Environmental Friendly Mining Best Practices for Concessions around Gishwati, part of the Gishwati-Mukura National Park (GMNP)

FINAL REPORT

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ACRONYMS AND ABBREVIATIONS

As:	Arsenic
ASM:	Artisanal and Small-scale Mining
Au:	Gold
Cd:	Cadmium
CEC:	Cation Exchange Capacity
Cr:	Chromium
Cu:	Copper
DO:	Dissolved Oxygen
FHA:	Forest of Hope Association
GMNP:	Gishwati-Mukura National Park
LAFREC:	Landscape Approach to Forest Restoration and Conservation
LSM:	Large Scale Mining
MSM:	Medium Scale Mining
Nb-Ta:	Niobium-Tantalum
NGVDW:	Namibian Guideline values for Drinking Water
NISR:	National Institute of Statistics of Rwanda
Pb:	Lead
pH:	Hydrogen Potential
RDB:	Rwanda Development Board
REDEMI:	Régie d'Exploitation et de Développement des Mines
REMA:	Rwanda Environment Management Authority
Sn:	Tin
TDS:	Total Dissolved Solids

EXECUTIVE SUMMARY

Mining contributes to the socio-economic development not only at the local level by providing jobs and moderate income for the surrounding community but also at the national level as it significantly contributes to the gross domestic production (GDP). Furthermore, mining could potentially promote economy of scales. However, the present study revealed, from the case of Gishwati forest area, that mining also induces numerous negative environmental impacts on landscape, soil, water systems and on biodiversity in general context. This mining-environment nexus requires a well-defined framework that involves all concerned stakeholders to implement environmental friendly mining practices.

Gishwati forest is part of Gishwati-Mukura National Park created in 2015. The forest has had a long history of degradation due to human activities including mining. Many efforts were initiated by various governmental and non-governmental stakeholders, including Forest of Hope Association (FHA), in environmental protection and conservation of the forest. Though the illegal mining activities have been reduced, there are still some indications of negative mining impacts on landscape, soil and water bodies, which threaten both terrestrial and aquatic forest biodiversity. In this regard, this study was conducted to provide a baseline to better understand the impact of mining practices on biodiversity in Gishwati forest area and to develop environmental friendly mining best practices for mainstreaming biodiversity conservation in Gishwati Forest area.

Concerning the methodology, a desk review helped to understand the context of the study. Thereafter, a baseline study was conducted to assess mining impact on biodiversity through the analysis of vegetation, landscape, soil and stream water quality at the study area. Five mining sites were investigated through field observations of the landscape, physico-chemical analysis of water and soil (mine tailings) and vegetation inventory. Those sites are Nduruma, Ntobo, Masengati, Twabugezi and Kinyenkanda. The water physico-chemical parameters analysed included pH, Conductivity, Dissolved Oxygen (D.O), Total Suspended Solids (TDS) and Turbidity while the soil physico-chemical parameters analysed include pH, cation exchange capacity (CEC) and soil texture. Furthermore, the concentrations of metals/metalloids including As, Cd, Cr, Cu, Pb and Zn were measured in both water and soil (mine tailings). The findings from the baseline study have been fundamental to develop the mining best practices. They were complemented by the information from Focus Group Discussions (FGD) and Key Informant Interview (KII).

The baseline study revealed that mining activities have negative impacts on biodiversity of Gishwati forest area. From the five aforementioned studied sites, it has been observed that mining has accelerated the erosion, landslides and stream/river sedimentation and created new landforms. The most concerned sites are Kinyenkanda and Ntobo. The physico-chemical properties of mine tailings piled and scattered on mining sites are not conducive for biodiversity. The concentrations of metals/metalloids in the water and soil are generally higher on mining sites than the non-mined area. For example, Arsenic concentrations in the mine tailings of 187.03 mg/kg and 1.4.44 mg/kg respectively at Ntobo and Kinyenkanda are very high compared to 3.76 mg/kg of the control site of Kinihira and even higher than international standards of 30 mg/kg. Such high metal/metalloid

concentrations threaten both aquatic and terrestrial life. They have induced the extinction of 14 and 18 vegetation species at Ntobo and Kinyenkanda sites respectively. They may also cause toxicity and migration to a variety of animals living in Gishwati forest like the invertebrate (giant earthworm), the amphibians (Forest fogs), reptiles (eg. Great lakes bush viper, Ruwenzori three-horned chameleon), mammals (eg. Jackal, serval), chimpanzees, monkeys and birds because they cannot survive on the cleared ground. The present results serve as an alert and therefore appeal for urgent intervention to safeguard the biodiversity of Gishwati forest area. With this view, the mining best practices described below have to be taken into action properly.

For better protection of the landscape, there is a need to revegetate, refill excavated pits, control erosion and establish a buffer zone along streams and rivers in mining areas. Similarly, best practices for soil protection and conservation should include revegetation of bare lands, overburden and tailings. Erosion is to be controlled by constructing trenches or establishing a vegetation cover on bare lands where mining is no longer operational. Moreover, the overburden and tailings should be stored and disposed of in appropriate places to ensure the safety of agricultural soil. There is a need to conserve mined areas and water resources by avoiding pouring mine effluent and tailings in water bodies, construction of check dams and silt retention ponds to prevent silt runoff and deposits into watercourses. Furthermore, the revegetation of mined area should be considered to avoid and prevent flooding risk.

Overall, safeguarding biodiversity in Gishwati forest area entails rehabilitation of degraded mine areas to re-establish functional properties necessary for maintaining biodiversity, re-establishment of the vegetation cover to re-attract wildlife. There is a need to construct hard surfaces and artificial ponds to provide safe drinkable water for animals and birds. The living organisms in the area should be protected from noise disturbance produced by mining equipment. Finally yet importantly, monitoring and evaluation should be integral part of the implementation plan of the proposed mining best practices. This will help to assess the extent to which such practices have mitigated and prevented the negative impacts from mining activities in Gishwati area.

1. GENERAL INTRODUCTION

Presentation of Gishwati forest

Gishwati forest is part of Gishwati Mukura National Park (GMNP). It is a mountain rainforest lying on Congo-Nile watershed between 1° 36´52´´ and 1° 52´17´´ South and 29° 21'40´´ and 29° 28´50´´ East. It is located in Rutsiro district precisely in Kigeyo, Mushonyi, Nyabirasi and Ruhango sectors. Gishwati is home to important biodiversity including world-wide recognized species such as eastern chimpanzees, golden monkeys and mountain monkeys and other animals including serval, genet, African civet, side-striped jackal, Ruwenzori sun squirrel, frogs, Great Lakes bush viper, Chameleons, skinks, Giant earth worm. It also hosts more than 200 species of birds like Sunbirds, Turacos, Handsome francolin, Martial Eagle, Grey-crowned crane, etc. and a variety of flora, the main one being Carapa grandiflora "Umushwati", Symphonia globulifera "Umushishi", Giant tree fern "Igishigishigi".

Gishwati was established as natural reserve since 1930s when it was covering 700 km². It has been gradually destroyed up to 6 km² in 2002 (RDB, 2017). The restoration and conservation programmes have upgraded the forest up to 15.70 km² (REMA, 2014). In the same framework, the government of Rwanda gazetted the two forest patches Gishwati and Mukura as Gishwati-Mukura National Park by the law N^{o} 45/2015 of 15th October 2015 (Republic of Rwanda, 2016). However, all above-mentioned efforts of protecting and preserving GMNP are still challenged by artisanal mining activities inside the park and its vicinities.

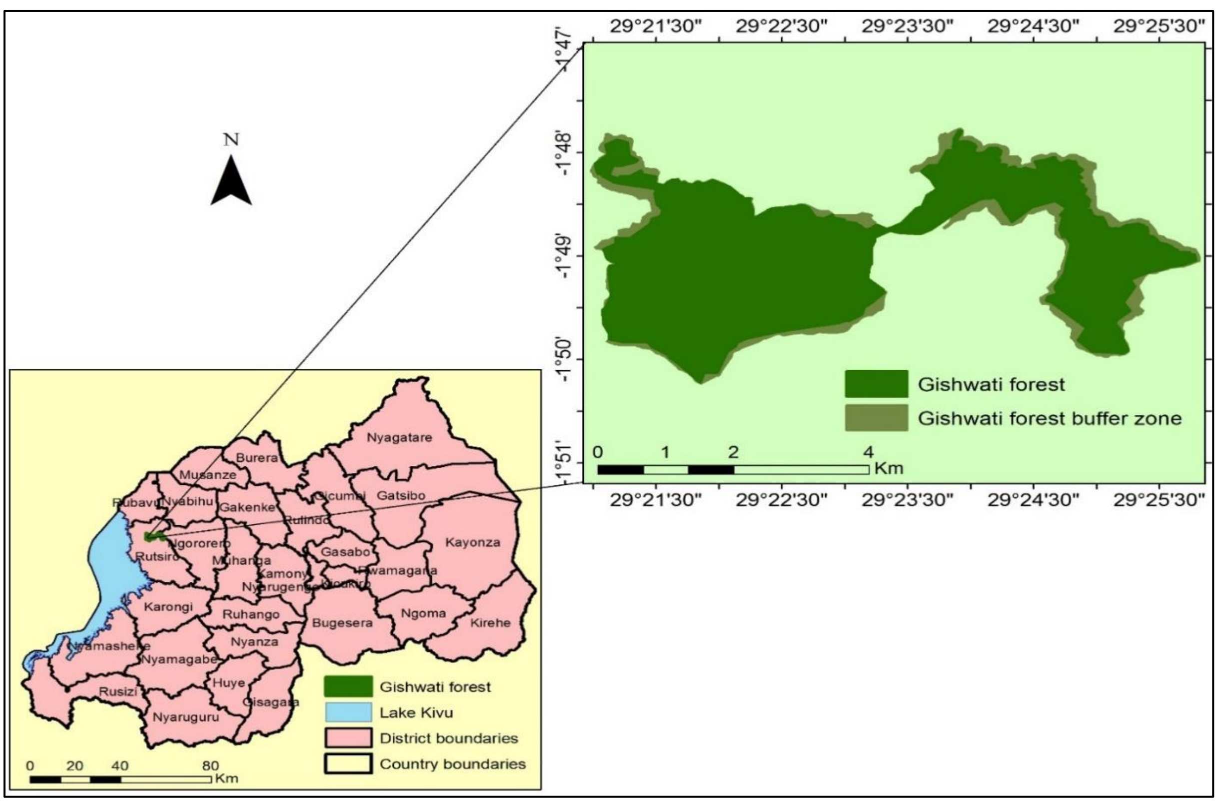


Figure 1: Location map of the study area

Mining and environment nexus in Rwandan context

Worldwide, mining has a big socio-economic impact by considering the employment and revenue it generates for both the population and the country (Bansah et al., 2016). The World Bank states that mining ensures the existence for millions of families in rural areas of developing countries, particularly the artisanal and small-scale mining sector. About 100 million people (workers and their families) depend on artisanal and small scale mining (World Bank, 2009). However, there is always a conflict of interest between mining as a key economic development sector and the environmental protection as a current national and global issue. Indeed, mining activities cause severe environmental effects including loss of biodiversity, soil erosion and pollution and contamination of surface and ground water. Environmental impacts of mining also have major repercussions on the surrounding population's health because of contamination caused by the leakage and fly out of chemicals (World Atlas, 2017).

Concerning the context of Rwanda, there are many mining sites scattered in the country and the presence of mined minerals depends on the type of the rock. Indeed, the geological perspective indicates that Rwanda is located on the western part of the renowned mineralisation zone. That is the northeastern Kibara belt of Pan-African age. It concentrates various minerals like tin (Sn), niobium-tantalum (Nb-Ta), tungsten (W) and gold (Au) which chiefly occurs in greisens, pegmatites and quartz veins interpreted to be related to the G4 granites (de Clercq et al. 2008; Dewaele, 2010). The figure below shows the distribution of minerals and mining sites.

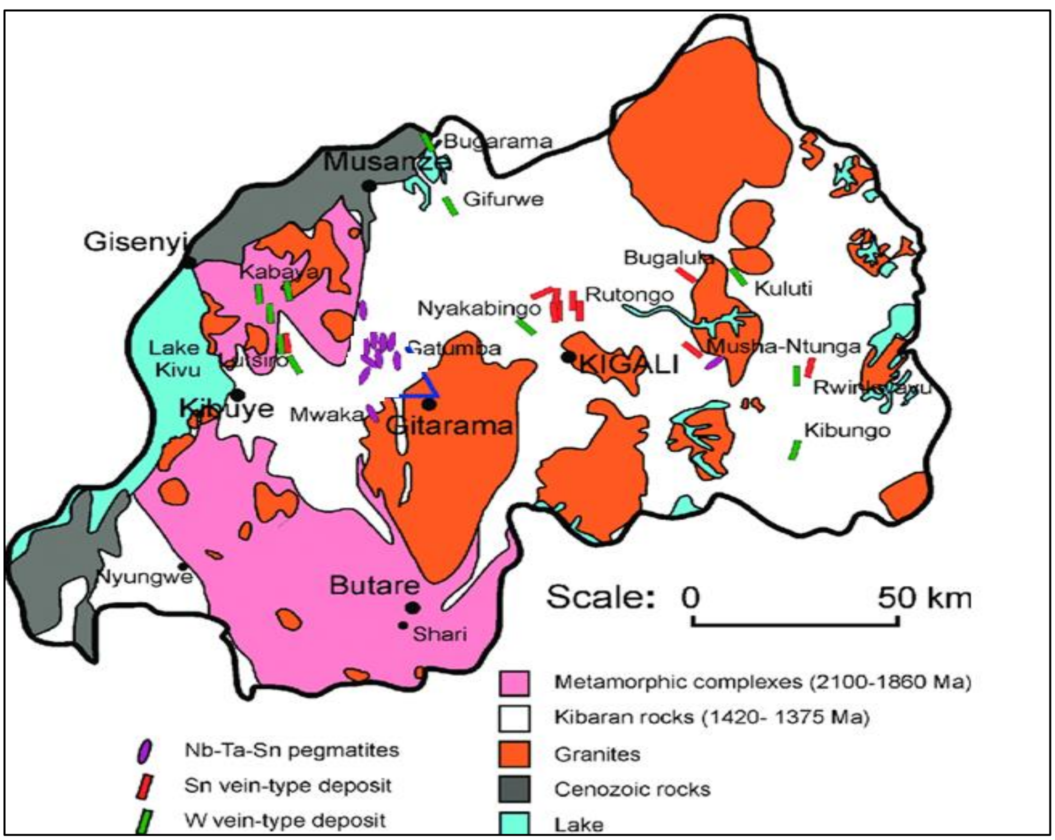


Figure 2: Mining zones in Rwanda

Currently the minerals being mined and traded are:

- The key minerals are cassiterite (a tin ore); colombo-tantalite (commonly called coltan - an ore that is the source of niobium and tantalum); wolfram (a tungsten ore); and Gold mined from Gicumbi, Nyamasheke, Rulindo, Rutsiro (including Gishwati area) districts, etc.
- Other minerals include ambrigonite, beryl and semi-precious stones such as tourmaline, topaz, corundum, chiastorite, amethyst, sapphires, opal, agate and flint.
- There are also various construction materials to use in their primary state or processed. They include amphibolites, granites and quartzite, volcanic rocks, dolomites, clay, kaolin, sand and gravel.
- Mining in Rwanda presents unexploited opportunities in ores, processing and diversification.

The Government of Rwanda is committed to develop the mining sector as one of the pillars of national economic development. It is with this regard that a strong and investor-friendly legal and policy framework has been put in place[1]. The current vision for the mining sector is to ensure the optimal and sustainable utilization of the mineral resources. Exploration works to identify and delineate more mineral deposits are still underway (MINIRENA, 2010).

Indeed, mining is the second largest export in the Rwandan economy. In 2017, the sector generated about $373.4 Million of foreign exchange. The mining sector provides income and employment to approximately 50,000 people (16% of which are women); 14,000 people are employed in quarries; 773 sites are under exploration and/or exploitation. Artisanal and Small-scale Mining (ASM) is predominant counting for around 80% of the mining activities of the country’s mineral production.[2].

Despite this remarkable importance of mining sector, there are still many persisting challenges. These include among others the difficulties to deal with taxes and to cope with price risks, the scarcity of locally and less expensive skilled workers, the persistence of some groups of illegal mines, the poor mining techniques and dead accidents of clandestine miners (IISD, 2017. Another and huge mining issue that even applies most in and around Gishwati Forest is the non-consideration of environmental requirements. This issue is related to the non-environmental friendly mining methods mainly used such as open cast and underground mining. These methods are associated with alluvial mining, which leaves mineral residuals in the water. An environmental impact of mining starts by degrading the natural site through informal prospecting and mining with simple handheld tools. The process involves cutting vegetation, digging pit, trenching, dredging, panning and sluicing. This causes land degradation, water pollution and loss of biodiversity while there is no appropriate mechanism for site restoration as well as a systematic or sustained rehabilitation plan.

Mining situation in Gishwati

[1] http://rdb.rw/investment-opportunities/mining/

[2] https://waterportal.rwfa.rw/sites/default/files/inline-files/Towards%20sustainable%20mining.pdf

The mining context in Gishwati natural forest reflects all the aforementioned mining issues.

Figure 3: Landscape degradation and silted river by mining activities, Nduruma site, inside Gishwati forest

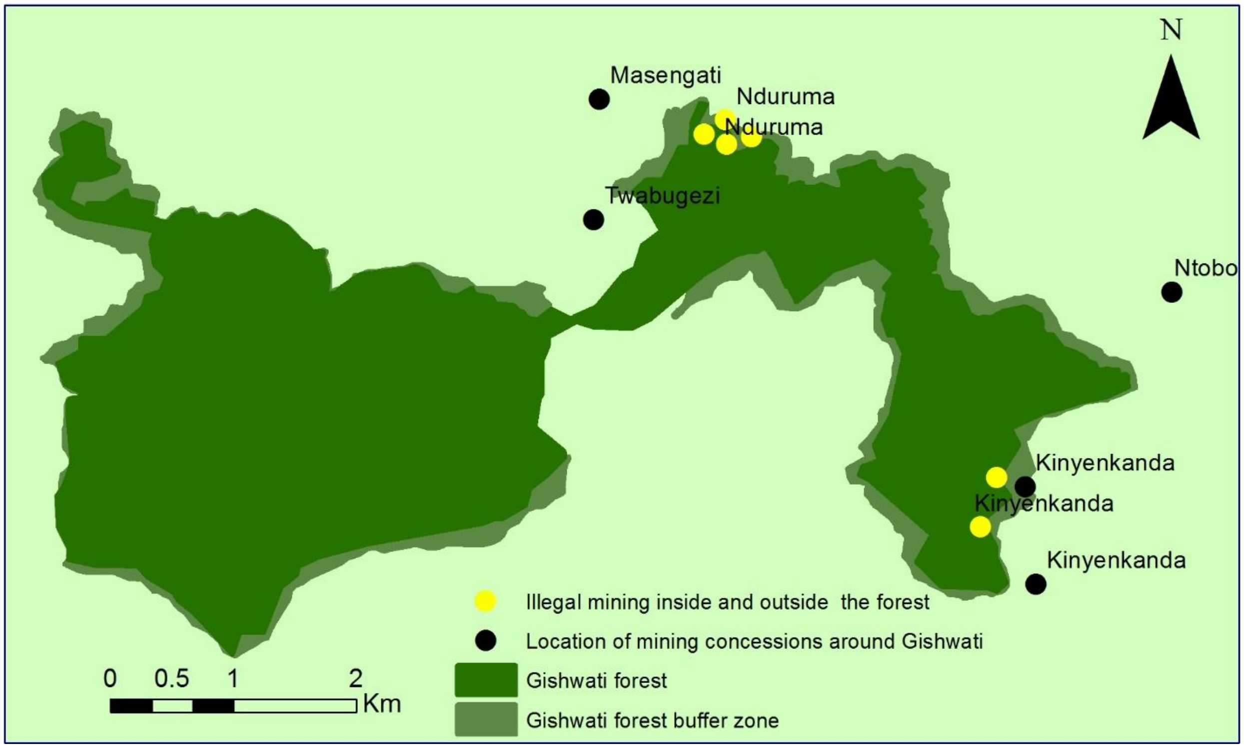


Figure 4: Sampled sites

Mining activities in Gishwati started late in 1980s by REDEMI (*Régie d'Exploitation et de Développement des Mines*). REDEMI was replaced by NRD mining company operating in the vicinity of Gishwati, in the side of Kinyenkanda but stopped in 2015 because of the shortage of minerals. Twabugezi Mining Company that was operating in Twabugezi area closed also for the same reason. Two other companies namely NYAMICO and UMURAGE Mining were created in the same concession. They closed in 2018 because of working without official Licenses and proof of Environment Impact Assessment. The mining concessions in Gishwati are currently and legally under exploitation of DEMIKARU (Developpement Minier Kanama Rubavu) working on the part of Nyabirasi (in Rutsiro) and Kanama (in Rubavu), TMT (Tantalum Mineral Trading) operating at Ntobo zone and Munyaneza Mining Company Ltd that started to operate in 2017 in the vicinity of the forest at Kinyenkanda site. However, despite the presence of these legal companies, there are still numerous illegal mining activities that bitterly affect the natural forest of Gishwati and the water of Sebeya River.

In 2014, the Government of Rwanda has set up a taskforce to review mining activities in Gishwati and Mukura landscape and harmonize them with conservation efforts initiated by Landscape Approach to Forest Restoration and Conservation (LAFREC) project. The latter project aimed at promoting sustainable mining practices and curtailing the negative impacts of illegal mining within and around Gishwati-Mukura National Park. However, a non-environmental friendly mining remains a serious issue threatening the forest biodiversity and its surroundings that draws attention of the forest protection stakeholders, mainly the Forest of Hope Association (FHA). This issue called upon this study to develop an environmental friendly mining best practices for concessions around Gishwati forest area.

Objectives of the study

The main objective of this study is to provide a baseline to better understand the impact of mining practices on GMNP biodiversity and to develop environmental friendly mining guidelines. More specifically, it is targeting to:

- Assess mining impact on landscape, water quality and vegetation in Gishwati forest area;
- Propose the appropriate mechanism to mainstream biodiversity conservation around mining concessions in the vicinities of Gishwati Forest;
- Develop environmental friendly mining best practices for the Gishwati area concessions and train local mining companies in its implementation.

2. DATA AND METHODS

The methodology applied to have a clear picture of artisanal mining activities taking place at the concessions around Gishwati forest and thereafter to suggest the appropriate mining best practices includes the following four techniques: Desk review of key documents, the Baseline study, the Focus Group Discussions (FGDs) and Key Informant Interviews (KII).

2.1. Desk review

The desk review was done by consulting the books, reports, journals, papers, maps and other relevant documents related to the topic under investigation. The basic documents sourced include but not limited to: Mining and quarrying code of practice, Mining safety standards; Mining and quarrying law, 2018; Gishwati-Mukura National Park ten years management plan and three years action plan; Environmental monitoring of small-scale mining areas in Rwanda; Effects of heavy metals on soils, plants, human health and aquatic life, among others.

2.2. Focus Group Discussions (FGDs)

Two Focus Group Discussions (FGDs) were held with selected people involved in mining activity including miners and their leaders selected from each mining site. They were conducted at the FHA Headquarter. Each group was made of eight participants. The discussions helped to apprehend the level of understanding of the impacts of mining on water, soil, vegetation and landscape and to assess the knowledge of miners on the needed best practices to undertake at the mining sites.

2.3. Key Informant Interviews (KII)

Key informant Interviews were mainly targeting experts with deep understanding of mining activities in Rwanda and specifically in Gishwati concessions. This group includes, mining field supervisor and Mining officer in Western Province respectively from Rwanda Mining Board (RMB) and Rutsiro district; experts from Rwanda Environmental Management Authority (REMA) in charge of LAFREC project and the officer in charge of mineral environmental protection from Rwanda Standards Board (RSB). Furthermore the interviews were sought and conducted with the Environment Impact Assessment Specialist and Environmental Protection Specialist from Rwanda Development Board (RDB) and Ministry of Environment (MOE) respectively. All of them have hands on experience and thorough understanding of mining activities taking place in Gishwati concessions.

2.4. Baseline data

The elaboration of environmental friendly mining best practices for concessions around Gishwati forest required a prior analysis of the environmental impact assessment of mining on biodiversity and stream water quality at the study area. The methodology and the findings that fed this document of friendly mining best practices are summarized in this sub-section.

2.4.1. Selection of sites

The present study focuses on mining sites located around the Gishwati forest. Five operational sites were selected for soil and water sampling, and for vegetation analysis (Table 1). These sites are owned and managed by private companies which use artisanal mining methods and mineral extraction techniques. Mined minerals mainly include coltan, tin and wolframite.

Table 1: Information on sites of study

Mining sites	**Extracted minerals**	**First year of mining**	**Status**	**Current Owner company**
Nduruma	Coltan	1995	Active: legal outside and Illegal inside the forest	NyamiCo Ltd
Ntobo	Coltan, Tin and Walframite	Before 1994	Active	TMT (Tantalum Mineral Trading)
Masengati	Coltan	1995	Active	NyamiCo Ltd
Twabugezi	Coltan	1995	Active	Illegal mining
Kinyenkanda	Coltan and Tin	Before 1994	Active: legal outside and illegal inside the forest	Munyaneza Ltd

The field visits have led to the decision to investigate all sites in the study and in order to take into account differences concerning physical characteristics, extracted minerals, and proximity to the forest and water streams. Four of the sites are owned by registered private companies whereas one site (Twabugezi) does not have a legal owner, and therefore it qualifies for illegal mining. Illegal mining is also observed along the Sebeya River which is one of the river flowing across the Gishwati forest. At two sites such as Kinyenkanda and Nduruma, mining has encroached on the protected forest area. Though, mining inside the forest is prohibited and illegal, there are some indices that it is still being carried out in clandestine inside the forest at these two sites (i.e, Kinyenkanda and Nduruma).

2.4.2. Studied parameters

Mining activity affects both living and non-living components of the ecosystem. Non-living components do support life; therefore, any detrimental effects on them would directly jeopardize biological processes and living organisms. It is against this view that the present study focuses on investigation of the quality and status of water, soil and vegetation in mined sites.

- **Water**

The extraction of minerals requires the use of much water. In artisanal mining, the used water, commonly known as mined water is directly poured into the environment and it ends up by joining natural surface water channels. Yet, it is well known that mineral residues, which can modify water characteristics, contaminate water in the area. Moreover, polluted water compromises aquatic life especially animals; those either living in or drinking the water. Therefore, we have measured the potentially toxic metals and metalloids to evaluate the impact that mining would have on aquatic life. Not all of them have been measured, but the ones which commonly and globally threaten the ecosystems in mining environment, namely Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb) and Zinc (Zn). Moreover, the physico-chemical characteristics of any water bodies change when mined water reaches and mixes with them. As far as the water quality is concerned, the physico-chemical parameters which are commonly assessed include pH, conductivity, Dissolved oxygen (DO), Total Dissolved Solids (TDS) and Turbidity (Nukpezah et al., 2017). The Table 2 summarizes the potential harmful effects of measured parameters when they have exceeded their normal concentrations and/or values.

Table 2: Measured parameters and their potential harmful effects

Measured parameters	**Potential harmful effects**
pH	Low pH (<6.5) increases dissolution of metals and metalloids in water,
Conductivity	Values outside of a normal range (100-2000 µS/cm) can result in fish kills due to changes in dissolved oxygen concentrations, osmosis regulation and TDS toxicity
D.O	Ideally, surface stream water DO should be 90-100%. Low DO (<40%) affects respiration of aquatic organisms, increase fish mortality
Total Dissolved Solids (TDS)	High TDS decreases light penetration, reduces oxygen dissolution, decreased photosynthetic activity, increases metals and metalloids attachment.
Turbidity	High turbidity renders water dirty, increase water temperature, reduces light penetration and photosynthetic activity
Metals and metalloids (As, Cd, Cr, Cu, Pb & Zn)	High concentrations have devastating effects into ecological balance; induce stress in aquatic organisms; limit and reduce aquatic diversity; can accumulate into aquatic organisms and be transferred into food chain; and they increase susceptibility to fish diseases and mortality

- **Soil**

Soil is the substrate for all living organisms and for man-made objects. Soil chemical composition determines its fertility as well as the type of plants that can grow and get adapted to the soil. The vegetation cover stands as a natural buffer zone against downstream erosion. However, mining activity modifies both physical and chemical characteristics of the soil. More specifically, long-term mining contaminate and pollute the soil. Many animals and plants can be affected by these changes in soil chemical composition either by losing their habitats (niche shift) or by suffering from detrimental effects on their physiology.

The chemical analysis of the soil could allow answering the following key questions: - Could mining tailing support plant growth? Could mining tailing contribute to the stream/river water contamination by potentially toxic substances, especially metals/metalloids? Like in water, the potential toxic metals and metalloids have been measured. Moreover, some of the important soil physico-chemical characteristics including pH, Cation Exchange Capacity (CEC), and soil texture were measured. The table 3 summarizes the effects of measured soil parameters and their potential effects when modified from their normal values.

Table 3: Measured parameters and their potential harmful effects

Measured parameters	**Potential harmful effects**
pH	Normal range: 6.5-7.5. Higher than 8 becomes alkaline. Availability of nutrients/minerals decreases, hence slow plant growth. Below 6 to 5, availability of nutrient increases together with potentially toxic metals which can inhibit plant growth. Below 5, the soil is acidic; soil microorganisms hardly growth and only adapted plant species can growth.
Cation Exchange capacity	Normal ranges: 5-16 mol/kg. Below this range, the soil is less fertile, little essential mineral content, decreased plant growth and productivity
Soil texture	-Normal range: 20-45 %. Above this range, there less water retention, not vegetation growth, few microorganisms. - Normal range: 15-25%: The values higher than this range result into water logging, reduced aeration, and stunted plant growth.
Metals and metalloids (As, Cd, Cr, Cu, Pb & Zn)	- Metal and metalloid contamination exerts toxic effects on soil microorganisms and invertebrates. - It inhibits bacterial growth, affects earthworm life cycle, results into changes of the diversity and population size. - Contamination also decreases the number and activity (respiration rate, enzyme activity) of microorganisms. - Contamination results into accumulation of metals and metalloids into plants with a higher risk of transferring these accumulated elements into the food chain from soil to plants to animals and humans. - Toxicity to plants results into chlorosis, stunted plant growth, yield depression, reduced nutrient uptake, and delayed seed germination

- **Vegetation**

One of the most obvious mining impact is the change in the physical appearance of the environment by complete or partial destruction of the vegetation. Indeed, the creation of mine pits, the accumulation of mine tailings, the erosion, etc., results into some removal of some plants species. To appreciate the impact of mining on plant diversity, plant species inventory has been conducted on selected sites, namely Kinyenkanda and Ntobo.

- **Landscape analysis**

The change in the landscape appearance is the most obvious impact due to mining activities. During the study, landscape have been given due importance. Each site was visited to observe and analyse the morphological change in the landscape. To keep and analyse the observation records, photographs were taken during field observation for further analysis. Moreover, some photographs previously taken by FHA staff were referred to so as to connect current and past information about the sites.

2.4.3. Sample collection and analysis

- **Water**

Two samples of water were collected from each site using polyethylene bottles (500mL). One sample was immediately used to measure physico-chemical characteristics and was not acidified. The other sample was immediately acidified with nitric acid (10%) in order to avoid further modification of the chemical composition during preservation period prior to analysis.

The physico-chemical parameters of water were measured using portable devices: Digital TDS meter for TDS, Digital D.O meter for DO, Digital Turbidity Meter (range 0-100 NTU) for Turbidity, Mettler Toledo AG (Seven Easy conductivity) for conductivity and Mettler Toledo AG (SevenEasy pH) for pH. Metals/metalloids were measured using Atomic Absorption Spectrophotometry (AAS).

- **Soil**

Collected soil mainly consisted of superficial mine tailings left after mineral extraction. From each of the five mining sites, one sample (0.5–1 kg) was collected and transported in polyethylene sacs. A control soil sample was also collected from an area which was not affected by mining and/or which has not been in contact with mine tailings. Such a soil would serve to measure the mining impact and/or deviation from normal soil characteristics. The samples were dried at room temperature in laboratory, ground and passed through a 2-mm and 250 µm sieves.

The soil particle size distribution (soil texture), the pH, the cationic exchange capacity (CEC) were determined on soil samples sieved to 2 mm. The metal and metalloid concentrations in samples were measured from soils sieved to 250 µm.

The particle size distribution was determined by sedimentation and sieving after destruction of organic matter by H_2O_2. The pH (H_2O) was measured after stirring a mixture of soil and deionized water (1:5, v/v). The CEC was determined after percolation of CH_3COONH_4 (1M, pH=7) solution into soil samples followed by an extraction of ammonium ions (NH_4^+) with sodium chloride (NaCl, 1 M). The pseudo-total Cd, Pb and Zn concentrations were determined after acid digestion in aqua regia (HCl:HNO_3, 3:1 v/v, 6 mL) of 300 mg of soil using the digestion block at 95°C for 75 min. After cooling, the volume was adjusted to 25 mL with distilled water and the solution was filtered (0.45 µm cellulose acetate filters). Metal and metalloids were then determined by atomic absorption spectrophotometry (AAS).

- **Vegetation**

Plant specimens were collected through transects and quadrats with the main purpose to investigate the diversity of plants on some selected mining sites (White and Eduards, 2000; Braun Blanquet, 1932). Two transects of one 200 m were used in each selected sampling point per site. On each site, one transect was located in mining area whereas the other one was located in an area which has not been physically affected by mining activities. On each transect, a distance of 20 meters was selected as a sampling unit, leaving at least a distance of 4 meters from the edge, to avoid edge effects. In each sampling unit along the transect, a quadrat of 1 meter square was sampled. Names of plants were immediately noted down. Plant species which could not be identified immediately were collected and preserved in papers and then transported to the laboratory. They were then analyzed to species level by the use of dichotomous keys in the literature (Troupin, 1985, 1987).

2.4.4. Data analysis

Both primary and secondary data were collected. Primary data were obtained by conducting field observations and analyzing collected samples from mining sites. The measured water and soil parameters were presented in tables and figures to assess their general trends.

A comparative approach has been adopted to describe and explain the similarities and differences between all data obtained from mining sites and the control one. The control site will serve as the benchmark to analyze how mining affected or could affect both aquatic and terrestrial biodiversity in our studied area of Gishwati. However, we will also compare our results with other existing values to have a general view and know at which extent are our cases. In that perspective, we referred to the Namibian Guideline Values for Drinking Water (NGVDW) (Table 4) and the international and selected countries maximum allowable standards of metal concentrations in the soil (Table 5).

Table 4: Framework for interpretation of results on water quality assessment

Namibian Guideline Values for Drinking Water	**pH**	**EC** (µS/cm)	**As** (µg/L)	**Cd** (µg/L)	**Cu** (µg/L)	**Pb** (µg/L)	**Zn** (µg/L)
Group A: excellent quality	6-9	1500	100	10	500	50	1000
Group B: acceptable quality	5.5-9.5	3000	300	20	1000	100	5000
Group C: low health risk	4-11	4000	600	40	2000	200	10000
Group D: high health risk	4-11	4000	600	40	2000	200	10000
Austria Standards for Agriculture			100	10	200	5000	2000
East African Standards (1st Edition, 2000)			50	5	0	50	
Limits for Toxic Substances in Drinking Water					1000	0	
Aesthetic Quality	6.5-8.5				1		

Source: [1]Haidula *et al*., 2011

Table 5: International maximum allowable standards of metal concentrations (mg/Kg) in the soil

Country/Region	**As**	**Cd**	**Cr**	**Cu**	**Pb**	**Zn**
Canada[1]	12	10	-	63	140	-
Germany[1]	50	20	350	200	1000	600
Austria[2]	50	5	100	100	100	300

Europe[2]	-	3	150	140	300	300
Worldwide[3]	30	2.7	530	70	70	220

Source: [1]Haidula *et al*., 2011*;* [2]Maleki *et al*., 2014; [3]Kabata-Pendias and Pendias, 2001.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical characteristics of water

Water samples were collected from five mining sites namely Nduruma, Ntobo, Masengati, Twabugezi 1 and Kinyenkanda 1 and from a control area, Kinihira. Then the following parameters were measured from sampled water: pH, Electrical Conductivity, Dissolved Oxygen (DO), Total Dissolved Solids (TDS) and Turbidity (NTU). Apart from D.O, the values of all other measured parameters generally reflect the negative impact of mining in Gishwati forest area.

The measured pH was plot on pH scale or chart numbered from 1 to 14 to be able to interpret the results. Numbers from 1 to 6.9 indicate acidity while numbers 7 shows neutral state, then numbers 8 to 14 indicate alkalinity. The figure below presents the pH values of the sampled water at selected sites.

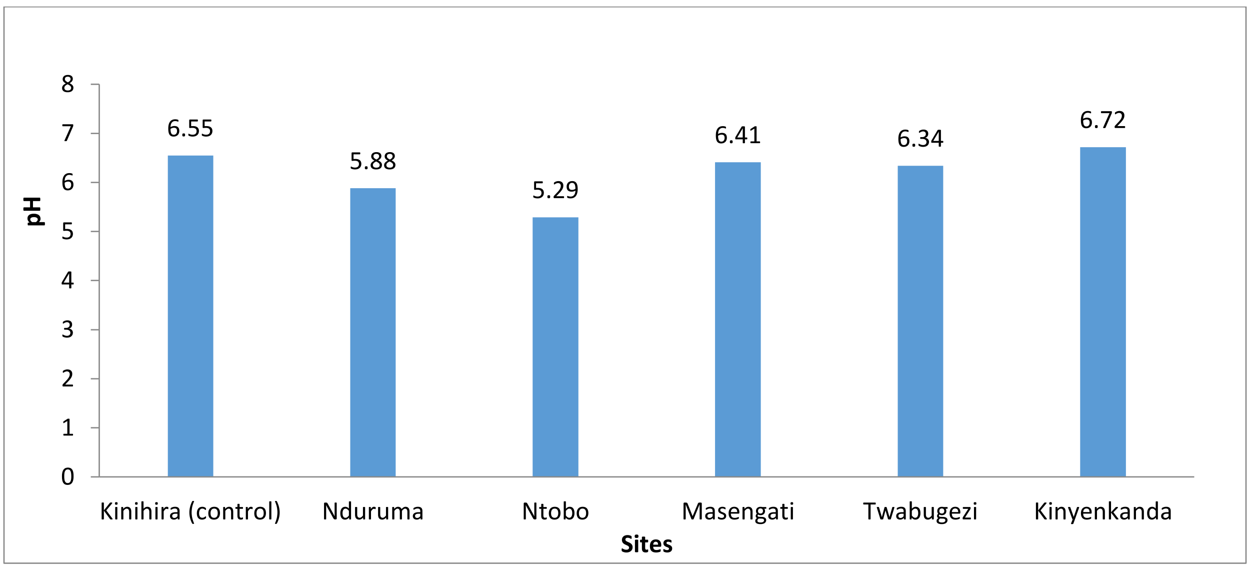


Figure 5 : pH values of sampled sites

The figure above depicts that pH values of sampled water vary between 5.29 and 6.72 which make them to be slightly acid but near to the neutral. Apart from the water collected from Ntobo site with pH (5.29) falling into group C of the NGVDW (Low health risk) and Nduruma falling into group B (acceptable quality), the remaining sites have pH oscillating between 6.34 and 6.72 which falls into group A of the NGVDW (excellent quality). The pH values show that the stream/river water from mining sites is still having a good quality in general. However, there is a need to put a special attention and control on the quality of water in two sites namely Ntobo and Nduruma to avoid further degradation and detrimental effects on physiological processes and reproduction of aquatic biota such as invertebrates and vertebrates, notably fish and frogs.

The Electrical conductivity (EC) in µS/cm of sampled water is presented in the figure below.

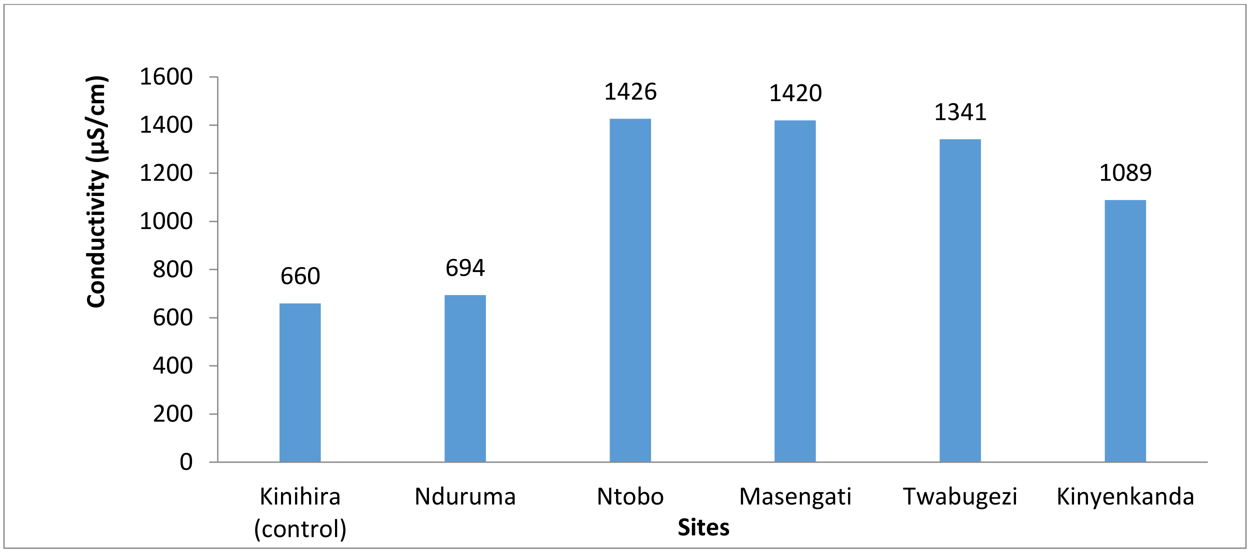


Figure 6: Electrical conductivity of sampled water

The EC of sampled stream/river water oscillates between 660 µs/cm and 1426 µs/cm. The analysis reveals that all sites have values that fall within the frequent range (100-2000 µs/cm) and also below the guideline limit values (1500 µS/cm) which make them to fall into Group A of NGVDW (excellent quality). The low values of EC are found at Nduruma (694 µS/cm) which are almost similar to the measured values at control area of Kinihira (660 µS/cm). The remaining sites have values varying between 1089 and 1426 µS/cm which are below also the guidelines limit value of 1500 µS/cm (Haidula, et al., 2011). The electrical conductivity of the water is still acceptable referring to these external standards but the real impact of mining is remarkable as we can see that the measured EC at all mining areas is above the value obtained from control area of Kinihira. The increasing conductivity on the mining sites will interfere with life processes and exacerbate toxicity of dissolved elements including heavy metals and metalloids in the water. The contaminated water will be toxic to developing animal embryos and will be harmful to adult mammals and birds which drink it.

The measured dissolved oxygen in percentages is presented below. The analysis of dissolved oxygen of the sampled water gave the values oscillating between 92.3% and 94.6%. These values are in the same range with the water collected from control area (Kinihira). The good quality of water in terms of DO could be explained by the fact that it was sampled from shallow and constantly flowing streams. This suggests that there is no water layering and the constant movement allows penetration and dissolution of air. Moreover, there was no decaying materials nor plant growing inside which could decrease the oxygen content.

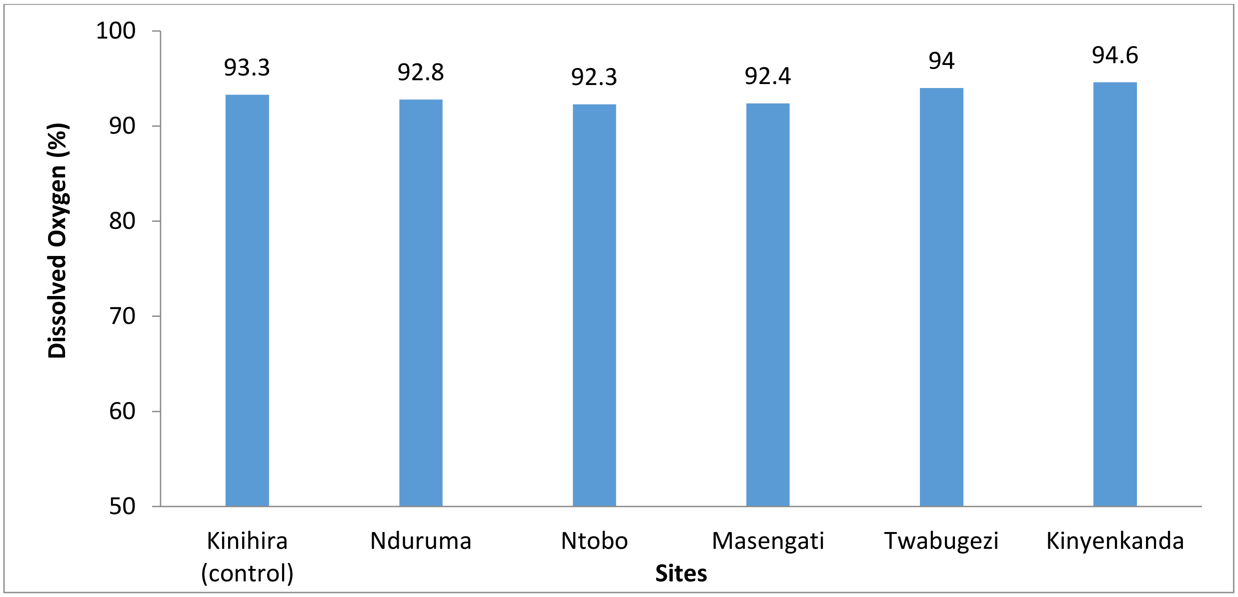


Figure 7: Dissolved Oxygen (%)

Total dissolved solids (TDS) measurements are presented in the figures below. Usually, TDS comprise inorganic elements (eg. calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water.

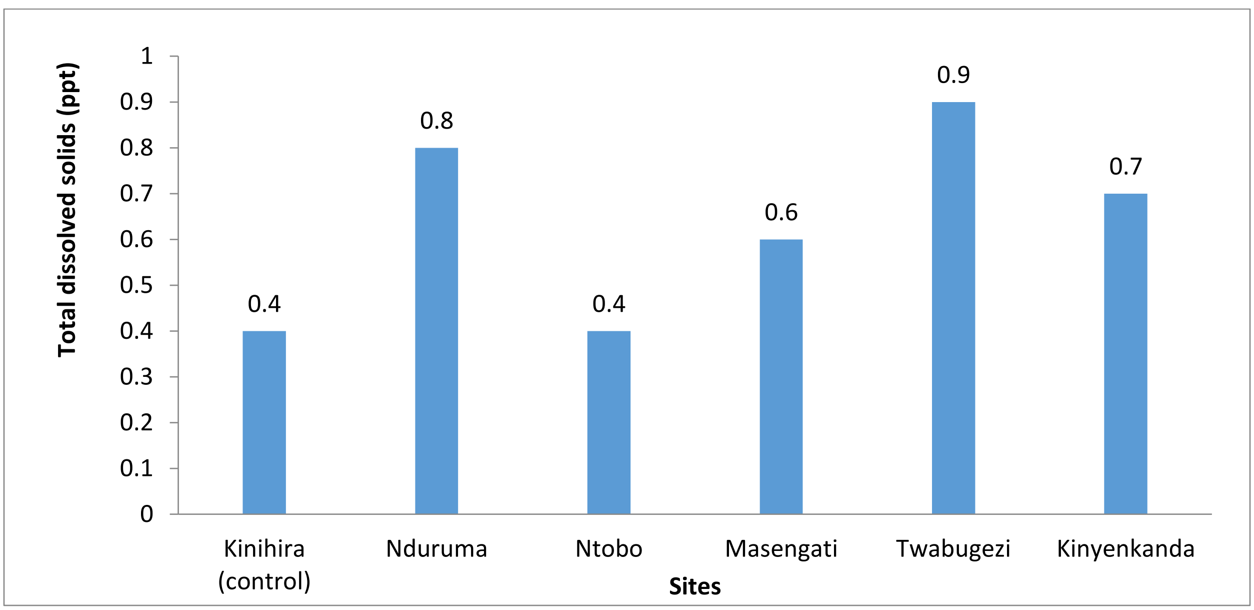


Figure 8: Total Dissolved Solids (ppt) at sampled sites

The measured TDS in the water ranges between 0.4 and 0.9 ppt. At Ntobo site, TDS isthe same rate as the water collected from Kinihira (control site) which implies the absence of influence of mining activities on this site. However, more influence of mining on solid dissolution in the water is observed at Twabugezi and Nduruma with 0.9 and 0.8 ppt respectively. These values are higher than 0.5 ppt (or 500 ppm) fixed by Bureau of Indian Standards (BIS) as the upper limit of TDS for drinking water[3]. The increasing trend of TDS on mining sites will result into reduce light penetration and oxygen. This will negatively affects aquatic animals but also plants. For the latter, especially algae, photosynthesis and growth will be impaired. Low algal productivity will reduce food for microorganisms and invertebrates which serve as food for higher organisms in aquatic ecosystems, and thus affects negatively the biodiversity.

The results from Turbidity (NTU) analysis are presented in the figure below.

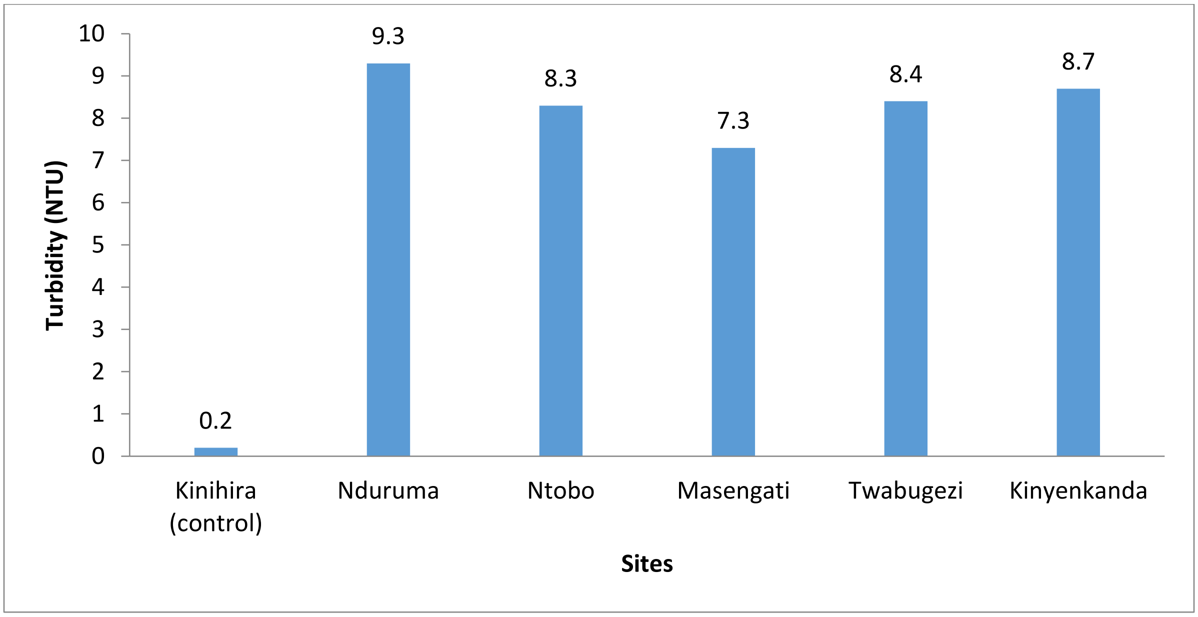


Figure 9: Turbidity (NTU) at sampled sites

This figure above reveals a high turbidity rate of water of between 7.3 - 9.3 NTU at sampled sites compared to the control area of Kinihira (0.2 NTU). These results show very high turbidity rates at all mining sites as many drinking water utilities strive to achieve levels as low as 0.1 NTU. The European standards for turbidity state that it must be no more than 4 NTU. The World Health Organization, establishes that the turbidity of drinking water should not be more than 5 NTU, and should ideally be below 1 NTU[4] This shows a high influence of mining activities on the water turbidity of mining areas of Gishwati. Through direct observation, it can also clearly seen that the mining activities have increased the turbidity of water of surrounding area as it can be observed on the photographs below.

Like TDS, higher turbidity will negatively affect light penetration and the algal growth in the water. Higher turbidity also increases water temperature and this will affects oxygen dissolution. All these consequences create unfavorable living conditions and probably reduce the aquatic biodiversity.

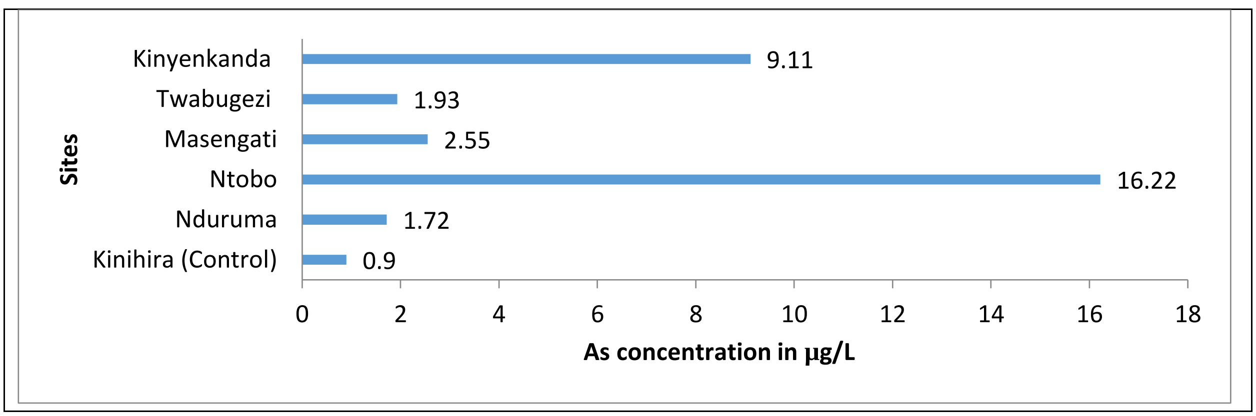
[3] https://www.google.com/search? =dissolved+solids+in water, 2018.

[4] NTU (https://en.wikipedia.org/wiki/Turbidity, retrieved on 8/11/2018).

Figure 10: A photograph showing the water turbidity at selected sites

3. 2. Concentration of heavy metals and metalloids in stream water

The elements of concern, such as heavy metals and arsenic, enter into the stream especially in two ways; either directly in suspension as solids or dissolved in water. When contaminants enter course, a number of reactions take place which result into contaminants in form of either settling, adhering or adsorbed on the sediment particles. These reactions are dependent on the physico-chemical conditions of the aqueous environment, the characteristics and types of trace metal of concern (Parizanganeh, 2008). Changes in the conditions of deposition, result in the release of heavy metals back into the water column. Indeed, low pH, textural characteristics, mineralogical composition and organic matter content of the sediments, amongst others, determine the metal concentration of sediments (Parizanganeh, 2008). In that regards, arsenic (As) along with the following metals were measured: Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb) and Zinc (Zn) and the obtained results are summarized in the figures presented below.



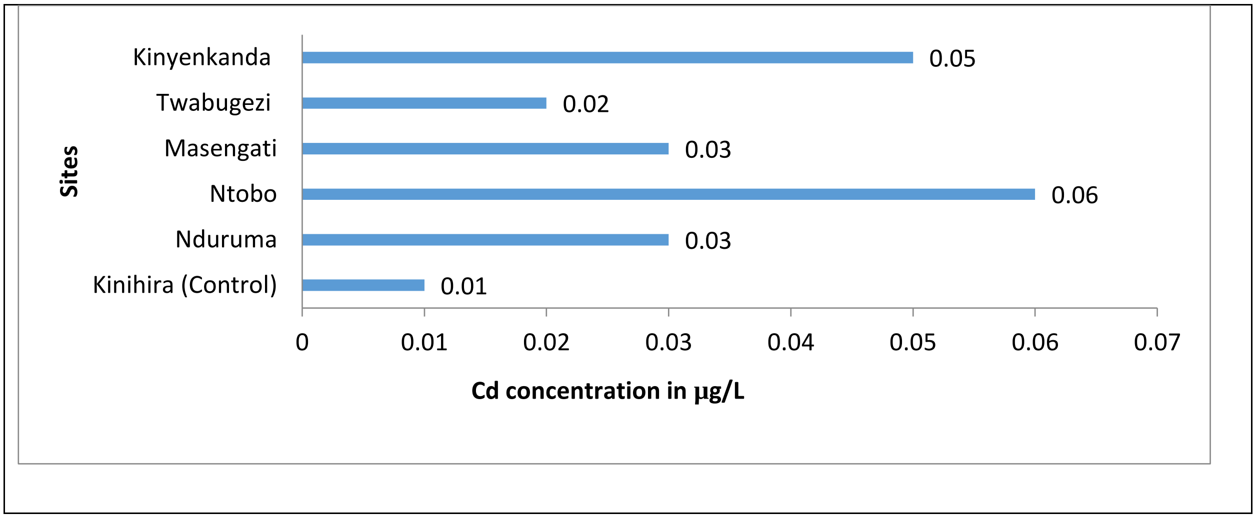
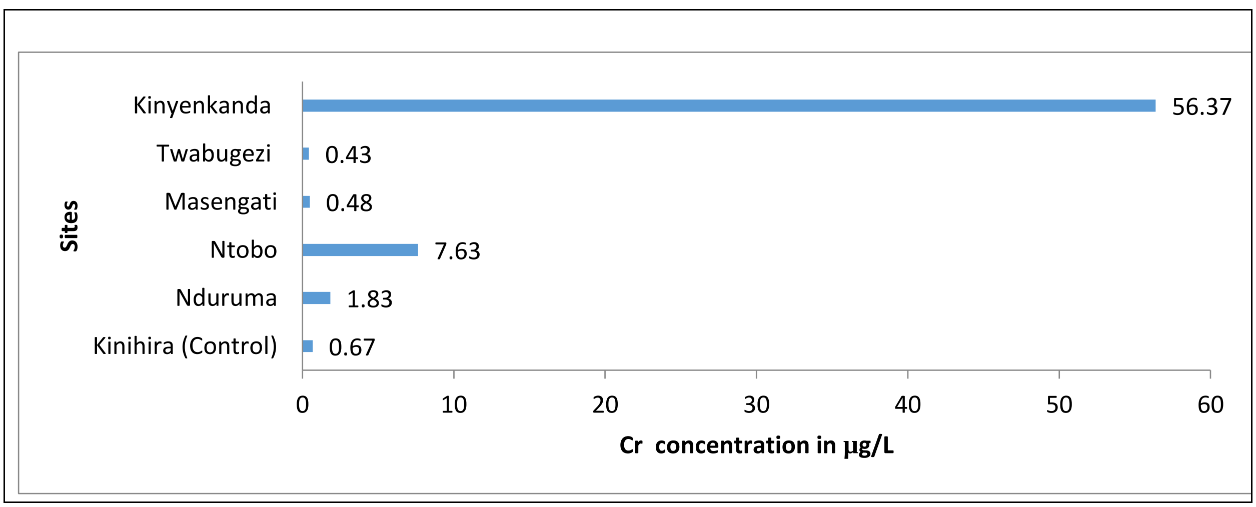


Figure 11: Concentration of Arsenic and Cd at study area

The Arsenic (As) concentration and Cadmium (Cd) vary between 0.9 – 16.22 and 0.01 – 0.06 µg/L respectively. Both As and Cd concentrations at all sampled sites fall in group A of DNGVDW (Excellent quality) as faras the measured Arsenic and Cadmium values are under 100 µg/l and 10 µg/L respectively. However, the measured values of arsenic from mining sites (between 1.72 µg/l - 16.22 µg/L) are higher than the value of 0.9 µg/L obtained from control area (Kinihira). The same applies for Cadmium because the lowest value (0.01 µg/L) was measured from control site (Kinihira). It is important noting that Ntobo site have the highest values of both Arsenic and Cadmium followed by Kinyenkanda. All these confirm the contribution of mining activities in increasing the quantity of As and Cd in the study area. Animals, especially small mammals and birds living in Gishwati forest will likely uptake these toxic elements while drinking the water. On long term, these elements will accumulate in their body which will negatively affects physiological processes and reproduction, hence increased morbidity and progressive reduction of this animal population size.



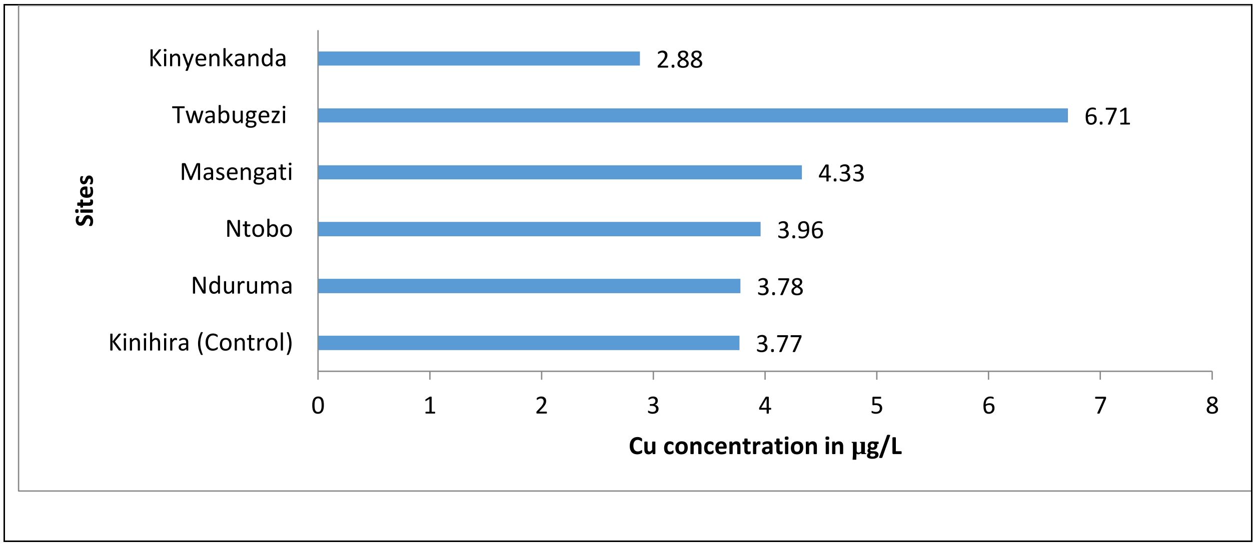
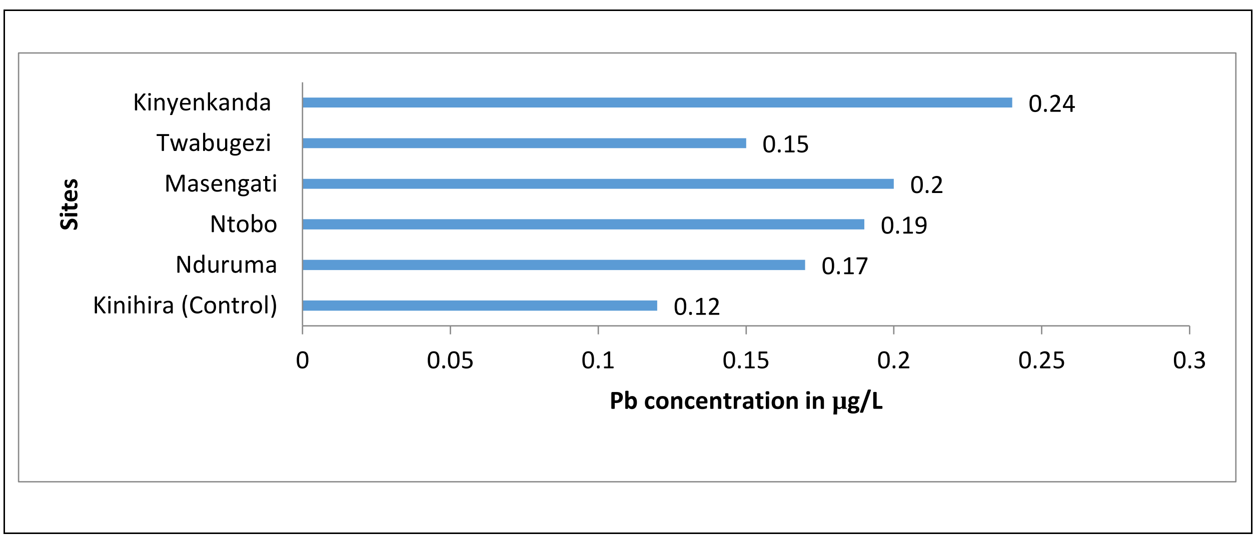


Figure 12: Concentration of Cr and Cu at study area

The Cr concentration is highly varying at study area as it is increasing from 0.43 at Twabugezi 1 site to 0.48 µg/L at Masengeti to become 1.83 µg/L at Nduruma and 7.63 µg/L at Ntobo to culminate to 56.37 µg/L at Kinyenkanda. Cr concentration (0.67 µg/l) at control area of Kinihira is closer to that of Masengeti. Kinyenkanda site which showed a very high concentration of Cr has the lowest Cu concentration of 2.88 µg/L followed by the control area (Kinihira) with 3.77 while the highest concentration of 6.71 µg/L was seen at Twabugezi. These concentrations are very low to 500 µg/L minimum standard concentrations provided by NGVDW and show the excellent quality of water in terms of its copper concentration but a special attention is to be focused to the site of Twabugezi for Cu and Kinyenkanda for Cr.



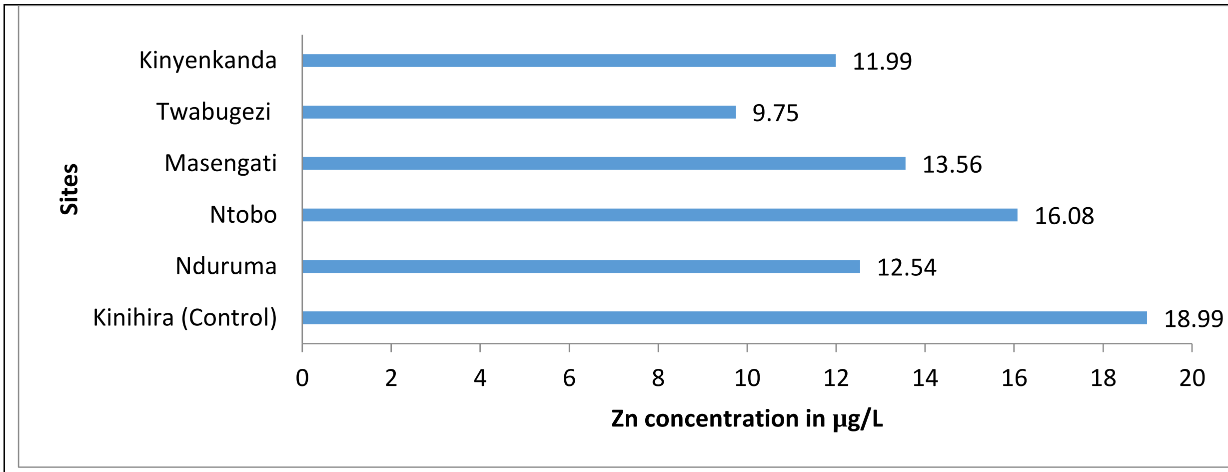


Figure 13: Concentration of Pb and Zn in sampled water

Lead (Pb) concentrations at the study area vary between 0.12 µg/L at control area (Kinihira) and 0.24 µg/L at Kinyenkanda. It was evaluated at 0.12 µg/L, 0.15 µg/L, 0.17 µg/L and 0.19 µg/L for Kinihira (control area), Twabugezi, Nduruma and Ntobo sites respectively and it raised to 0.2 µg/l and 0.24 µg/L at Masengati and Kinyenkanda respectively. This means that there is no significant difference between control area (Kinihira) and the mining areas as far as the highest range in Pb concentration is only 0.12 µg/L. Furthermore, Pb concentration at all sampled sites is very low to 50 µg/L considered as minimum acceptable concentration for drinking water. Hence, the measured Pb concentration at control area and mining areas is not yet harmful to the plant and animal life.
For Zinc concentration, Twabugezi 1 with 9.75 µg/L is the only site with less than 10 µg/L, the remaining sites have the values between 11.99 µg/L and 18.99 µg/L which fall under Group A of DNGVDW (Excellent quality). Surprisingly the control site (Kinihira) has the highest concentration (18.99 µg/L) of Zinc (Table 7). This means that Zinc concentration in mining tailing tend to be lower at sampled sites. This suggests that mining activities did not play relevant role in enriching Zinc in water.

3. 3. Concentration of heavy metals and metalloids in soil

As for the water, we have also measured the following minerals in the soil: Arsenic (As) Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb) and Zinc (Zn). The obtained results are below presented.

The figures below shows the concentration of Arsenic (As) and Cadmium (Cd) in the soil. For **As**, compared to the control site, all the five mining sites present a high concentration of arsenic. The highest concentration is at Ntobo (187.3 mg/kg) followed by Kinyenkanda (104.44 mg/kg) while the lowest concentrations are respectively observable at Twabugezi (35.46 mg/kg) and Nduruma (41 mg/kg) sites. This concentration is above the global standard (30 mg/kg) and Austria and Germany standards (50 mg/kg), (Table 5). Therefore, all the five sites are affected and mostly Ntobo and Kinyenkanda. It important to note that higher concentration increases toxicity to microorganisms. It also induces stress and interferes with photosynthesis in plants. This reduces growth and biomass production.

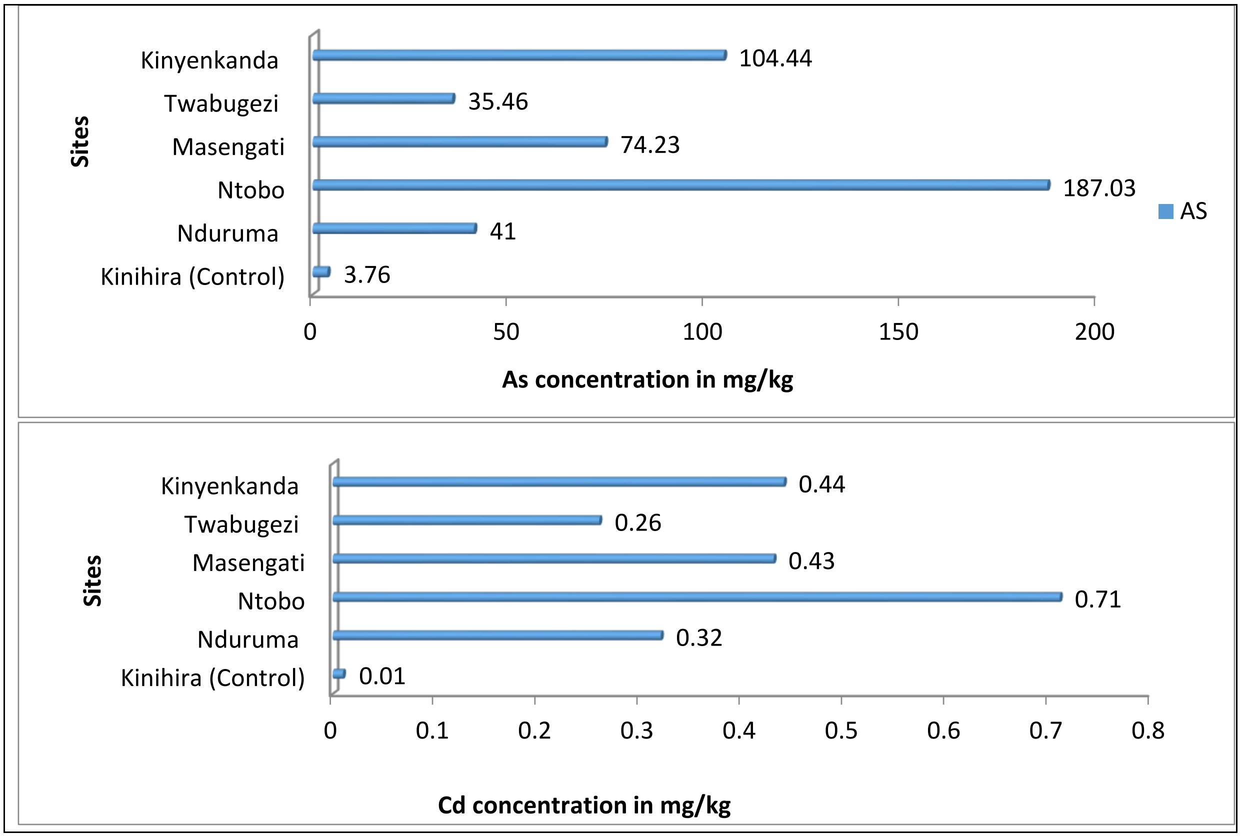


Figure 14: Arsenic (As) and cadmium (Cd) concentration in the sampled sites

Compared to the control site of Kinihira with 0.01 mg/kg, the Cd concentrations show a high concentration at all sites, with the highest value at Ntobo site. This shows that the mining activities increase Cd in the soil referring to the Cd concentrations measured from all the five sites. However, all measurements, including Ntobo site, are still low compared to the selected allowable standards Cd concentrations in the soil that are 10 mg/kg for Canada, 20 for Germany, 5 for Austria, 3 for Europe and the global average of 2.7 mg/kg.

The figure below shows the concentration of Chromium (Cr) and Copper (Cu) in the sampled sites.

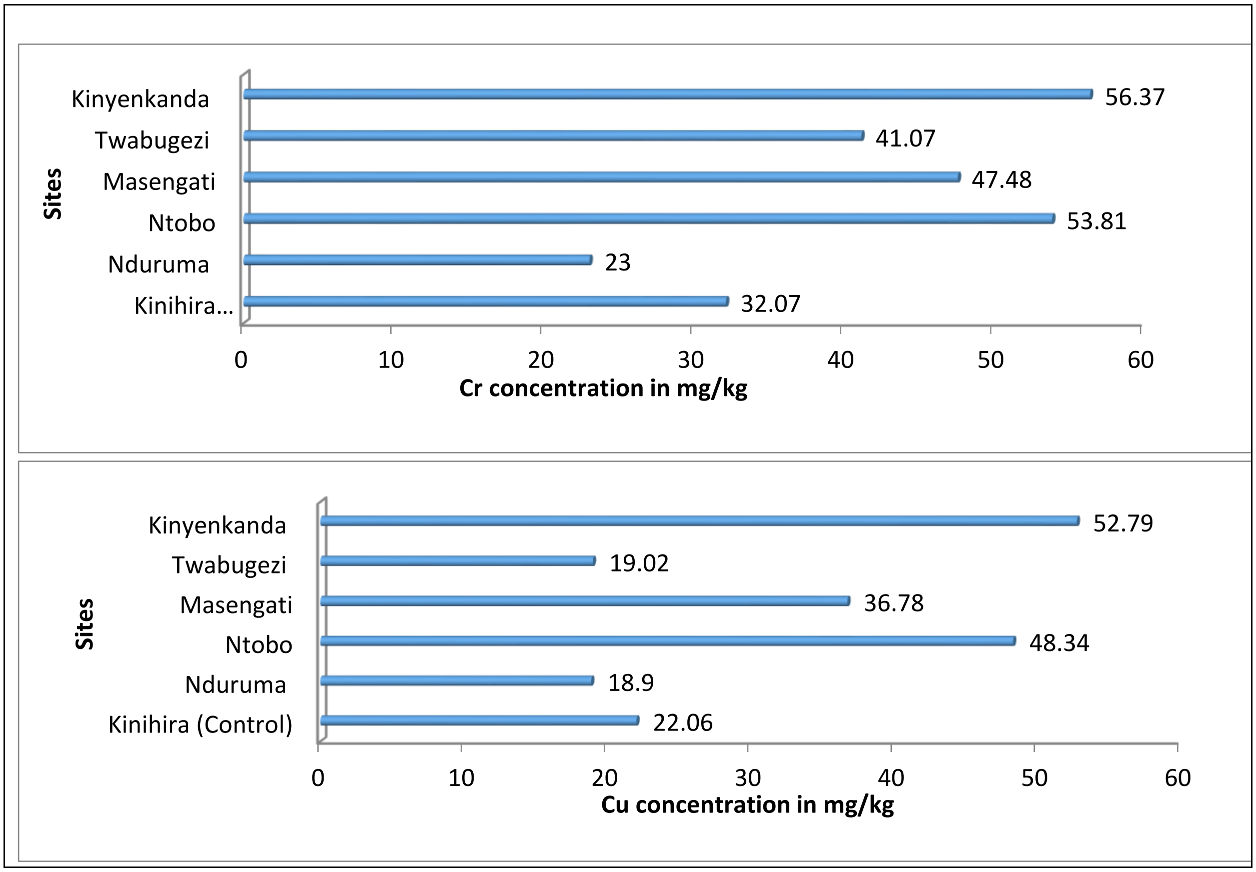


Figure 15: Chromium (Cr) and Copper (Cu) concentration in the sampled sites

The four sites, Kinyenkanda, Ntobo, Masengati and Twabugezi have respectively and in descending order the concentration values that are above the control (32.07 mg/kg); and that can be perceived as an impact of mining activities. The concentration is only below at the site of Nduruma. However, as it is the case of cadmium, all measurements are below the selected minimum acceptable standards of Germany (350 mg/kg), Austria (100 mg/kg), Europe (150 mg/kg) and Worldwide (530 mg/kg). Therefore, the effect is still manageable.

Concerning the Cu, the concentration at the sites of Kinyenkanda (52.79 mg/kg), Ntobo (48.34 mg/kg) and Masengati (36.78 mg/kg) is above the control (22.06). For Twabugezi (19.02 mg/kg) and Nduruma (18.9 mg/kg), the concentration is lower to the control. Compared to the selected standards, measurements from the Kinyenkanda and Ntobo are relatively closer to the standards of Canada (63 mg/kg) and Global standards (70 mg/kg). German, Austrian and European standards, respectively 200, 100, and 140 mg/kg are higher. Therefore, a relative impact of the Cu concentration is observable at Kinyenkanda, Ntobo and Masengati.

The figure below shows that the lowest lead (Pb) concentration of 9.04 mg/kg was measured at Kinihira while the highest of 69.55 mg/kg was seen at Ntobo site followed by Masengati with 45.02 mg/kg. The measured Pb concentration at Nduruma and Kinyenkanda were 39 mg/kg and 32.13 mg/kg respectively while it was 18.97 mg/kg. This reveals that the Pb concentration measured at Ntobo is the only one that is closer to considered as the worldwide standard lead concentration (70 mg/kg) but it is very low compared to Canada, German, Austrian and European standards (Table 5). However, compared to the control site, all values are high and this proves that mining activities have a considerable impact in what concerns the concentration of lead in the soil, and more especially at Ntobo site. The increasing trend of Pb concentrations at mining sites will be toxic to all organisms including plants and soil invertebrates. Moreover, erosion on steep slopes and proximity of mining sites to streams may lead to easy contamination of aquatic water bodies by Pb from mine tailings.

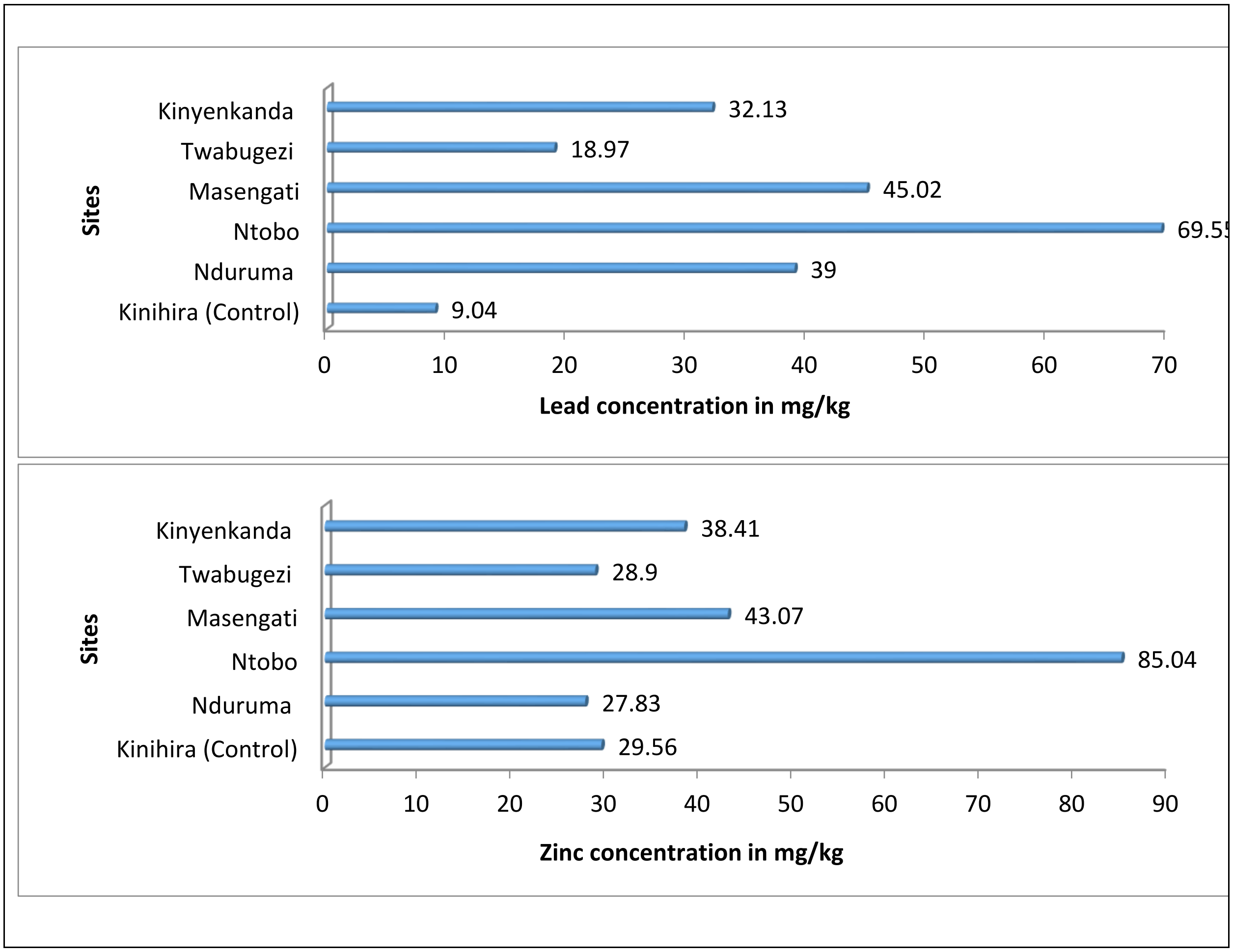


Figure 16: Lead (Pb) and Zinc (Zn) concentration in sampled soil

As for Lead, Zn concentration at study area culminates at Ntobo site with 85.04 mg/kg and it decreases almost to the half at Masengati (43.07 mg/kg) to become 38.41 mg/kg at Kinyenkanda. The remaining sites of Twabugezi, Nduruma and control area (Kinihira) have almost the same Zinc concentration of 28.9 mg/kg, 27.83 mg/kg and 29.56 mg/kg respectively. Though Ntobo site has the highest Zinc concentration, it is far below the world standard concentration of 220 mg/kg, obviously lower than Canada, German, Austrian and European standards (Table 5). This implies that the content of Zinc at mining areas is not yet harmful to plant and animal life but the value observed at Ntobo site stands as an alert.

3.4. Soil physico-chemical parameters at mining sites

The soil physico-chemical parameters measured include pH, Cation Exchange Capacity (CEC) and soil texture. The results are presented in the two following figures (16 & 17).

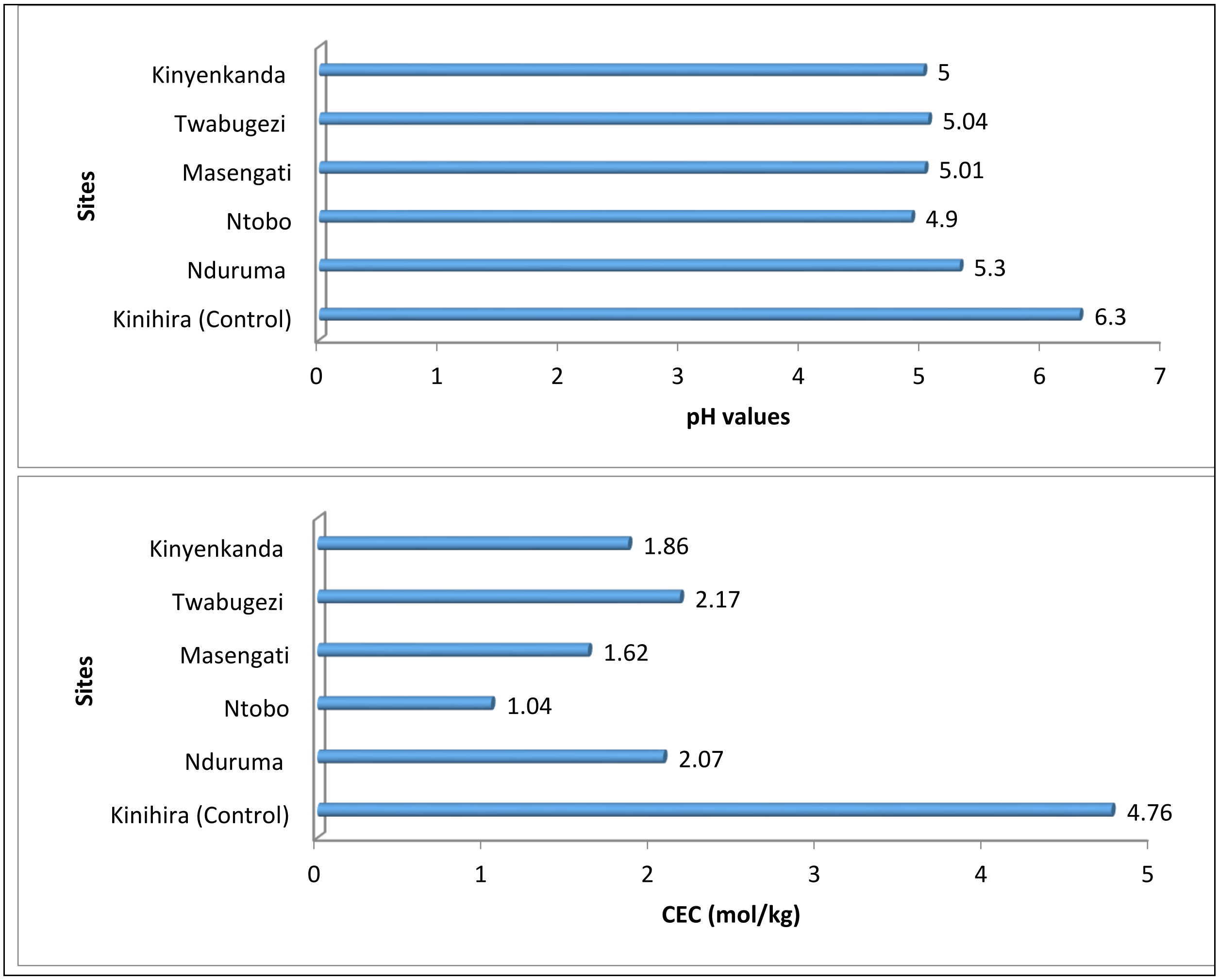


Figure 17: pH values and CEC of sampled water

The study area is covered by acidic soils as far as all sampled mining sites are present soils with pH oscillating around 5 (between 4.9 and 5.3). However, the soils collected from control area (pH 6.3) are still acidic though are nearer to the neutral. This means that mining activity has contributed to soil acidification. As such, many plant species will hardly grow and only adapted plant species can grow in mining areas of Gishwati as consequence of the decline in availability of nutrients and minerals necessary for plant growth.

The study revealed that CEC at mining areas varies between 1.04 mol/kg at Ntobo and 2.17 mol/kg at Twabugezi while it rises up to 4.76 mol/ kg at control area (Kinihira). This shows that mining tailings are poor in CEC. These results inform that soils covering the mining areas would be less fertile and less productive because they have little essential mineral content.

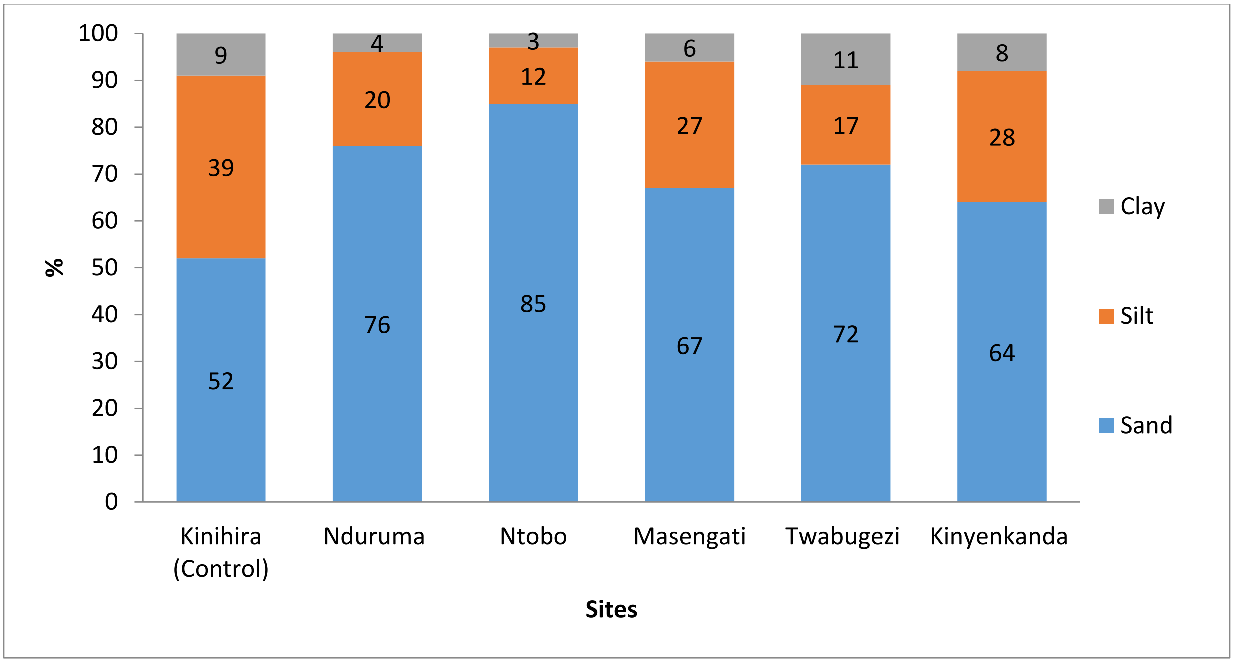


Figure 18: Texture of sampled soils

The figure above depicts that most of sampled soils are dominantly composed of sand especially at Ntobo which are sandy at 85%, followed by Nduruma with 76% and Twabugezi with 72%. Soils from Masengati, Kinyenkanda and Kinihira (control area) contain 67%, 64% and 54 of the sand respectively. A part from Twabugezi's soils which have 11% of clay, the remaining soils contain less than 10% of the clay while the portion of silt varies between 12% at Ntobo and 28% at Kinyenkanda with maximum of 39% at control area of Kinihira. Therefore, the mining tailings contain more sand and less clay. Hence, it can be concluded that the mining tailings are composed by sandy soils which may result into high rate of infiltration with low water retention in the upper part of the soil. This soil will not be conducive for many plant species, hence reduced vegetation cover in the studied sites.

3. 5. Effect of mining on vegetation

The impact of mining on vegetation was assessed through direct observation, photograph and plant diversity analysis. The impact observed on each site is that mining contributed to the destruction of the vegetation. The most vulnerable types of plants are grasses and herbs. Large open pits lead to the removal of tree species. Overall, the vegetation cover decreases as mining activities invade more and more space. This was more obvious at Nduruma site where mining activity contributed to the destruction of the trees, threatening the protected area of Gishwati forest (Figure 18).

Figure 19: A photography showing a destruction of vegetation at Nduruma site

The plant inventory conducted on grasslands of two mining sites, namely Kinyenkanda and Ntobo showed that plant diversity, as represented by the number of species per site and transects, was higher in areas which were not affected by mining activities: at Kinyenkanda mining site, a total of 35 plant species were collected. The non-mined area presented a higher number of plant species (26) than mined area (17). Only 8 plant species were shared between the two areas. At Ntobo mining site, a total of 30 plant species were collected. Like at Kinyenkanda mining site, the mined area at Ntobo presented a low number of plants species (14) that non-mined area (24), and only 10 plant species were common between the two sampled areas.

The removal of some tree species suggests accelerated downstream erosion, reduced habitats for tree-dwelling and dependent animals including birds and primates found in Gishwati forest area. In addition, few number of plant species on mining sites implies not only reduced shelter opportunity but also little choice of food for herb or grass eating animals. The observations on plant diversity also suggest that some species might be completely removed by mining activities or some few species would adapt to disturbance due to mining, and thus become endemic. However, this statement cannot just be confirmed by the present single period study. In depth-study on long term basis is needed to validate it.

Table 6: Inventoried plant species at Kinyenkanda mining site

S/N	Species vernacular name	Scientific Name	Presence/absence	
			Non-mined area	Mined area
1	Idoma	*Asteraceae div. spp.*	+	-
2	Igifuraninda	*Gynura scandes*	+	+
3	Igiherahere		+	-
4	Igihwarara	*Plectranthus sylvestris*	+	-
5	Igishihe	*Cyathea manniana*	+	+
6	Igishokoro (igishokonkoro)	*Cynoglossum amplifolium*	+	-
7	Igisura	*Urtica massaica*	+	-
8	Igitenetene		+	-
9	igitobotobo	*solanum aculeastrum*	+	+
10	Ikirumbi	*Panicum div. sp.*	+	-

11	Imbatabata	*Plantago palmata*	+	+
12	Intomvu	*Loberia giberroa L.*	+	-
13	Inyabarasanya	*Bidens pilosa L.*	+	-
14	Isununu	*Crassocephalum duci-aprutii*	+	+
15	Kazigashya	*Adenostemma caffrum DC.*	-	+
16	Nyiramuko		-	+
17	Nyiramunukanabi	*Tagetes minuta L.*	-	+
18	Rurira	*Sonchus oleraceus L.*	+	-
19	Igitsinatsina	*Setaria poiretiana*	-	+
20	Ubwungo	*Loberia rubescens L.*	+	-
21	Umucaca	*Cynodon aethiopicus*	+	+
22	Umugano	*Bambus vulgaris*	-	+
23	Umuhe	*Clerodendrum fuscum*	+	-
24	Umukaragata	*Embelia schimperi*	-	+
25	Inturusi	*Eucalyptus maidenii*	+	-
26	umukeri	*Rubus rigidus*	-	+
27	Umunyuragisaka	*Rhus vulgaris*	+	-
28	Umuryahene	*Clerodendrum buchholzii*	+	-
29	Umusazugona	*Digitaria velutina*	+	-
30	Umushabarara	*Canthium oligocarpum*	+	-
31	Umuturanyoni	*Conyza sp.*	+	+
32	Ururandarike		-	+
33	Ururandaryi		+	-
34	Umusereka		-	+
35	Uruzi		+	+

Table 7: Inventoried plant species at Ntobo mining site

S/N	Species vernacular name	Scientific Name	Presence/absence	
			Non-Mined area	mined area
1	Arinusi (Agroforest tree)		+	+
2	Cyumya	*Asteraceae div. spp.*	+	-
3	Desmodium	*Desmodium gangeticum L.*	+	-
4	Igifuraninda	*Gynura scandes*	+	+
5	Igishihe	*Cyathea manniana*	-	+
6	Igishokoro (igishokonkoro)	*Cynoglossum amplifolium*	-	-
7	Igisura	*Urtica massaica*	+	-
8	Imbatabata	*Plantago palmata*	+	+
9	Indagarago	*Cyperaceae dv. Sp.*	-	+
10	Intomvu	*Loberia giberroa L.*	+	-
11	Isununu	*Crassocephalum duci-aprutii (CHIOV.) S.*	+	+
12	Kazigashya	*Adenostemma caffrum DC.*	+	+
13	Kimali	*Galisonga parviflora*	+	-
14	Nyiramuko		+	-

15	Pinus	*Pinus strobus*	+	-
16	Umucaca	*Cynodon aethiopicus*	+	+
17	Umugaragara	*Vernonia div. spp.*	+	-
18	Umuhanga	*Maesa lanceolata*	+	-
19	umukeri	*Rubus rigidus*	-	+
20	Umunaba		+	-
21	Umunyuragisaka	*Rhus vulgaris*	+	-
22	Umusazugona	*Digitaria velutina*	+	+
23	Umuturanyoni	*Conyza sp.*	+	+
24	Urukangaga	*Cyperus latifolius*	+	+
25	Uruteja	*Commelina benghalensis L.*	+	+
26	Uruzi		-	+
27	Uruzi rw'ishyamba		+	-
28	Urwagara	*Lamiaceae div. spp.*	+	-
29	Igorogonzo	*Polygonum pulchrum*	+	-
30	Umuhurura	*Capparis fascicularis*	-	+

3. 6. Effect of mining on landscape

Most of mining activities, especially in developing countries where traditional mining methods are still in use, involve excavation of geomorphological and geological structures resulting into directly or/and indirectly into a range of landforms. The mining activities affect the landscape in the following ways.

(i) **Rills and gullies:** They are formed by surface run off at mining sites. Piping water used in course of filtering minerals through sluicing has likely played a significant role in the development of these features. These rills resulted also from the created water channels which were further enlarged with fluvial erosion and developed into gullies. This process can ultimately lead to the formation of badlands (Byizigiro & Biryabarema, 2008).

Nduruma site — Ntobo site

Figure 20: Photographs showing rills and gullies resulting from piping water

The disturbance of one side of slope has often led to the weakening of adjacent areas, particularly on the upper part of the back slope, resulted into the development of cracks. The cracked areas allow the entry of water into weakened zones between blocks to form rills and gullies (van Beek, et al., 2008). These weakened zones often constitute the plane for further mass movements from the upper part of the pit.

Nduruma site Ntobo site

Figure 21: Rills and gullies resulting from cracks as result of mining activities

(ii) Landslides (rock slides or debris slides): They take place along steepened mined slopes resulting from shear-strain which collapse and displaced along one or several surfaces (Westerberg & Christiansson, 1999). The observed landslides at mining sites may also be induced by natural agents like heavy rain and earthquakes on the weakened sloppy areas by mining activities. These landslides alter the geometry of the slopes that most of time result into the flow of material to the base and creation of steeper slopes at their heads (Byizigiro *et al.*, 2015).

A landslide on the bank of Sebaya River Rock fall at Kinyenkanda 1

Figure 22: Landslides and rock falls at mining areas

(iii) Scars: They occurred upslope of mine pits, from which displaced material has been removed to constitute a 'remaining landform' known as 'crown' (Westerberg & Christiansson, 1999). Inside the forest, deep pits may also constitute unwanted traps for mammals including primates living in Gishwati forest area.

Nduruma site   Sebeya river banks in Nduruma

Figure 23: Scars at mining areas

(iv) Slumps: They have developed due to an accelerated under cutting process that is more active under the influence of running water, weakening the whole fabric of the regolith, which collapses in gradual landforms resembling stairs.

Kinyenkanda site   Nduruma site

Figure 24: Formation of slumps at mining areas

The above presented photographs show that the mining activities have highly affected the landscape of the area of the study.

(v) Disruption of drainage system: During mining, the rock structures are interfered with. This affects surface and underground flow of water. The result is lowering of the water storage.

The mining activities have also deviated the river and stream courses, which affected also the general landscape arrangement and features.

Sedimentation and silting on Sebeya River

Figure 25: Sedimentation and silting of river at mining area

The photograph above reveals the influence of sedimentation and silting caused by mining activities on Sebeya river course. Both banks of the river were destroyed as well as the bed of river. This should probably change the existing drainage pattern.

4. MINING BEST PRACTICES IN GISHWATI FOREST AREA

The mining best practices described below, here referred to as *'Environmental mining friendly best practices'*, are specifically tailored to biodiversity supporting ecosystem components to mitigate and minimize the negative impacts of mining activities in Gishwati forest area. They are to be mainly implemented by mining companies and miners.

4.1. Mining impacts on landscape and best practices

The study demonstrated that mining activities exert a negative effect on landscape through destruction of vegetation cover and creation of geomorphological structures including rills, gullies, and scars. Such structures accelerate erosion and induce landslides in mining zones. In some points, the eroded materials that reach the stream and rivers contribute to the disruption of the drainage system. The following table summarizes actions and practices that need to be adopted in order to minimize mining impact on the landscape.

Key impacts on landscape	**Environmental friendly best practices**
Destruction of vegetation cover.	• Excavation of the mining pits where there is less vegetation cover; • Avoiding disturbing large and/or mature trees because their roots sustain the landscape on a large scale: select specific trees to be cleared if a need arises; • Avoiding cutting trees rootstocks to allow easy regeneration and regrowth; • Avoiding clearing the vegetation surrounding the mining pit; • Re-vegetate disturbed areas at the completion of mining activity.
Downslope erosion leading to geomorphological structures (e.g. rills, gullies and scars) and landslides.	• Reshaping the topography by properly filling or closing the open pits and/or re-arranging the overburden stockpiles; • Regularly inspect the status of pits to prevent erosion and weakening of the embankments; • Excavation of the new pits should begin after closing and refilling the existing open pits and tunnels; • Minimizing at all cost the potential runoff by channeling water in less risk zone and by increasing the land vegetation cover; • Prevent animal accidents by fencing of any soft surface areas.
Disruption of drainage system.	• Creating a vegetation buffer zone along the watercourse to prevent siltation, sedimentation and collapsing of banks;

	• Cleaning up regularly the sediments traps, ponds and drains to maintain them in an effective working order.
Unsafety pits	• Fencing off and post warning signs to prevent livestock, native animals and even humans being accidentally trapped in the pits; • Backfilling the pits soon after mineral extraction has ended. Use the overburden stockpiles to fill deep layers and put the top soil to allow regeneration of the vegetation cover; • Regularly inspect any soft embankments around the edge of the pits to control accidents for native animals and even miners.

4.2. Mining impacts on soil and best practices

Mining has resulted into degradation of soil physicochemical properties and contamination by metals and metalloids. There is a clear loss of agricultural soil by accumulation of sandy overburden. The bare mine tailings and overburden are prone to erosion. The soil texture is dominated by sand fraction and not suitable for cropping. Such a soil will hardly retain nutrients/minerals and water necessary for plant growth, hence reduced vegetation cover and increased downstream erosion in mined areas. The following table summarizes actions and practices to adopt in order to minimize mining impact on the soil in Gishwati forest area.

Key impacts on soil	**Environmental friendly best practices**
Loss of agricultural soil by removal of the topsoil and accumulation of the sandy overburden in mined areas.	• Removing the topsoil and stockpile it in a safe area prior to carrying the mining activities; • Re-covering the refilled pit by the stored topsoil for quick recovery of vegetation cover; • Adding fertilizers to supply essential nutrients and speed up vegetation growth on overburden soil and mine tailings.
Contamination by metals and metalloids and degradation of physico-chemical properties	• Storing the topsoil and overburden in separate stockpiles; • Avoiding mixing topsoil with mining tailings to prevent its contamination by metals and metalloids; • Re-establish a vegetation cover to revive the soil and allow quick regeneration of organic matter; • Monitoring regularly the mineral content and other soil physico-chemical properties to check the quality of soil in and around the reclaimed mining sites.
Erosion	• Minimizing the erosion on topsoil and overburden stockpiles by establishing a cover crop on them; • Limit the height of soil stockpiles to two (2) meters to minimize downslope erosion; • Construct trenches to slow down, retain and channel runoff.

4.3. Mining impacts on water and best practices

Mining activities have caused metal and metalloid contamination modification of physico-chemical properties of water, siltation and sedimentation of streams and flooding risks. Best practices to contain and prevent such negative effects are summarized in the table below.

Key impacts on water	Environmental friendly best practices
Metal and metalloid contamination	• Avoiding pouring mine effluent and tailings into water bodies; • Retreating wastes left after extraction of minerals before releasing them into the environment because mineral content in the effluent should be maintained within the permissible concentration.
Modification of physico-chemical parameters	• Avoiding releasing mined or wastewater into naturally flowing water. Such water is often acidic and contains high load of dissolved particles; • Avoiding dumping tailings in the water bodies which may decrease pH and light penetration in the water; • Monitoring regularly the water quality in the mined areas through the analysis of physico-chemical parameters in order to take appropriate adaptation and mitigation measures in due time.
Siltation and sedimentation	• Constructing the check dams or silt retention ponds to prevent silt runoff from mined area; • Cleaning up regularly silts and sediments from the watercourses; • Designing and maintaining in good status adequate erosion and sediment barriers to prevent erosion in disturbed areas and sedimentation of watercourses.
Risk of flooding	• Re-establishing the vegetation cover on the bare lands and mined areas to slow down erosion on slopes; • Constructing water retention trenches in mining area to decrease the runoff which may lead to flooding in lowlands and wetlands; • Avoiding the accumulation of mine tailings or sediments into water bodies that may reduce the size of water channels.

4.4. Mining impacts on biodiversity and best practices

Mining may negatively affect biodiversity of Gishwati forest area through toxicity by metals and metalloids, loss of suitable habitats, spoiling drinkable water for animals, and noise pollution. Best practices to contain and prevent such negative effects are summarized in the table below.

Key impacts on biodiversity	Environmental friendly best practices
Toxicity by metal and metalloids leading to stress and reduced reproduction potential	• Dumping tailings in exhausted pits and tunnels to reduce contamination of nearby soil and water bodies. • Reclaiming the mined areas to restore the physico-chemical and biological quality previously disturbed by mining activities.
Loss of vegetation cover and suitable habitats	• Removing the topsoil and stockpile in a safe area prior to carrying the mining activities, and then bring it back when mining operations have ended. • Re-establishing the lost vegetation cover to rapidly allow the colonisation of essential soil microorganisms and to re-attract wildlife presence in mined areas; • Afforestation of mined areas to re-establish the lost trees during mining operations.
Spoilage of water	• Providing safe access to water for livestock and native animals by artificially creating hard surfaces and ponds to retain water. • Avoiding dumping mine tailings, sediments and effluents in the water bodies. • Avoiding sluicing inside the water bodies.
Noise pollution	• Constructing and maintaining noise barriers and enclosures around noisy equipment and along the noise transmission path. • Stopping temporarily or avoiding mining operations during time when birds and animals use actively the area. • Using low noisy equipment.
Water pollution	• Monitoring water quality for ground and surface waterbodies, tailings or overburden soil storage facilities, effluent quality and quantity to limit water pollution. Monitoring should also entail periodic inspection of the vegetation for signs of erosion damage or failures of vegetation establishment process.

5. GENERAL CONCLUSIONS AND RECOMMENDATIONS

Artisanal mining prevails in Gishwati forest area and it is carried out by both registered companies and opportunistic miners from the local populations. Results from environmental impact assessment show that mining has a negative impact on soil, water, and landscape in general. Damage caused to these ecosystem components would result into biodiversity loss, especially trees, birds and mammals including endangered primates living inside and around the Gishwati forest. Biodiversity threatening impacts include soil and water contamination by metals and metalloids, destruction of the vegetation cover resulting into loss of habitats and food for living organisms, and creation of abnormal or new geomorphological structures in the mining areas.

The aforementioned impacts have guided the elaboration of environmental mining best practices in Gishwati forest area in order to reduce or prevent adverse effects on ecosystem integrity and on biodiversity in particular. Most of the impacts are generated during the mine operations phase in the mining cycle. During this phase, ore extraction, rock crushing and grinding, pits and waste management are of great concern. Moreover, it has been observed that miners tend to ignore the mine closure phase and ecosystem degradation continues after mine operations have ended in given points. For instance, bare lands without vegetation are prone to erosion and this increases the flooding risk in the mined areas and accumulation of sediments in watercourses. Lack or insufficient vegetation cover in such areas will rarely attract wildlife. The implementation of the proposed mining best practices will undoubtedly reduce and prevent the observed and measured impacts on soil, water and landscape. Minimizing the impacts on such elements of the ecosystem will probably allow maintaining the integrity and self-regeneration of the biodiversity.

In this study, the observations and discussions with stakeholders in mining and in environmental protection emphasized on the need to raise awareness of potential environmental impacts associated with mining. This is because mining guidelines and laws are available but are rarely applied by both registered mining companies and opportunistic miners. The awareness of impacts should be conducted through trainings based on the above elaborated mining best practices. For such training to be successful, the contribution and involvement of environmental management experts and the use of case studies from local or other contexts will be required. Various actions are proposed as best practices to be implemented in order to reduce and prevent the impacts on landscape, water and biodiversity. Their smooth implementation requires that miners and mining companies have already skills required to implement the proposed actions. During the study, no investigation was done to probe the “know-how- to do” skills possessed by individual miners and mining companies. However, the gap in such skills would be revealed during the training on such best practices and thus form the basis for developing specific procedures or protocols for a given action. Monitoring should be an integral part of implementation of the proposed guidelines. If it is well planned, monitoring will inform on the suitability of selected actions to reduce and prevent observed and potential environmental impacts. With this regards, regular and consistent analysis of vegetation cover and regeneration in mined areas, soil and water quality is required.

This study was conducted for the case of Gishwati forest area. The findings show an alerting situation. This issue is not absolutely specific to Gishwati. Similar studies should be conducted not only for the mining areas around the protected areas like Mukura or Nyungwe to protect biodiversity but also in all mining zones to protect human beings, landscape and natural resources in whole. This action is recommended to different organs and stakeholders involved in the sectors of mining and environmental management activities.

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