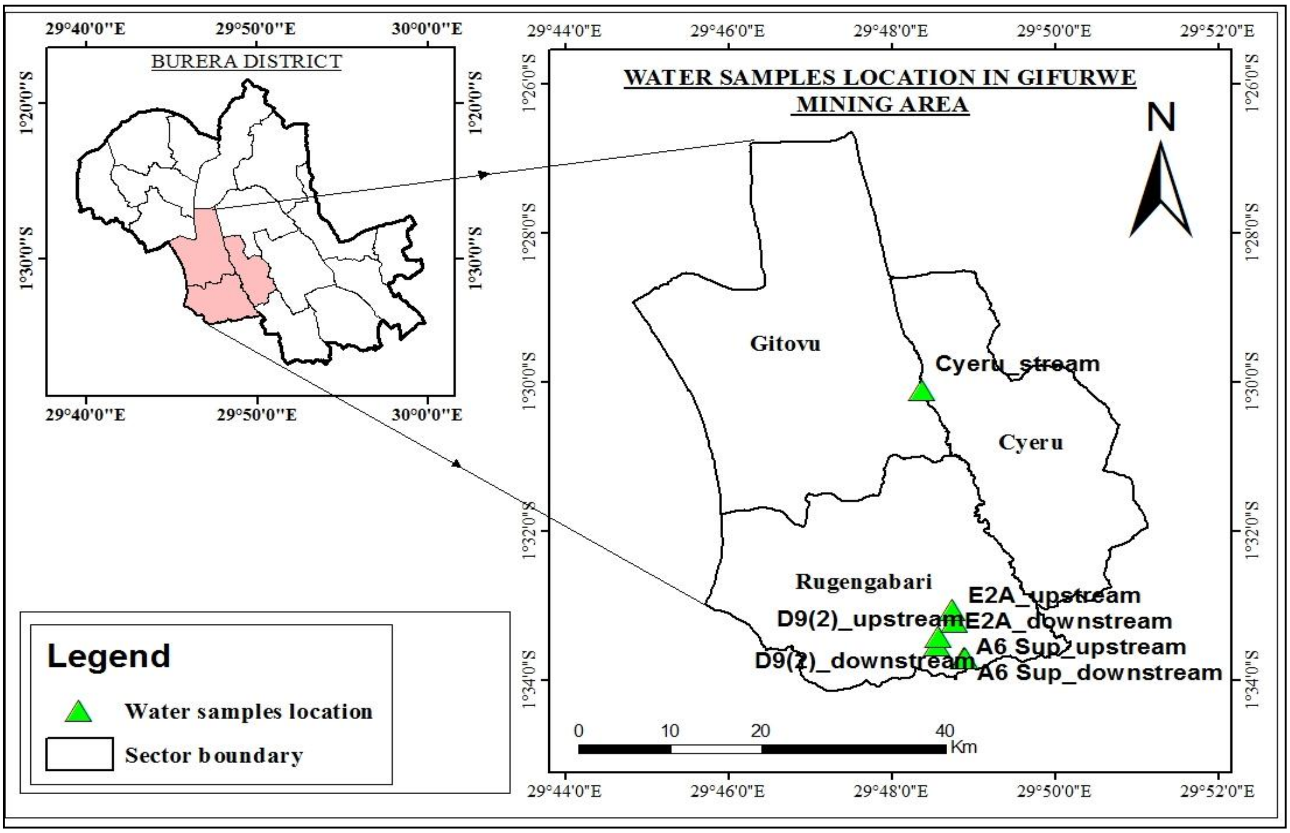

Figure 1: Location of Gifurwe Mining Area in Burera District.

2.2. Sampling collection and preparation

Seven sampling points 150 meters were chosen along Gifurwe mining area from upstream to downstream Gifurwe industrial area after identifying points sources from the industries. The stations were E2A, D9 (2), A6 Sup and near Cyeru River. A Global Positioning System (GPS), Garmin instrument (GPSMAP 64) was used to locate water samples as the experimental materials (Figure 1).

Sample containers were thoroughly washed with detergent, rinsed with water followed by distilled water before soaking in 5% HNO_3 for about 24 hours and dried at room temperature. Water samples were collected from hand dug wells using plastic drawers into 1/3-litre acid washed polypropylene sample containers. All samples were transported to INES Civil Engineering and Biotechnology Laboratory in an icebox jar to avoid unusual change in water quality and stored in a refrigerator (4°C) before analysis. The samples were at the end used for physical parameters measurements (pH, Temperature, Electrical conductivity and Total Dissolved Solids) and chemical parameters measurements (Iron, Manganese, Aluminium, Magnesium, Calcium, Potassium and Sodium). The method of collection, preparation and preservation were similar to those reported in previous studies [20, 23] and standard methods were followed that listed by American Public Health Association (APHA) [24].

Figure 2: Wastewater flow and the downstream tailing dams in Gifurwe mining site.

2.3. Laboratory and statistical analysis

The pH values of water were measured using potentiometric method *(ISO 10523)* by glass electrode in the suspension of water. Electrodes of pH-meter was introduced in the supernatant and the pH-meter will give directly the readings corresponding to the pH of the solution as described in [15].

The temperature of water was determined using the digital thermometer. Carefully place the bulb end of the thermometer into the beaker of water and wait two minutes for the thermometer reading to stabilize. Once the thermometer reading is stable, determine the temperature in Celsius degree (^{0}C) [12]. Total dissolved solids were determined using conductimetric method (*ASTM D5907*). A well-mixed sample is filtered through a weighed standard glass fiber filter. The filtered sample (liquid phase) is evaporated to dryness and heated to 180°C in a tarred vessel to a constant weight. Calculate TDS as follows in mgL^{-1} (Equation 1).

$$TDS = \frac{mg\ of\ residue + dish) - mg\ of\ dish}{mL\ of\ sample\ filtered}\ x\ 1000 \quad \text{(Equation 1)}$$

The electrical conductivity was determined using conductimetric method (*ISO 7888*), the electrode thoroughly with deionized water. The readings are displayed directly [12]. It is expressed in µS/cm. The concentrations of Fe^{2+}, Mn^{2+}, Al^{3+}, Mg^{2+}, Ca^{2+}, K^+ and Na^+ were determined using Atomic Absorption Spectrometry (AAS) method as described by [7]. The metals are extracted with 0.1N H_3PO_4. The extracted metals are determined by AAS (AA-6800, Shimadzu, Japan). However, the values obtained were subjected to statistical analysis. The descriptive statistics were computed. All statistical analyses were done by Microsoft Excel 2013 software for graphical representation and mean calculation.

3. Results and discussion

3.1. Physico-chemical parameters of water in Gifurwe mining site

The table below illustrates the maximum, minimum, mean and standard deviation (STDEV) values of physico-chemical parameters of Gifurwe mining site.

3.2. Correlation matrix between variables

The results (Table 2) shows that very smallest correlation (-0.93) was observed between Al^{3+} and Ca^{2+} whereas the strongest correlation (0.993) between Mn^{2+} and Al^{3+}.

Table 1. National Standards for Drinking Water, National Tolerance Limits for Discharged Wastewater and World Health Organization (WHO: 2011) drinking water quality guidelines.

Water	pH	T°C	EC	TDS	Fe^{2+}	Mn^{2+}	Al^{3+}	Mg^{2+}	Ca^{2+}	K^{+}	Na^{+}
			(µS/cm)	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})	(mgL^{-1})
RS:110:2009	5.0-9.0	25	≤2500	-	-	0.2-1	-	-	150	-	-
RS EAS 12:2014	6.5-8.5	25	1500	700	0.3	0.1	0.2	-	150	200	100
WHO (2011)	6.5-8.5	25	250	-	0.3	0.1	0.15	0.2	100-300	-	-

Table 2. Water characterization in Gifurwe mining area

Sample Codes	pH	Temp.	EC	TDS	Fe^{2+}	Mn^{2+}	Al^{3+}	Mg^{2+}	Ca^{2+}	K^{+}	Na^{+}
		^{0}C	µS/cm	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}	mgL^{-1}
D9(2)_upstream	6.4	23	44	82	0.167	0.053	0.072	1.15	3.01	2	1.4
D9(2)_downstream	7.2	21	54	87	0.288	0.22	0.142	1.14	2.67	0.2	1.6
E2A_upstream	5.6	22	35	89	0.171	0.067	0.069	1.12	3.02	1.6	1.3
E2A_downstream	5.3	21	37	87	0.25	0.21	0.146	1.07	2.57	0.22	1.5
A6_Sup_upstream	5.5	23	42	88	0.151	0.069	0.073	1.13	3.03	2.2	1.2
A6_Sup_downstream	5.4	21	50	84	0.163	0.23	0.144	0.98	2.77	0.8	1.3
Cyeru_Stream	7.6	20	36	79	0.266	0.21	0.139	0.93	2.54	0.9	1.6
Minimum	5.3	20	35	79	0.151	0.067	0.069	0.93	2.54	0.2	1.2
Maximum	7.6	23	50	89	0.288	0.23	0.146	1.15	3.03	2.2	1.6
Mean	6.14	21.6	42.57	85.14	0.208	0.151	0.112	1.074	2.801	1.131	1.414
STDEV	0.94	1.1	7.30	3.62	0.057	0.083	0.038	0.086	0.217	0.814	0.157

STDEV: Standard deviation

Table 3. Correlation matrix between physical and chemical parameters in the study area.

	pH	Temp.	EC	TDS	Fe^{2+}	Mn^{2+}	Al^{3+}	Mg^{2+}	Ca^{2+}	K^{+}	Na^{+}
pH	1										
Temp.	-0.434	1									
EC	0.158	0.014	1								
TDS	-0.609	0.382	0.046	1							
Fe^{2+}	0.659	-0.743	0.086	-0.203	1						
Mn^{2+}	0.264	-0.892	0.330	-0.257	0.686	1					
Al^{3+}	0.263	-0.878	0.301	-0.282	0.712	0.993	1				
Mg^{2+}	-0.222	0.768	0.198	0.640	-0.235	-0.638	-0.617	1			
Ca^{2+}	-0.419	0.915	-0.023	0.382	-0.848	-0.906	-0.932	0.633	1		
K^{+}	-0.223	0.825	-0.264	0.029	-0.801	-0.912	-0.922	0.364	0.877	1	
Na^{+}	0.763	-0.707	0.079	-0.442	0.946	0.617	0.656	-0.274	-0.809	-0.717	1

The results (Table 2) showed that the highest pH values were found in the downstream region which are 7.6 and 7.2 for Cyeru river and D9(2) (downstream or farm field) respectively. The pH of water in the study area ranged between acidic (5.3) to basic (7.6). The highest water temperature was $23^{0}C$ in D9(2) (upstream) and A6Sup (upstream) whereas the lowest temperature is $20^{0}C$ (Cyeru River). In addition, the maximum value of EC of water is equal to $54µScm^{-1}$ [D9(2)_downstream] whereas the lowest value ranges between $35µScm^{-1}$ to $36µScm^{-1}$ (E2A_upstream and Cyeru River respectively). Moreover, the higher TDS in water $89mgL^{-1}$ (E2A_upstream) whereas the lowest is 79 mgL^{-1} (Cyeru River).

The results (Table 2) were compared with World Health Organization (WHO), East Africa Community (EAC) and the Rwanda Standards Board (RSB) guidelines for drinking water (Table 1). Nevertheless, the temperatures which ranged from $20^{0}C$ to $23^{0}C$ were found below the WHO, RSB, and EAC standards of $25^{0}C$ for domestic water supply. According to [20], at high temperatures total dissolved solids are increased as more solute go into solution. According to [20], at high temperatures total dissolved solids are increased as more solute go into solution. The decrease in temperature leads to decrease in solubility. The conductivity was within the range recommended by RSB, EAC and WHO which requires that conductivity should be less than 1500μScm^{-1}, 1500μScm^{-1} and 250μScm^{-1} correspondingly.

In most water of the study area, the TDS values were slightly lower than the recommended values by the EAC (700mgL^{-1}) for potable water. Also, Calcium and Aluminium were below to the range suggested by WHO, EAC and RSB. In fact, the water samples in the study area were found to be from acidic to basic with mean value of 6.4 to 7.6 which is behind the WHO, RSB and EAC guidelines for drinking water. The pH of water is very important in determination of water quality since it affects other chemical reactions such as solubility and metal toxicity [20]. [13] indicated that Burera Lake and its catchments presented a strongly acidic and alkaline pH (4.2 to 10.3). These results were in agreement with those of Gifurwe WMP sites. The acquired results are also in agreement with those of [1], the tailings pond water of Gifurwe mining site has an acidic pH of 5.3.

- *Manganese concentrations of water in Gifurwe WMP sites*

For all Gifurwe sampling points Manganese concentrations ranged from 0.23mgL^{-1} to 0.22mgL^{-1} in A6 Sup downstream and D9(2) downstream respectively as shown in Table 2. This exceed the maximum Manganese permissible level in water (WHO and RSB guidelines of 0.1 mgL^{-1}; and EAC of 0.05 mgL^{-1}). About 100% of water samples collected at sample points in the Gifurwe catchment area were very much higher than these threshold values for Manganese, the values increased from D9(2)_downstream; E2A_downstream; A6_Sup_downstream and Cyeru River to the upstream zones. This could have been due to contribution from the mine for the points downstream the mine and land use activities such as artisanal mining. Several studies has shown that Mg2+ and Ca2+ ions influence the hardness of groundwater. The source of these ions are in the lithology of the aquifer and hydrolysis of silicate minerals [3, 4, and 14].

- *Iron concentrations of water in Gifurwe WMP sites*

The findings (Table 2) showed that Iron concentration ranged from 0.151mgL^{-1} to 0.288mgL^{-1} which is above the standards of RS EAS 12:2014 guidelines of 0.1mgL^{-1}. The D9(2)_downstream and Cyeru_River water samples Iron values are 0.288mgL^{-1} and 0.266 mgL^{-1} respectively which are near the [22] and RS 110:2009 guidelines of 0.3mgL^{-1}. The high Iron values in downstream areas could be as a result of no self-purification and dilution effects in the mining sites as at Cyeru River receives water from different tributaries such as Rwankeri stream and its components.

The results (Table 2) of Iron showed increasing values from downstream to upstream. High levels of Iron at D9(2)_downstream and Cyeru_River could be linked to mining waste and could possibly be attributed to Iron mineralization associated with the natural geology of Wolfram mining areas. In fact, the Iron concentration at the various sampling points along the Gifurwe mining sites were found to be high, the elevated values measured at river sampling points were attributed to anthropogenic sources (land use activities) with low inputs from mine activities at the project site. The literature review suggests that the higher proportions of dissolved metals such as iron are found in groundwater than in surface water because of the greater exposure of groundwater to soluble materials in geologic strata [18]. High levels of heavy metals such as iron upstream of the mine could therefore be attributed to groundwater contamination plumes which can subsequently contaminate surface water via base flow as noted by [9]. This can lead to the inference that the geologic condition of the area may contaminate the groundwater aquifer and subsequently contaminate surface water through base flow recharge. According to [19], the forms in which dissolved and non-dissolved iron occur depend on pH and the presence of complex forming inorganic and organic substances. The iron concentration standard associated with the aquatic life use is <0.3 mgL^{-1} [7].

- *Aluminium concentrations of water in Gifurwe WMP sites*

The concentrations of Aluminium for Gifurwe WMP sites water ranged from 0.069mgL^{-1} to 0.146mgL^{-1} as indicated in Table 2. The results showed that the highest concentration of Aluminium (0.146mgL^{-1}) corresponds to acidic condition (5.3). The metals concentration in water of Gifurwe mining zones follows the trend $Ca^{2+}>K^{+}>Na^{+}>Mg^{2+}>Fe^{2+}>Mn^{2+}>Al^{3+}$. The concentrations of Aluminium are behind the RS EAS 12:2014 guidelines for drinking water. Therefore, [20] declared that the Aluminium sticks to soil particles and enters drinking water only if the water is acidic or soft which are in agreement with the results of Gifurwe WMP zones. Metals tend to be more soluble and more reactive at lower pH. The sulphuric acid, which is generated, easily dissolves metals such as Iron, Copper, Aluminium, and Lead [14]. A study by [14] in Bulyanhulu Gold Mine in Shinyanga in Tanzania revealed that discharges generally had high concentrations of acidity, Iron, Manganese, Aluminium, and sulphate thus negatively degrading aquatic habitats. Aluminium oxide precipitates can be toxic to benthic algae, invertebrates, and fish as the bottom dwelling organisms are particularly sensitive to Acid Mine Drainage (AMD) precipitates. Although, the research of [13] concluded that there were some heavy metals like Iron, Copper, and Manganese in the surrounding areas of National Volcanoes Park water resources, which shows high levels but that are within the limits allowed by standards.

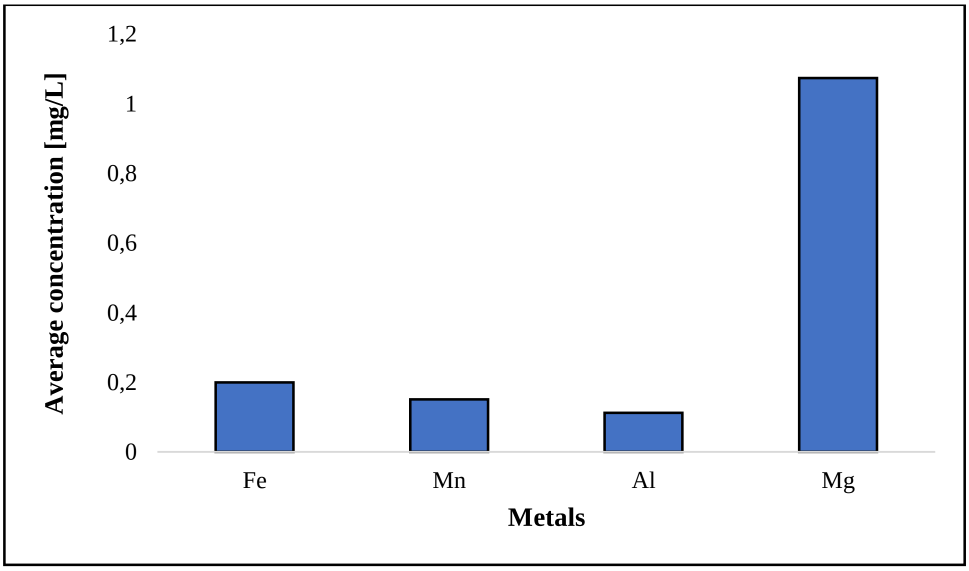

Figure 3: Spatial distribution of Iron, Manganese, Aluminium and Magnesium in Gifurwe, Burera.

Conclusion

The physical and chemical parameters of water in Gifurwe mining areas, Burera, Rwanda were assessed. The temperature was found to be below the WHO: 2011, RS EAS 12:2014, RS 110:2009 limit of 25ºC for potable water. The pH of water varied from acidic to basic with mean value of 6.4 to 7.6 which is behind the WHO, RSB and EAC guidelines for drinking water. The total dissolved solids values were slightly lower than the recommended values by the EAC (700mgL^{-1}) for potable water. The conductivity was within the range recommended by RSB, EAC and WHO which requires that conductivity should be less than 1500µScm^{-1}, 1500µScm^{-1} and 250µScm^{-1} correspondingly. Furthermore, the metals concentration in water of Gifurwe mining zones follows the trend $Ca^{2+}>K^{+}> Na^{+}>Mg^{2+}>Fe^{2+}>Mn^{2+}>Al^{3+}$. The maximum level of Manganese exceeds the permissible level in water (WHO and RSB guidelines of 0.1mgL^{-1}; and EAC of 0.05mgL^{-1}). The Iron concentration ranged from 0.151mgL^{-1} to 0.288mgL^{-1} which is above the standards of RS EAS 12:2014 of 0.1mgL^{-1}. After the research and getting all information concerning some physical and chemical parameters of water in WMP Gifurwe. Some recommendations have been formulated for future consideration:

Much efforts should be invested in treating the effluent of the control ponds by precipitating metals. Though, the construction of additional water treatment facilities and tailing ponds with satisfactory retention times that can enhance the removal and retention of metals were advised; application lime materials and caustic soda in order to neutralize the drainage and avoid release of pollutants in water which results to the lowering of pH in water; further research should be conducted in both seasons wet and dry to obtain more information pertaining to heavy metals and other parameters in many groundwater boreholes and surface water samples within the study area, so as to determine the effect of seasonality; to develop and improve the water monitoring network at WMP in Gifurwe; which indicates a detailed conceptual site model (CSM). The model will help in ensuring that there is discharge of contaminated water emanating from the specific mining site to the surface water environment; and train all permanent and casual workers on environmental sustainability in mining areas of Gifurwe.

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