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Effects of Illegal Artisanal Gold Mining on Water Quality and Vegetation Cover Within Muzvezve River Catchment, Zimbabwe

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Abstract: Illegal artisanal gold mining activities is a growing industry and have been identified as a significant contributor to a range of environmental disturbances in many developing countries. This paper sought to investigate the effects of illegal gold mining activities on Muzvezve River water quality and vegetation cover within the catchment. The study employed two methods to collect data: water quality sampling and determination and the normalised difference vegetation index (NDVI). The NDVI was used to assess the extent and severity of the vegetation cover changes in the illegal artisanal gold mining hotspots in the last decade (2013-2023). Water samples were taken on three sampling sites/river sections (upstream, middle and downstream) of Muzvezve River for three months and analysed for nine physico-chemical parameters (pH, EC, Fe, Hg, sulphate, cyanide, total dissolved solids, total hardness and turbidity. The data collected were analyzed using R software. The findings suggest that illegal gold mining had significant negative impacts on the quality of water in Muzvezve River. Turbidity, pH and heavy metals (Hg, Fe and cyanide) concentrations were found to be significant at various p levels. Four of the nine physico-chemical parameters (pH, Fe, Hg and turbidity) were found to be above the WHO maximum allowable levels. There was a strong positive correlation among the tested water quality parameters. NDVI values of 0.27 and 0.68 for sparse vegetation and dense vegetation were recorded in the illegal artisanal gold mining hotspots in 2013 and generally vegetation cover decreased by 20% and 8% in 2017 and 2023 respectively.

Keywords: Vegetation Cover, Pollution, Physico-chemical Parameters, NDVI, Muzvezve Catchment

INTRODUCTION

Artisanal gold mining have been a perennial feature in Zimbabwe for more than half a century. According to the Organisation for Economic Cooperation and Development (OECD), artisanal mining refers to formal or informal mining operations with predominantly simplified forms of exploration, extraction, processing and transportation. Artisanal mining is also associated with use of simple tools like picks and shovels as opposed to mechanised mining. Artisanal gold mining can either be done legally or illegally. Illegal mining is defined as any mining activity carried out without state approval or regulation, specifically with regards to land rights, mining licenses, nor exploration or mineral transportation permits (Boadi et al., 2016; Mutemeri and Petersen, 2019).

As of 2003, the estimated population of illegal artisanal gold miners in Zimbabwe ranged between 300,000 and 400,000, who in turn supported the livelihoods of at least two million people (Maponga and Ngorima, 2003). Today, this number is estimated to have ballooned to more than 1.5 million miners. At the epicentre of illegal artisanal gold mining operations is the Kadoma-Chakari area which was identified as having the highest population of artisanal and small-scale miners in the country (Shoko and Veiga, 2004). Reasons for the continued growth of the illegal artisanal gold mining sector includes a poor performing economy, endemic unemployment rates and recurrent droughts within Zimbabwe and its neighbours (Shoko and Veiga, 2004; Spiegel and Veiga, 2010). Further, the unregulated nature of this sector, corruption, violence and other associated vices has fuelled to the expansion of illegal mining operations base (Mutemeri and Petersen, 2019). The economic structural adjustment programmes of the mid-1990s and early 2000s resulted in the laying-off of employees by several gold mining companies in the Kadoma-Chakari area such as Chakari Gold Mine and Venice Gold Mine. Moreover, the scaling-down of operations by mining companies like Brompton and Rio-Zim confined their former employees to illegal gold mining as a source of income

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and livelihood. Consequently the environment has continued to suffer unimaginable harm in more ways than one.

For one, the illegal artisanal gold mining requires the removal of multiple layers of overburden rock, followed by the logging of trees and the clear-cutting or burning of the vegetation above the ore deposit. These actions cause seriously harm to the soil structure and surface morphology of land including the destruction of naturally vegetated areas. Further, the sediments generated from all these processes coupled with the actual mining effluents and processing chemicals (mercury and cyanide) often end up polluting the receiving surface waters. The deforestation and land degradation also results in high turbid surface waters, emission of greenhouse gases and contributes towards climate change (Nyahwai et al, 2022; Masere et al., 2023). This is the situation that has been obtaining in Muzvezve River and its catchment area. The pollutants and contaminants from illegal artisanal gold mining pose serious health hazards to aquatic and terrestrial organisms, as well as to miners themselves. As with catchment dynamics, water flows from upstream to downstream due to gravity and any activities done upstream affecting the quality and quantity of water or flow rate affects locations downstream (Wohl et al., 2017). Understanding the dynamics between illegal artisanal mining operations and the negative environment footprint is crucial, as it aids in the formulation of effective management strategies and sound policies intended on reducing the impacts.

It is for this reason that, this study was conducted in Muzvezve River catchment to achieve three objectives namely: to investigate the concentrations of several physicochemical water parameters along Muzvezve River; to determine the correlation and associations between the tested physico-chemical water quality parameters; and identify and map the illegal artisanal gold mining hotspots in Muzvezve River as well as to determine the extent of vegetation loss within the mapped illegal artisanal mining hotspots over the last decade (2013 - 2023). We hypothesise that: illegal artisanal gold mining activities results in substantial increase of concentration levels of physico-chemical water quality parameters in Muzvezve River; there is a strong positive correlation between the tested physico-chemical water parameters; and that illegal artisanal gold mining operations result in substantial vegetation loss over time.

MATERIALS AND METHODS

Study Area

Muzvezve River catchment is located in Mashonaland West province of Zimbabwe. It lies between latitude 29.574 ^{o}E and 30.751 ^{o}E and at longitude 18.369 ^{o}S to 18.552 ^{o}S, with a total coverage area of 3,271 square kilometres of Kadoma and partly of Mhondoro (Figure 1).

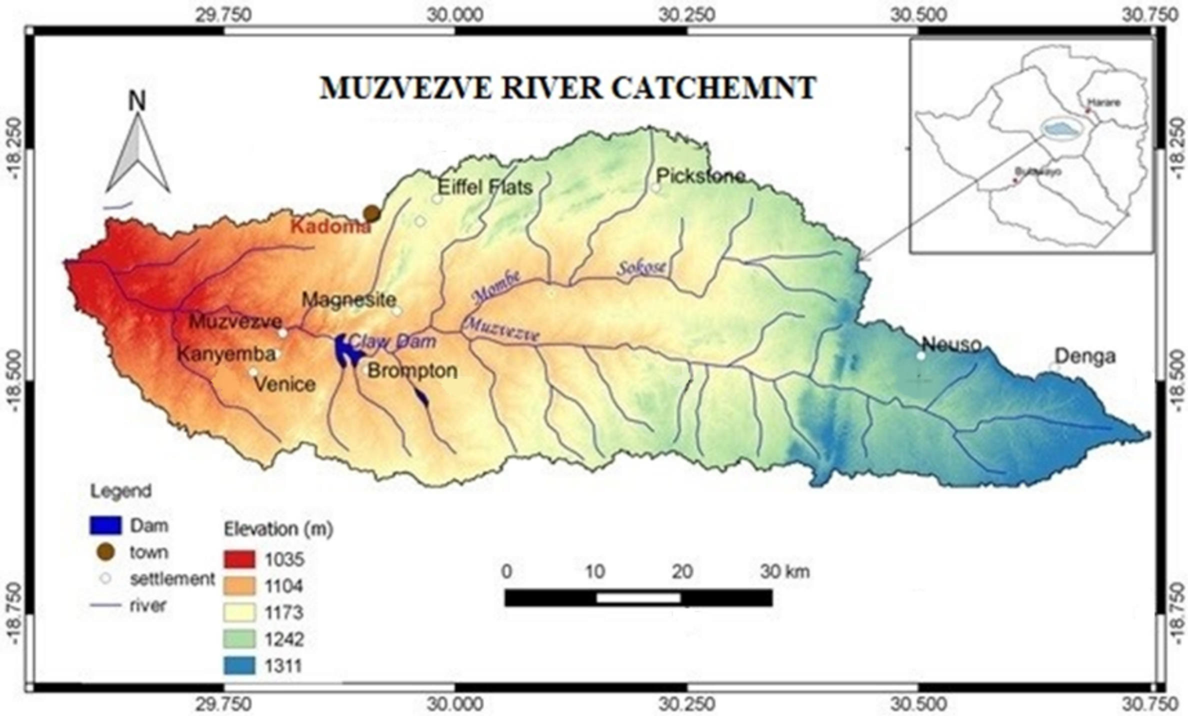

Figure 1. Geographic location of the study area; Muzvezve River Catchment

Muzvezve River catchment is part of a larger catchment, Sanyati catchment, which is one of Zimbabwe's seven main river catchments. Muzvezve River is also a major tributary of the Munyati River, which in turn also flows into Sanyati River. Muzvezve River catchment has a tropical climate, with distinct wet and dry seasons. The wet season (November-March) is marked by brief convectional thunderstorms and drizzle (Shoko and Veiga, 2004). The area receives mean annual rainfall ranging between 650mm and 800mm. Kadoma is the major city in Muzvezve catchment. The city is located about 135km South of Harare, the capital city of Zimbabwe. The catchment is generally at an altitude of 1250m above mean sea level (Shoko and Veiga, 2004). The main sources of livelihood for the people in Muzvezve River catchment are mining and farming (Shoko and Veiga, 2014). The farming systems within the catchment include communal farming and small to medium-scale commercial farming where staples like maize and cash crops like cotton are grown. On the other hand, the mining activities in the catchment are centred on gold where both established mining companies and illegal artisanal miners are the major players.

Water sampling and analyses

Grab sampling technique was employed to collect nine composite samples on three sampling sites along Muzvezve River profile, as shown in Figure 2 and described in Table 1. The selected sampling sites were designated as S1, S2 and S3 respectively. Samples were collected monthly for three months starting in February 2023. Sample bottles were rinsed three times with sample water before collection to avoid alteration of results (Ogunbode et al., 2017).

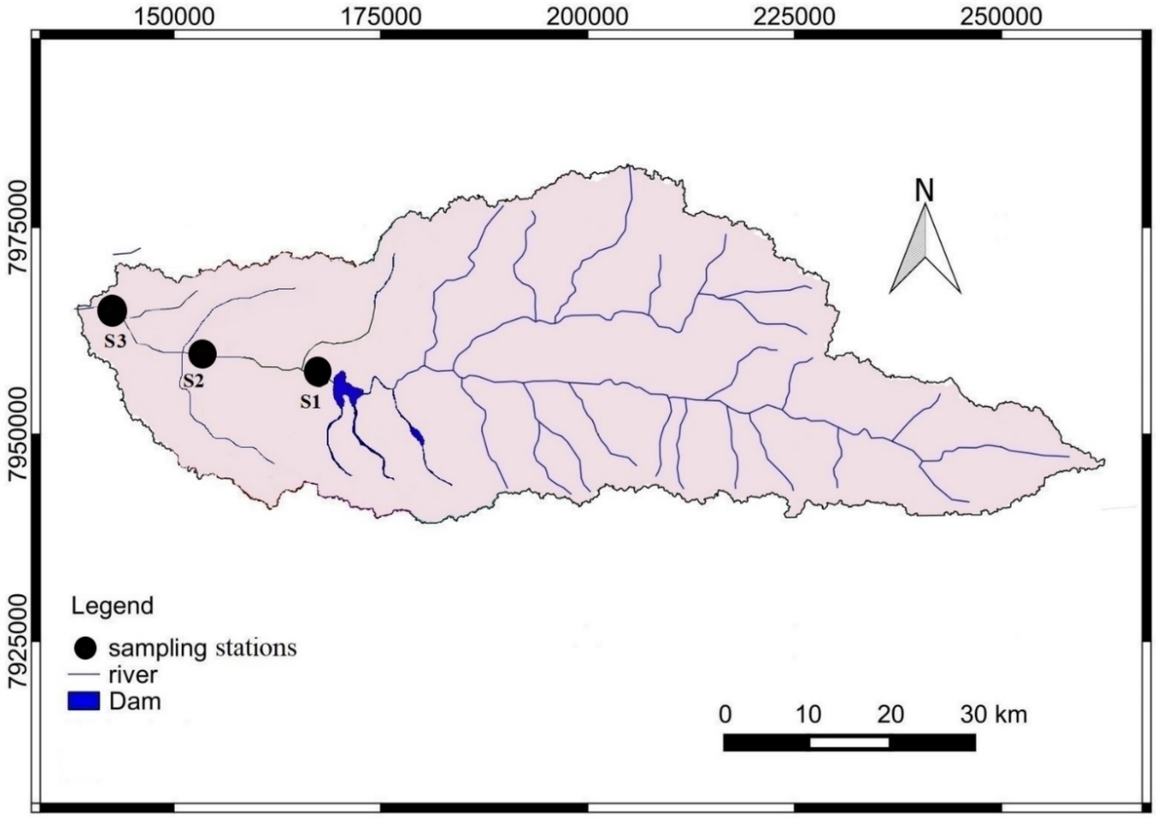

Figure 2. Geographic location of the sampling sites

Table 1. Sampling site location and description

Sampling Site	**Position along the River**	**Description/Notes**
S1	Upstream	Situated above site of the mining operations. Used as a control/reference, as it shows the water quality prior to the water passing through the mining region.
S2	Midstream	Located directly adjacent to the mining operations. At this point samples were taken to note the impact of mining on the river water quality
S3	Downstream	This site was chosen to assess the river water quality downstream of the mining site and to compare it with other sites

Each composite sample was made up of three representative subsamples. The composite samples were collected into 500ml clean plastic containers and labeled with specific reference tags. The following information was captured on each sample: Reference number, Date and time of sampling, Location and Reason for analysis. Thereafter the samples were tightly sealed and securely placed into a cooler box and were delivered to Antech laboratories in Kwekwe for analyses within 6 hours. In-situ measurements were taken for fast-changing parameters like pH and EC to avoid alteration in results (Olufemi et al. 2010).

The collected water samples were analyzed for a total of nine selected physicochemical parameters namely: pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, sulphates, mercury (Hg), iron (Fe), cyanide and turbidity (Table 2). These nine parameters were selected based on the potential ability of a parameter to be influenced by the illegal artisanal mining operations. The methods used to analyze each of the selected physico-chemical parameters were as described by APHA (1998) and Chaurasia and Gupta (2014).

Table 2. Physico-chemical parameters and laboratory methods used to analyse them

Parameter	**Method**	**Units**
pH	Electrode	
Fe	AAS Flame	mg/litre
Sulphate	Titirmetric	mg/litre
Hg	AAS Flame	mg/litre
EC	Conductivity meter	uS/cm
TDS	Gravimetric	mg/litre
Total Hardness	Electrode	mg/litre
Cyanide	AAS Flame	mg/litre
Turbidity	Turbidimeter	NTU

Mapping and characterisation of illegal artisanal gold mining hotspots over the past decade

Multispectral images from satellite observatory Landsat data covering the Muzvezve catchment area were used to assess vegetation cover changes over a 10-year period (2013 -2023). The 10-year period was chosen as it coincided with the time where mining companies retrenched the bulk of their employees, who then resorted to illegal artisanal mining for their livelihood. The Landsat-based images were downloaded from the United States of Geological Survey (USGS) website for the years 2013, 2017 and 2023. To this end, Landsat 8 (launched in February 2013) and Landsat 9 (of September 2021) were used. The normalised difference vegetation index (NDVI) was employed for this exercise. NDVI is a commonly-used metric to obtain information about the spatial and temporal distribution of vegetation cover from satellite data (Matsushita et al., 2007; Puente et al., 2019). The NDVI was selected and used in this study due to its ability to accurately capture vegetation cover changes as reported in several studies (Matsushita et al., 2007; Barasa et al., 2010; Puente et al., 2019; Saaty et al., 2020; Senanayake et al., 2020).

Equation 1 is used, in a Rasta calculator, to calculate the NDVI where reflectance values for the red and near-infrared portions of the electromagnetic spectrum were used. These values were obtained from the remotely sensed satellite images.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad \text{(Equation 1)}$$

Where *NDVI* is normalized difference vegetation index; *NIR* is the surface spectral reflectance in the near infrared band; *Red* is surface spectral reflectance in the red band. The NDVI numerical indicator scale ranges from -1 to 1, with values closer to 1 indicating dense, healthy vegetation and values closer to -1 indicating little to no vegetation. Conversely, an area devoid of vegetation will have an NDVI of zero.

Statistical analysis

Statistical data analysis was done using the R-Software to determine the impact of illegal artisanal gold mining on the quality of water in Muzvezve River. One-way analysis of variance (ANOVA) was conducted to isolate the sources of variation in the concentrations/levels of the selected nine water quality parameters. Pearson's coefficient analysis was used to assess the correlation or association between water quality parameters.

RESULTS AND DISCUSSION

Physico-chemical water quality parameters

Table 3 shows the statistical summaries for each of the eight physico-chemical parameters at the three sampling sites along Muzvezve River. The minimum, mean, median and maximum levels of each physico-chemical parameter at each of the three sampling sites are outlined. Each of the nine physico-chemical parameters is described in greater detail in this section.

Table 3. Summary statistics of water quality parameters in Muzvezve River

Parameter	Sampling Site	Mean	Median	Maximum	Minimum	Std Dev
EC (mg/l)	Upstream (S1)	71.067	68.2	81.6	63.4	9.433
	Middle (S2)	114.767	104	168.2	72.1	48.946
	Downstream (S3)	137.500	162.4	179.7	70.4	58.751
Cyanide	Upstream (S1)	0.006	0.0088	0.0089	0.00084	0.005
	Middle (S2)	0.013	0.014	0.016	0.01	0.003
	Downstream (S3)	0.015	0.014	0.017	0.014	0.002
Iron	Upstream (S1)	0.223	0.21	0.25	0.21	0.023
	Middle (S2)	0.263	0.248	0.321	0.22	0.052
	Downstream (S3)	0.325	0.321	0.349	0.304	0.023
Mercury	Upstream (S1)	0.001	0.0008	0.0019	0.0008	0.001
	Middle (S2)	0.002	0.0019	0.002	0.0017	0.000
	Downstream (S3)	0.002	0.002	0.0023	0.0019	0.000
pH	Upstream (S1)	8.693	8.72	8.76	8.6	0.083
	Middle (S2)	8.583	8.61	8.64	8.5	0.074
	Downstream (S3)	7.370	7.3	7.51	7.3	0.121
Sulphate	Upstream (S1)	0.096	0.093	0.107	0.087	0.010
	Middle (S2)	0.202	0.194	0.317	0.096	0.111
	Downstream (S3)	0.169	0.14	0.264	0.102	0.085
TDS	Upstream (S1)	33.667	31	49	21	14.189
	Middle (S2)	72.000	67	101	48	26.851
	Downstream (S3)	88.000	96	117	51	33.719
Total Hardness	Upstream (S1)	17.333	13	28	11	9.292
	Middle (S2)	42.333	45	61	21	20.133
	Downstream (S3)	31.000	37	41	15	14.000
Turbidity	Upstream (S1)	18.567	18.700	20.800	16.200	2.303
	Middle (S2)	31.800	32.400	33.300	29.700	1.873
	Downstream (S3)	32.700	32.700	33.900	31.500	1.200

Electrical Conductivity (EC)

Average EC levels generally increased from upstream to downstream of Muzvezve River (Figure 3). The upstream site (S1) recorded an average EC level of 70.93µS/cm while S2 and S3 recorded 114.77µS/cm and 137.50µS/cm respectively. The relatively higher EC levels at S2 and S3 can be attributed to the illegal artisanal mining hotspots adjacent to S2, where chemicals used by the miners in their operations find their way into the river.

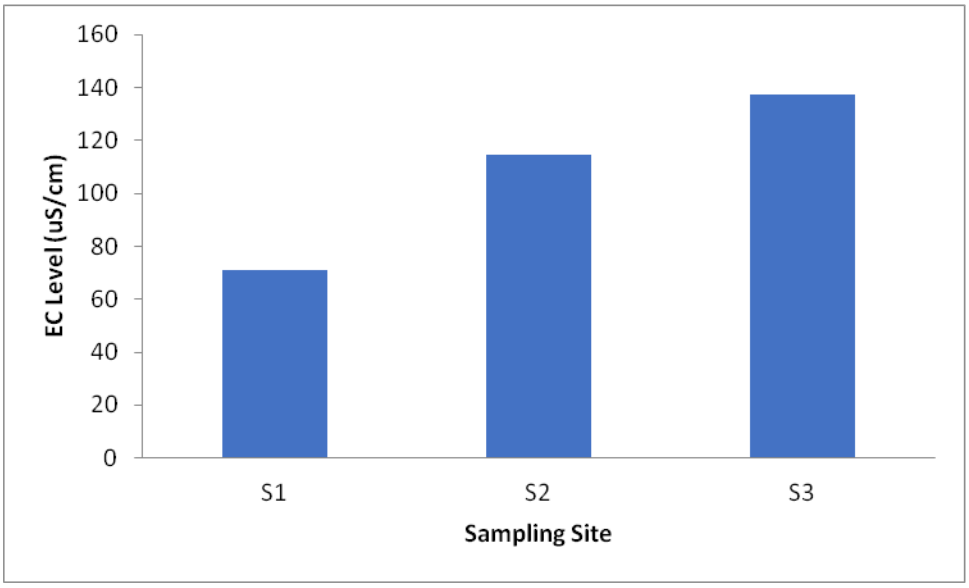

Figure 3. Average EC concentration levels at three sampling sites along Muzvezve River

Despite the seemingly large difference in EC levels of the upstream site (S1) and that of the midstream site (S2), statistically the average EC levels were not significant different (p=0.254). Similarly, S2 and S3 were not statistically different. Thus sampling site was not a source of variation in EC levels of Muzvezve River. Overall the EC levels recorded at all the sections (sites) of Muzvezve River were well within the WHO standards of 1000 µS/cm.

Total dissolved solids (TDS)

Average TDS levels generally increased from upstream to downstream of Muzvezve River (Figure 4). The upstream site (S1) recorded an average TDS level of 33.67mg/l while S2 and S3 recorded 72mg/l and 88mg/l respectively. The relatively higher TDS levels at S2 and S3 can be attributed to the illegal artisanal mining hotspots adjacent to S2, where chemicals used by the miners in their operations and their effluents containing dissolved ions find their way into the river. Similarly, Chen et al. (2018) found mining activities around the River Basin of Xijiang in China significantly increased TDS level in the River.

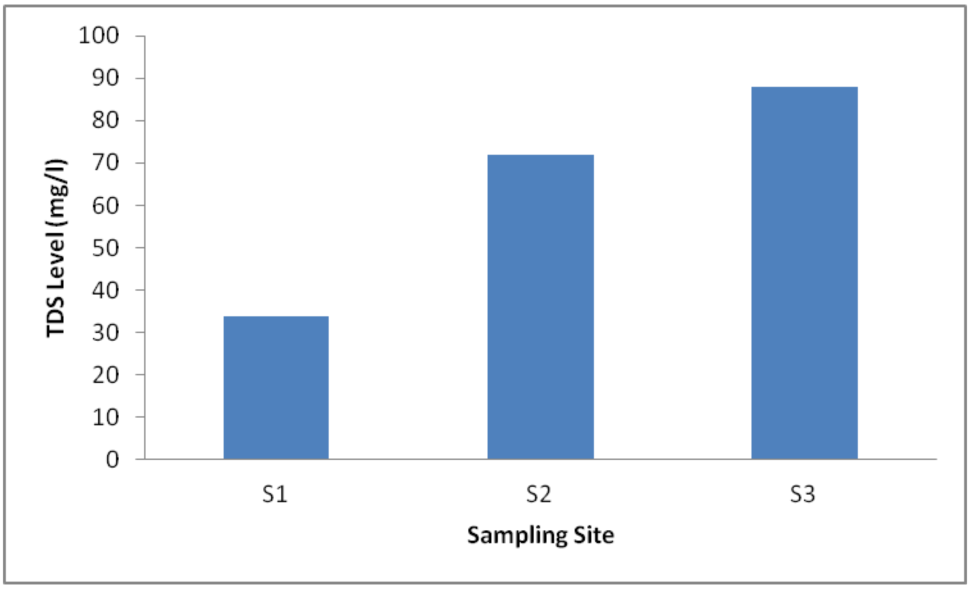

Figure 4. Average TDS concentration levels at three sampling sites along Muzvezve River

Despite the seemingly large difference in TDS levels of the upstream and the downstream sites, statistically the average TDS levels were not significant different (p=0.103). Thus sampling site was not a source of variation in TDS levels of Muzvezve River. Overall the TDS levels recorded at all the sections (sites) of Muzvezve River were well within the WHO standards of 500 mg/l.

pH

Generally pH levels decreased gradually from the reference site (S1) to downstream of Muzvezve River (Figure 5). While all the three sites/sections of Muzvezve River recorded alkaline conditions (pH greater than 7), there was evidence of acidic mining effluent being discharged into the river in the form of lowering pH levels after the midstream site (S2) (8.58) and at S3 (7.37). In similar studies (Masere et al., 2012; Gotore et al., 2022), it was noted that tributaries loaded with acidic wastes are capable of altering the pH level in the receiving waters. There was a significant effect of illegal artisanal gold mining on pH levels in Muzvezve River (F=179.31; d.f= (2, 6); p=0.000).

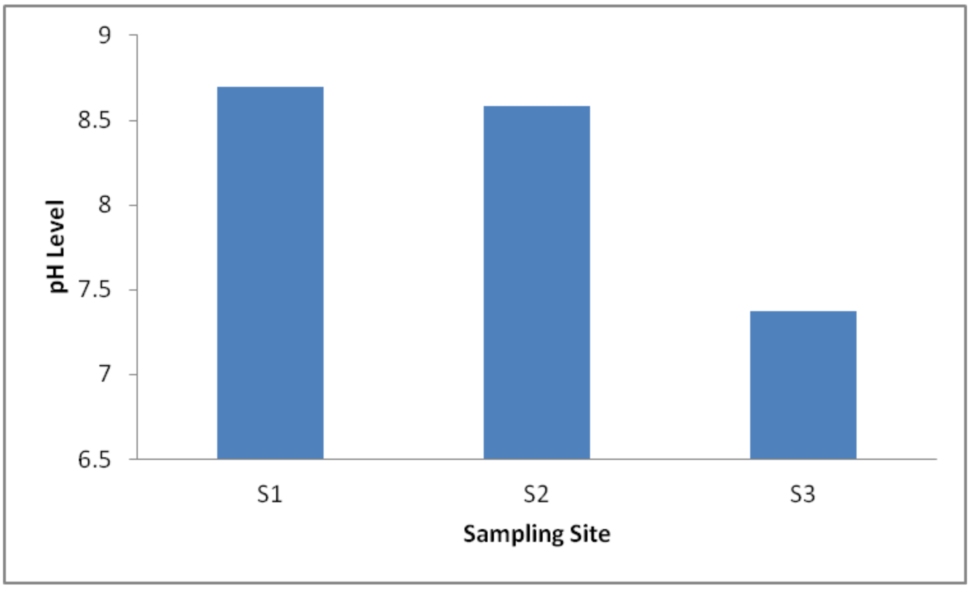

Figure 5. Average pH levels at three sampling sites along Muzvezve River

Statistically, the average pH levels at S1 and S2 are not significantly different. Conversely, the average pH levels at S3 were statistically different from S1 and S2. Thus the average pH levels at S2 and S3 were slightly above the acceptable WHO standards of 6.5 to 8.5. Only the downstream site of Muzvezve River was within the WHO standards.

Total Hardness (TH)

The upstream site S1 recorded the lowest hardness levels among the three sites, followed by the downstream site S3 and S2 (Figure 6). The upstream site (S1) recorded a mean total hardness level of 17.33mg/l while S2 and S3 recorded 42.33mg/l and 31mg/l respectively. The relatively higher TH levels at S2 and S3 can be attributed to the illegal artisanal mining hotspots adjacent to S2, where chemicals used by the miners in their operations and their effluents containing dissolved ions find their way into the river. Hardness in water is mainly due to the presence of ions of the elements calcium, magnesium and iron. In general water with hardness less than 60mg/l are considered soft water (Diggs and Parker, 2009). This implies the Muzvezve river water is considered soft and is lightly buffered against pH changes.

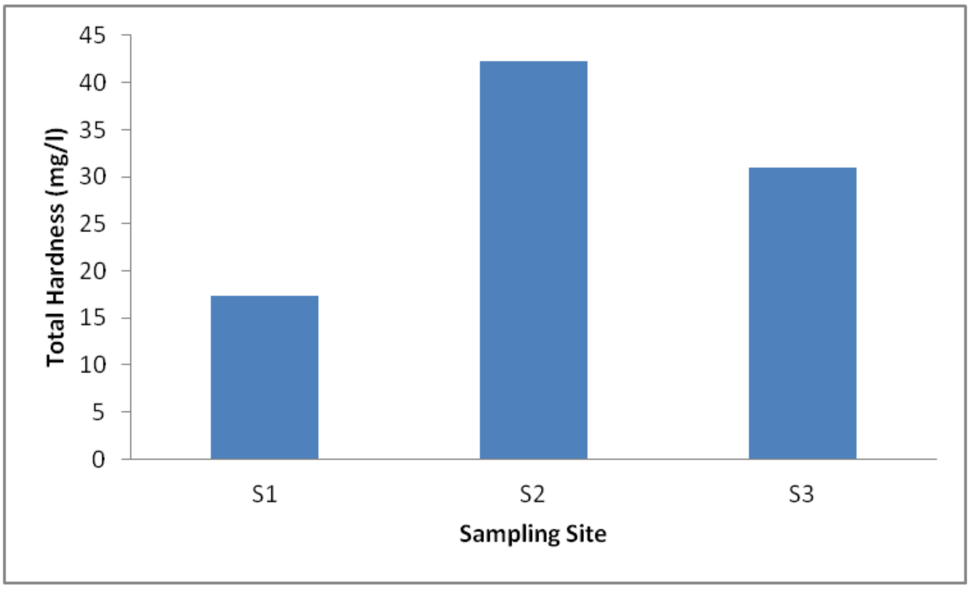

Figure 6. Average total hardness concentration levels at three sampling sites along Muzvezve River

Despite the seemingly large difference in TH levels of the upstream and the midstream and downstream sites, statistically the mean TH levels were not significant different (p=0.210). Thus sampling site was not a source of variation in TH levels of Muzvezve River. Overall the TH levels recorded at all the sections (sites) of Muzvezve River were well within the WHO standards of 150mg/l.

Sulphate

Like with TH concentration levels, the upstream site S1 recorded the sulphate levels among the three sites, followed by the downstream site S3 and S2 (Figure 7). The upstream site (S1) recorded a mean sulphate level of 0.096mg/l while S2 and S3 recorded 0.202mg/l and 0.169mg/l respectively. The highest average sulphate levels recorded at S2 can be attributed to mine effluents from the illegal artisanal mining hotspots adjacent to S2, finding their way into the river.

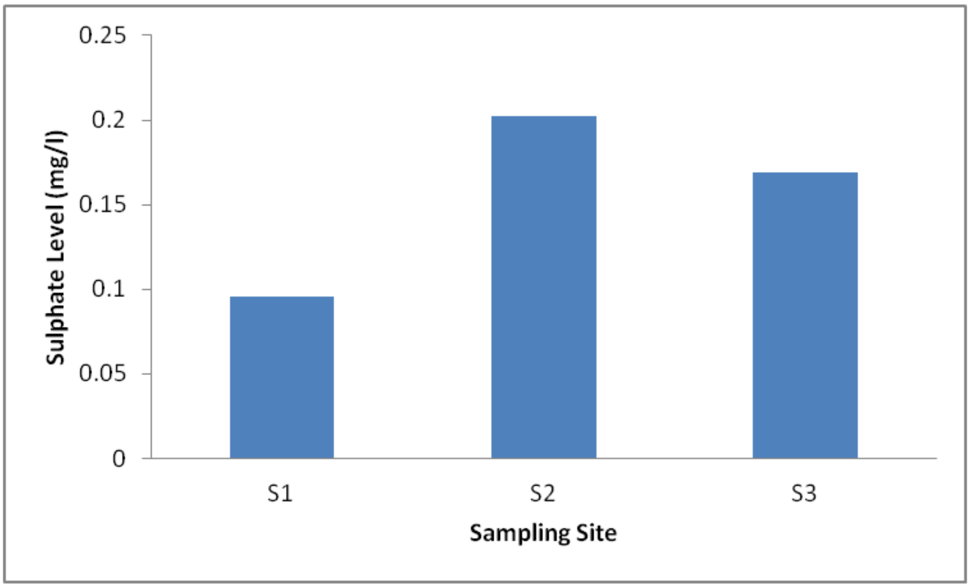

Figure 7. Mean sulphate concentration levels at sampling sites along Muzvezve River

Despite the seemingly large difference in sulphate levels of the upstream and the midstream and downstream sites, statistically the mean sulphate levels were not significant different (p=0.324). Thus sampling site was not a source of variation in sulphate levels of Muzvezve River. Overall the sulphate levels recorded at all the sections (sites) of Muzvezve River were well within the WHO standards of 250mg/l for river water.

Mercury (Hg) level

Generally Hg levels increased steadily from the reference site (S1) to downstream of Muzvezve River (Figure 8). The upstream site (S1) recorded a mean Hg level of 0.0012mg/l while S2 and S3 recorded 0.0019mg/l and 0.0021mg/l respectively. All these Hg concentrations exceed the WHO standard of 0.001mg/l. Again, and like with all the water quality parameters, there is evidence of alteration of concentrations after the midstream sampling site due to adjacent illegal artisanal gold mining operations. There was a significant effect of illegal artisanal gold mining on Hg levels in Muzvezve River (F=4.28; d.f= (2, 6); p=0.070).). Similarly, Mudyazhezha and Kanhukamwe (2014) found mercury levels in Ngwabalozi River, Zimbabwe, along with turbidity and sulphate levels to be significant at p value = 0.000.

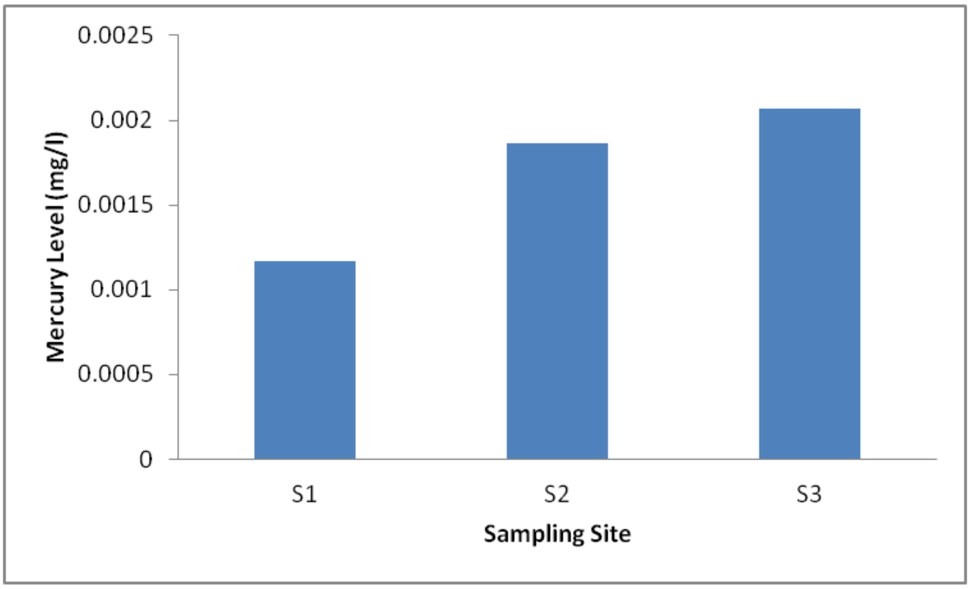

Figure 8. Mean mercury concentration levels at sampling sites along Muzvezve River

Statistically the mean Hg levels at upstream (S1) and downstream (S3) were different, although S1 and S2 were statistically not different. The same applies for S2 and S3. Artisanal gold panners mostly use Hg in higher proportions during their operations because of its low cost, reusability and capacity to simplify the gold separation process, low cost, and reusability (Mudyazhezha and Kanhukamwe, 2014). Muzvezve River flow characteristics and to a lesser extent, rainfall, may have diluted the concentrations downstream. This is consistent with what findings by Nkuli (2008) that Hg levels at the decreased during the rainy season, when river natural purification was at its highest.

Cyanide

Cyanide concentrations, like EC, TDS and Hg, generally increased from the upstream (S1) to the downstream (S3) of Muzvezve River (Figure 9). The upstream site (S1) recorded a mean cyanide level of 0.006mg/l while S2 and S3 recorded 0.013mg/l and 0.015mg/l respectively. Statistically, the upstream site (S1) is significantly different from the midstream and downstream sites (S2 and S3), which are statistically not different.

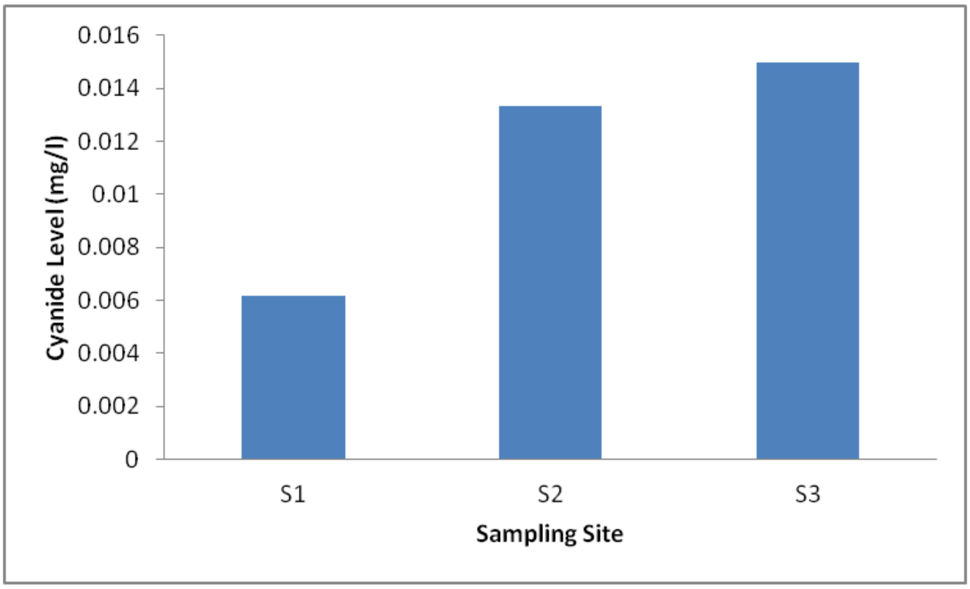

Figure 9. Mean cyanide concentration levels at sampling sites along Muzvezve River

There was a significant effect of illegal artisanal gold mining on cyanide levels in Muzvezve River (F=5.86; d.f= (2, 6); p=0.039). All the three sites recorded cyanide levels within the WHO standard of 0.07mg/l. Consumption of water with higher levels of heavy metals like cyanide results in acute health effects including rapid breathing and heart rate, dizziness, headaches and nausea (Chowdhury et al., 2016; Hu et al., 2019).

Iron (Fe)

Generally Fe levels increased steadily from the reference upstream site (S1) to downstream of Muzvezve River (Figure 10). The upstream site (S1) recorded a mean Fe level of 0.223mg/l while S2 and S3 recorded 0.263mg/l and 0.325mg/l respectively. There was a significant effect of illegal artisanal gold mining on Fe levels in Muzvezve River (F=6.23; d.f= (2, 6); p=0.034).

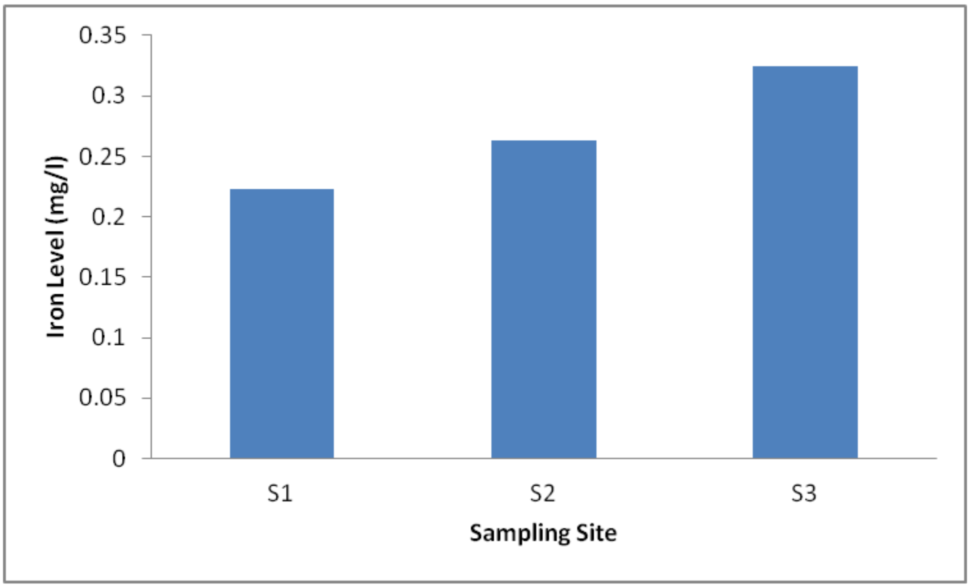

Figure 10. Average Fe concentration levels at sampling sites along Muzvezve River

Statistically the mean Fe levels at upstream (S1) and downstream (S3) were different, although S1 and S2 were statistically not different. The same applies for S2 and S3. The Fe concentrations at all the sampling sites, or simply in Muzvezve River, exceeded the WHO maximum allowable level of 0.1mg/l for river water.

Turbidity

Turbidity levels almost doubled from from the reference upstream site (S1) to midstream site (S2) and thereafter marginally in the downstream site (S3) of Muzvezve River (Figure 11). The upstream site (S1) recorded a mean turbidity level of 18.57NTU while S2 and S3 recorded 31.8NTU and 32.7NTU respectively. These findings are similar to those of Masere et al. (2012) who found turbidity levels in Manyame River, Zimbabwe to range from 21.16NTU to 30.33NTU. There was a significant effect of illegal artisanal gold mining on turbidity concentration in Muzvezve River (F=54.96; d.f= (2, 6); p=0.000). Similarly, Mudyazhezha and Kanhukamwe (2014) found turbidity concentration in Ngwabalozi River, Zimbabwe, along with mercury and sulphates to be significant at p value =0.000.

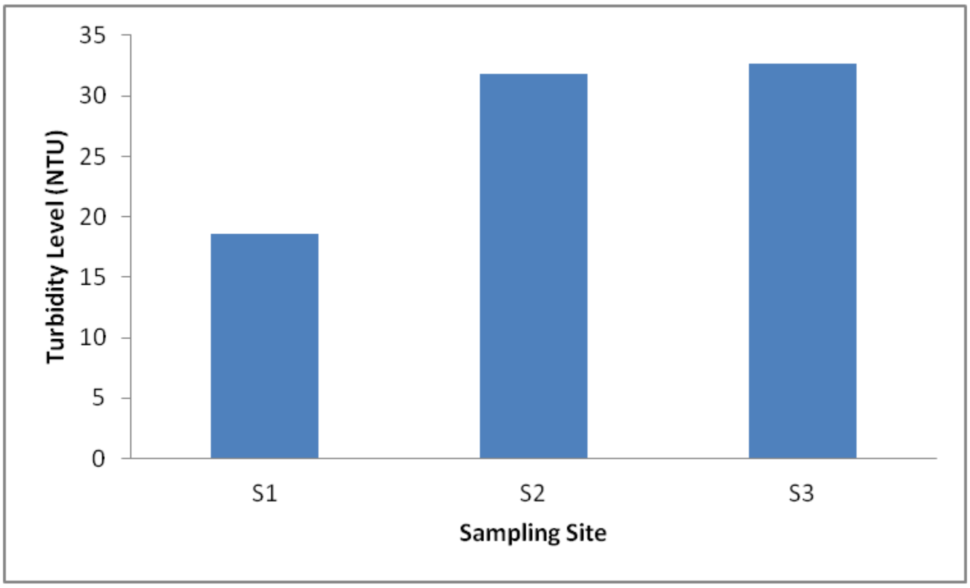

Figure 11. Average turbidity concentration levels at sampling sites along Muzvezve River

Statistically the mean turbidity levels at midstream site (S2) and downstream site (S3) were not different. However these mean turbidity levels are significantly different from the mean levels at the upstream reference site (S1). The turbidity concentrations at all the three sampling sites, or simply in Muzvezve River, exceeded the WHO maximum allowable level of 5NTU for river water.

Correlation and Association of Water Quality Parameters

Association between the eight selected and measured physico-chemical parameters was determined using correlation. Wang's (2018) correlation classification which utilizes correlation coefficient (r) among variables was applied. According to Wang (2018), when $r < 0.3$ the association is considered irrelevant, while r values between 0.3 – 0.49 are considered less relevant, 05 – 0.69 as moderately correlated, with $r > 0.7$ classified as strongly correlated. Table 3 shows that there was generally a strong positive correlation amongst most of the tested parameters. These associations include EC-cyanide (r=0.986), Hg-cyanide (r=0.999), TDS-EC (0.999), pH-turbidity (r=0.991); pH-Hg (r=0.959), TH-Sulphate (r=0.988), among others (Table 4). Tawari-Fufeyin et al. (2015) also noted the strong positive correlation between TDS and EC especially at higher temperatures. The Fe-pH correlation (r=0.750) is closely matching findings by Joshua (2023) who found an association between Fe-pH of r=0.692. While pH associations with heavy metals was generally strongly positively correlated, Amfo-Otu et al. (2014), found these correlations to be strongly negatively. The moderately positive correlated association were only between EC-TH (r=0.687) and Fe-sulphate (r=0.572). Positive correlation implies that an increase in one parameter is associated with an increase in the second variable and vice versa (Joshua, 2023). The Fe-TH association was the only one that was less relevant (r=0.437). Interestingly, there was no negative correlation between any two water quality parameters.

Table 4. Correlation coefficient (r) between selected physico-chemical water quality parameters

Parameters	**EC**	**Cyanide**	**Fe**	**Hg**	**pH**	**Sulphate**	**TDS**	**TH**	**Turbid**
EC	1.000								
Cyanide	**0.986****	1.000							
Fe	**0.954****	**0.892****	1.000						
Hg	**0.992****	**0.999****	**0.907****	1.000					
pH	**0.914****	**0.968****	**0.750****	**0.959****	1.000				
Sulphate	**0.792****	**0.881****	**0.572***	**0.864****	**0.972****	1.000			
TDS	**0.999****	**0.994****	**0.937****	**0.997****	**0.934****	**0.823****	1.000		
TH	**0.687***	**0.797****	0.437	**0.776****	**0.923****	**0.988****	**0.725****	1.000	
Turbidity	**0.959****	**0.993****	**0.830****	**0.988****	**0.991****	**0.932****	**0.973****	**0.864****	1.000

*Significant values are in bold, * indicates moderately correlated while **implies parameters are Strongly correlated*

Illegal artisanal gold mining hotspots in Muzvezve Catchment

Three illegal mining hotspots within Muzvezve catchment were identified and mapped. These were: Muzvezve-Kanyemba area, Brompton and Pickstone surrounding areas (Figure 12). It is clear from Figure 11 that the greater portion of the illegal artisanal mining hotspots was around sampling site S2.

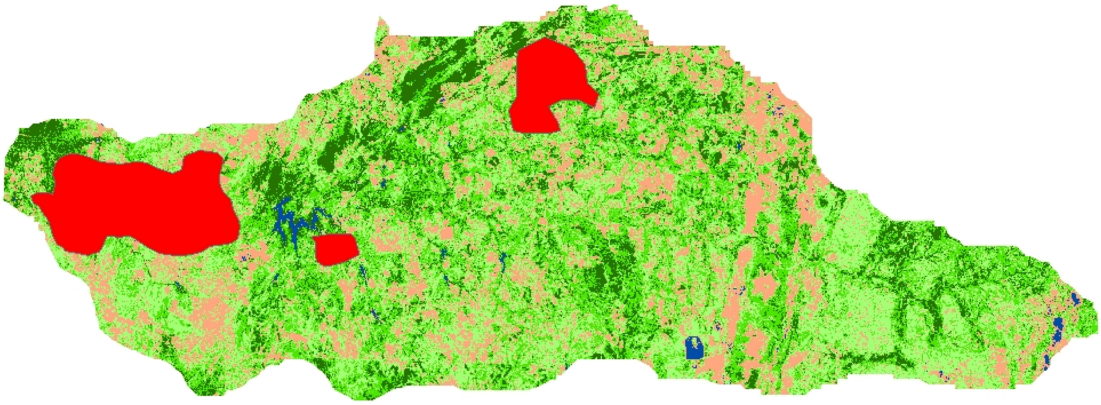

Figure 12. Geographic location of the illegal mining hotspots (shown in red colour)

The mapped hotspots were analysed using the NDVI and two broad vegetation classes were noted and these were sparse vegetation and dense vegetation. The area covered by each of the two vegetation classes where measured in 2013 to form the basis for comparison of the extent of vegetation loss due to illegal artisanal mining between 2013 to 2023 (Table 5). Of the total area covered by illegal artisanal hotspots dense vegetation occupied 36.31Ha while sparse vegetation covered 241.04Ha as of the year 2013.

Table 5. NDVI for different vegetation cover classes and their area of coverage in 2013

NDV1	**Vegetation Cover Class**	**Coverage (Ha) in 2013**
0.27	Sparse vegetation	241.04
0.68	Dense vegetation	36.31
Total		**277.35**

Vegetation cover changes in Muzvezve Catchment from 2013 to 2023

Vegetation coverage changed significantly in both vegetation classes (sparse and dense) from 2013 to 2017 to 2023 in the illegal gold mining hotspots in Muzvezve catchment (Figure 13). By the year 2017, total vegetation coverage decreased from 277.35Ha to 233.01ha translating to a decrease of 20%. A further 8.3% decline in overall vegetation coverage was observed by the Year 2023. The artisanal gold mining did greater damage in the dense vegetation class where vegetation coverage by

26.5% and 27.8% by year 2017 and year 2023 respectively. Conversely, sparse vegetation class loss 18.6% and 5.6% through the same time periods.

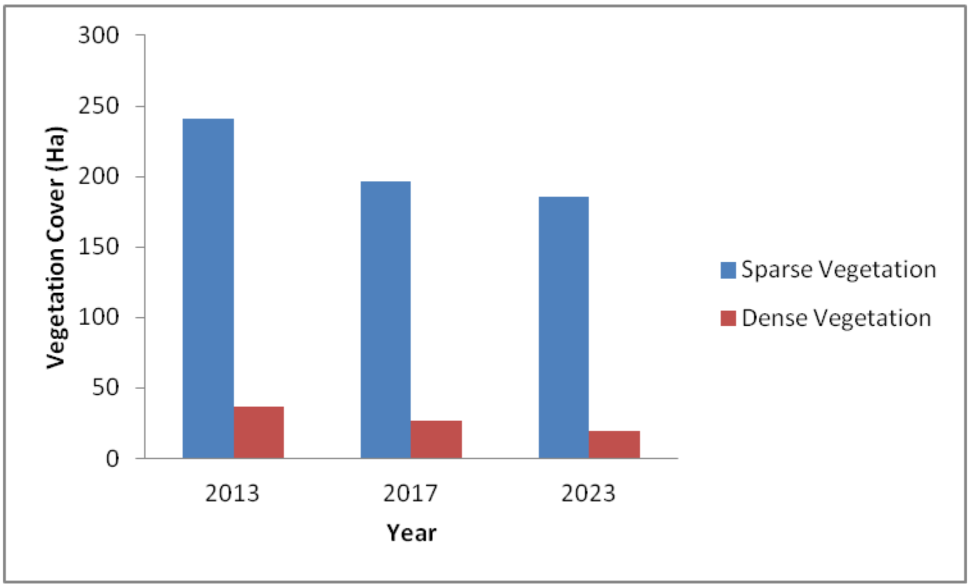

Figure 13. Vegetation coverage in the illegal artisanal gold mining over a 10-year period

The reduced in vegetation cover found in this study is a common phenomenon whenever unregulated and unsustainable land use practices. Several studies, both locally and abroad (Masere, 2022; Masere et al., 2023; Nyahwai et al., 2022; Senanayake et al., 2020) reported on deforestation for mining and other economic activities and its negative effect on the environment. These adverse externalities include; pollution of surface waters, soil erosion, land degradation, greenhouse gas emissions and climate change among others. Consistent with Masere et al. (2012), Mudyazhezha and Kanhukamwe (2014) and Gotore et al. (2022) human activities like mining, agriculture and the related unsustainable land management like deforestation contribute in river siltation resulting in high turbidity. Due to the illegal aspect of the operations of unsanctioned artisanal mining in Muzvezve Catchment it is difficult for the relevant authorities to control the loss of vegetation.

CONCLUSION

The study found that illegal artisanal mining operations were contributing to the deteriorating quality of water in Muzvezve River. The effects of this illegal gold mining activity are clearly noticeable by the rapid increase in the concentration level of, all but one tested water quality parameters (pH), at the midstream site (S2), which was in the vicinity of illegal gold mining hotspots. Only pH levels had an inverse negative relationship with distance from the reference upstream site (S1). One way ANOVA showed that of all the measured physico-chemical water parameters, statistically, pH, turbidity, Hg, Fe, and cyanide levels were significantly altered by illegal artisanal gold mining at varying p levels. Thus, it is mainly the heavy metals (Hg, Fe and cyanide) pollution that is of great concern, as they affect aquatic life and the health of people and animals using the Muzvezve River for drinking other domestic purposes. Among the heavy metals, Fe was found in the highest concentration levels followed by cyanide and mercury. The study further illustrated that there was strong positive correlation between most of the water parameters which implies that that an increase in one parameter is associated with an increase in the second parameter and vice versa. This also means that the pollution by various contaminants in Muzvezve is all linked to one source: illegal artisanal gold mining. Thus controlling or regulating this illegal activity will definitely arrest the pollution of Muzvezve River. Beyond this, four of the nine measured parameters (pH, Fe,Hg and turbidity) were found to be above the maximum allowable WHO standards. Through the use remote sensing imagery three illegal artisanal gold mining hotspots adjacent to the midstream sampling site (S2) where vegetation coverage was measured from 2013 to 2023. It can be concluded that illegal artisanal gold mining have significantly degraded the quality and quality of vegetation in the identified hotspots. As such the study recommends genuine engagements between the relevant authorities like the environmental management agency (EMA), Muzvezve Rural District Council, Mining Companies and Associations, the Zimbabwe Republic Police (ZRP), the artisanal gold miners and the community at large in coming up with restoration and rehabilitation efforts to address the environmental damages already suffered as well to arrest or reduce further the damage to environment.

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