An Explorement of the Implications of Dumpsite Leachate on Surface Water Quality in Muenene River, Mutare, Zimbabwe

Norman Gumbo[1], Charles Sithole[2]. Marshal Magenge[3]

[1]Occupational health, Safety, Quality and environmental management specialist National University of Science and Technology, Bulawayo, Zimbabwe Box AC 939, Ascot Bulawayo, Zimbabwe

[2]Lecturer, department of Environmental Science National University of Science and Technology, Bulawayo, Zimbabwe Box AC 939, Ascot Bulawayo, Zimbabwe

[3]Lecturer, department of Geography and Environmental Science Gwanda State University

DOI: https://doi.org/10.51584/IJRIAS.2024.908063

Received: 14 August 2024; Accepted: 22 August 2024; Published: 19 September 2024

ABSTRACT

Background: Solid waste is one of biggest challenges of the urban areas of all sizes, from mega cities to small towns and large villages, which are home to the majority of mankind. In addition, the non-industrialised countries have low levels of refuse collection rates of 30 to 60% in low income countries and 50-60% in middle income countries. Globally, there are ongoing campaigns encouraging the use of the environment in a sustainable manner, which implies that the negative impacts on the environment and climate change must be taken into consideration.

Methodology: The researchers instituted an experimental design. The researchers collected leachate samples from Mutare Open Dump site for laboratory analysis. Water samples were also collected from Muenene River for physico-chemical parameter analysis, heavy metal analysis and nutrient for laboratory analysis. The results were compared with the WHO standards and the Environmental Management Agency standards. The Winkler method was used for determination of Dissolved Oxygen, the multi-parameter brand 40HQD was used to test for the physico-chemical parameters [pH, Electrical conductivity (EC), and Total Dissolved Solids (TDS)]. Atomic Absorption Spectrometry (AAS) was used for the determination of iron, copper, zinc, cadmium, nickel, manganese, chromium, calcium, Magnesium and lead from samples The Spectrophotometer was used to measure the nutrients of phosphate, nitrates, sulphates, and ammonia. The broad objective of the study being to assess the impacts of dumpsite leachate in surface water quality in Muenene River in Mutare. The specific objectives were, to determine the levels and variations of the following physico-chemical parameters in Muenene River: pH, TDS, EC, and Salinity.to analyse the nutrient levels in leachate and leachate-contaminated Muenene River water in terms of nitrate, ammonia, sulphate, and phosphate and to measure the concentrations of selected heavy metals (Cd, Zn, Fe, Cr, Pb, Mg, Cu, and Ni) in Mutare dumpsite leachate.

Results: Nutrients such as ammonia, phosphate, nitrates were found to be above the permissible levels, subsequently leading pollution of the Muenene River. The heavy metals include Fe, Pb, Mn and Cd were found to be above permissible levels in terms of S.I 6 of 2007 for wastewater discharge regulations in Zimbabwe. Zn, Ni and Cr were detected but were at normal range that is not harmful to the environment. The leachate generated from dump site finally flows into a stream used to irrigate vegetables and fruits. The water quality analysis revealed unsatisfactory results due to the elevated concentrations of phosphorus, ammonia, and the biochemical oxygen demand ratio (BOD).

Conclusion: Results of the physico-chemical parameters analysis indicated that untreated leachate and unsegregated solid waste leads to deterioration of water quality. The nutrient quality of the water was also compromised as ammonia, phosphate, nitrates were found to be above the permissible. The heavy metals include Fe, Pb, Mn and Cd that were found to be above permissible levels in terms of S.I 6 of 2007 for wastewater discharge regulations in Zimbabwe. Zn, Ni and Cr were detected but were at normal range that is not harmful to the environment.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

INTRODUCTION

[1] report listed the world's 50 biggest dumpsites and highlights their environmental and health impacts. According to the estimates provided, those 50 dumpsites affect the lives of 64 million people[2]. ISWA President Newman in 2015 also said that open dumping usually takes place close to the urban centres and in some cases residential areas are formed and expanded around the dumpsites and almost all the world's 50 biggest dumpsites are located near or even within urban areas and close to natural resources. 42 out of the 50 dumpsites have settlements in a distance of less than 2km, 44 dumpsites are close 9less than 10km) to natural resources and 38 dumpsites are close to water sources such as rivers. lakes, oceans, posing a threat to marine and coastal pollution and obviously, although unquantified, the contribution of dumpsites to marine litter is substantial[2]. It has been estimated that globally, urban food waste is going to increase by 44% from 2005 to 2025 and if present waste management trends are maintained, dumped or landfilled food waste is predicted to increase the landfill share of global anthropogenic Greenhouse gas emissions from 8 to 10%.

According to[3] management of waste is demanding and challenging undertaking in all European countries, with important implications for human health and well-being, environmental preservation, sustainability and economy. Compliance with the regulations has resulted in significant progress; however, concerns remain as to possible health impacts of waste circulation, management and disposal especially in connection with informal practices and obsolete technologies, stated in the report[3].

Uncontrolled dumpsite and waste dumpsite threaten the ground water supply as movement of leachates from dumpsites through soil and aquifers pose a risk to the environment. As the release of pollutants through leachates from both functional and abandoned dumpsites pose a risk to nearby soil and groundwater of not adequately managed[4]. Though open dumpsite is the easiest form of disposal of municipal solid waste that is available and affordable to Private Sector Participants (PSP) and also utilised by the waste management Board, this basis on financial terms neglects the direct and indirect costs associated with the continuing and environmental degradation along with its concomitant effect on public health and environmental sustainability. Taking into cognisance the potential and actual impacts of associated direct and indirect costs, there is a fundamental need for upgrading the overall standards of final disposal of municipal solid waste in the State[4]

Groundwater remains a vital natural resource that requires continuous and concerted efforts to protect it. Continuous indiscriminate waste dumping and unruly human behaviour towards environmental management and strategies require a holistic approach to environmental security. Studies show that open dumpsites remain the most popular source of water and environmental pollution[5–6]. Open dumpsites are the most common practice all over the world for municipal solid waste (MSW) disposal and their environmental impacts have received much attention in the last decades [7], especially in developing countries where most solid wastes are carelessly disposed.

Environmental impacts and public health risks of open dumpsites include subsoil contamination, groundwater pollution, generation of volatile organic compounds (VOCs), and creation of greenhouse gas emissions remain issues of great concern [8]. Unlike developed countries, most African countries rely on open dumpsites without a standardized sanitary landfill[9].

According to the International Solid Waste Association (ISWA) and the United Nations Environment Programme (UNEP), the MSW generation in developed countries is fast beginning to stable. However, UNEP expresses fear over the upsurge in waste generation in developing nations, while economic activities continue to crawl across the world[10]. Developing nations are the most affected by this necessary devil (dumpsite). Nigeria has been reported as taking the lead position among the 50 world's biggest active dumpsites from 30 countries because Nigeria alone maintains 12% of the 50 world's biggest active dumpsites [11].

With the adverse effects of dumpsites on human health and the environment, urgent attention is required to prevent the prevailing indiscriminate wastes disposal in developing nations because the situation has reached a critical point[12]. Recent studies show that the challenge of environmental pollution and waste management is one of the major concerns of researchers and geoscientists across the globe [13]. However, the environmental

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

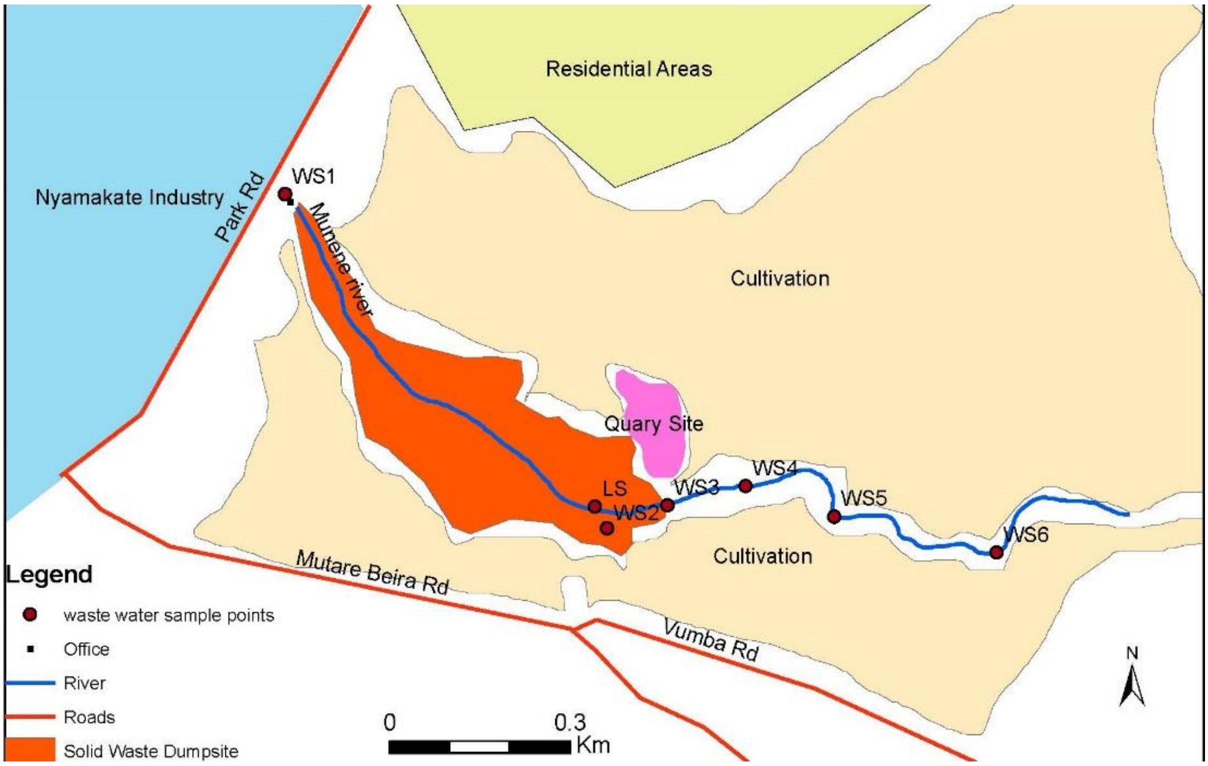
impacts of dumpsites are not limited to the groundwater resources, it also affects ground soil as well as human health [14].

With the current increase of open dumpsites all over the world, especially in Africa, the qualities of underground resources such as soil and water are under major threat [15]. This is because all dumpsites (large or small) are usually associated with leachate plumes and odorous gas polluting the environment and water resources [16]. Reports indicate that the degree of leachate impacts and emission gases of a landfill depends on the nature of landfills[17]. However, pollution problems are particularly severe for waste dumped in abandoned gravel pits and sediment regions which may extend down to the groundwater table[17].

The solution to these challenges in our modern urban society demands fast and effective special geophysical techniques due to high ion concentrations associated with landfill leachates, which in turn weaken the subsoil resistivity. Studies revealed that the leachates formed within the dumpsite rarely remained at the point of discharge[18], they are transported through the porous media within the subsurface. This is because water pollution happens mostly through the percolation of fluvial water and the infiltration of contaminants via the soil in waste disposal sites[19]. Therefore, ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock [2º].

The broad objective of the study being to assess the impacts of dumpsite leachate in surface water quality in Muenene River in Mutare. The specific objectives were, to determine the levels and variations of the following physico-chemical parameters in Muenene River: pH, TDS, EC, and Salinity.to analyse the nutrient levels in leachate and leachate-contaminated Muenene River water in terms of nitrate, ammonia, sulphate, and phosphate and to measure the concentrations of selected heavy metals (Cd, Zn, Fe, Cr, Pb, Mg, Cu, and Ni) in Mutare dumpsite leachate.

Study Area



Study area map

The study area is the Mutare City open dump site situated near Nyamakate industrial area and along park road. It is located 3km from the city centre of Mutare and is the main dump site for the city of Mutare. The dump site is not lined and leachate is not being treated. The dump site is also situated along side Muenene River which then crosses the border into Mozambiquean side where it feeds into Chicamba Dam. The site

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topography of Mutare city dump is undulating and the terrain is generally tilted towards the southern parts. The dumpsite area is located on the southern side of the city and Nyamakate industrial area. The terrain is fully sloped all the way down the river. Following the convex of the topography of the dump site surroundings, the terrain slopes both to the east and west. On the southern side of the dump site there is a river that flows after mixing with leachate from the dump site

Methods

The researchers instituted an experimental design. The researchers collected leachate samples from Mutare Open Dump site for laboratory analysis. Water samples were also collected from Muenene River for physico-chemical parameter analysis, heavy metal analysis and nutrient for laboratory analysis. The results were compared with the WHO standards and the Environmental Management Agency standards. The Winkler method was used for determination of Dissolved Oxygen, the multi-parameter brand 40HQD was used to test for the physico-chemical parameters [pH, Electrical conductivity (EC), and Total Dissolved Solids (TDS)]. Atomic Absorption Spectrometry (AAS) was used for the determination of iron, copper, zinc, cadmium, nickel, manganese, chromium, calcium, Magnesium and lead from samples The Spectrophotometer was used to measure the nutrients of phosphate, nitrates, sulphates, and ammonia.

Rationale

Physico-chemical parameters such as EC, TDS, salinity, pH, turbidity serve as indicators in water quality monitoring. These parameters help determine whether water is suitable for consumption. Heavy metals such as Cr, Cd, Fe, Zn, Cu can have adverse effects on health and the environment. Elevated levels in water can lead to chronic poisoning in aquatic life and pose risks to human health.Monitoring physico-chemical parameters alongside heavy metals helps to identify potential contamination and assess water safety.

Sampling Approach

Purposive sampling was instituted because some areas of the river and dumpsite were not accessible.

Sample collection, preservation and storage

A total of 6 samples of wastewater from Muenene River were collected and 3 sample bottles per each sampling point, for the Nutrients, Heavy Metals, and Dissolved Oxygen. These samples were collected in bottles measuring 1litre. A total of 1 sample of leachate was collected from the solid waste dump site. The leachate sample bottles were two (2) for the Nutrients and Heavy metals. The samples were collected in sample bottles measuring 500ml. All the samples were collected in plastic bottles. The bottles were thoroughly cleansed and rinsed with reagent water. The volumes collected were sufficient to ensure a representation of the sample. The samples for leachate were preserved with sulphuric acid (H_2SO_4). All these samples were then placed in cooler boxes and transported to Bulawayo National University of Science and Technology Laboratory for analysis.

Sampling coordinates for Mutare City Dumpsite and Muenene River

Sampling site	Sampling type	Coordinates	Altitude	Distance
LS 1	Leachate sample	S18.99364^0 E032.67373^0	1 039m	0
WS 1	Water sample	S18.98896^0 S032.66908^0	1 105m	0
WS 2	Water sample	S18.99396^0	1 054m	753m

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

		E032.67391^0		
WS 3	Water sample	S18.99371^0 E032.67477^0	1 056m	90m
WS 4	Water sample	S18.99340^0 E032.67596^0	1 039m	132m
WS 5	Water sample	S18.99385^0 E032.67729^0	1 020m	144m
WS 6	Water sample	S18.99349^0 E032.67954^0	995m	244m

The wastewater sample 1 (WS1) is the control and it was collected upstream of Muenene River before mixture with leachate residue from the dumpsite. The WS2 is another water point just at the dumpsite where the waters are just oozing and flows into the Muenene River. WS3 is a point where the leachate and water from the city council meet and flows together. WS4 is another sampling point situated at 132m from the point of leachate discharge. Along Muenene River another WS5 point was selected and at this point some waste pickers were washing their waste material that they were collecting from the dumpsite. WS6 was the last accessible point due to the terrain of the river and was furthest from the dumpsite.

Winkler Method

This is a technique used to measure dissolved oxygen in freshwater systems. Dissolved oxygen is used as an indicator of the health of a water body, where higher dissolved oxygen concentrations are correlated with high productivity and little pollution. The researcher tested the dissolved oxygen at NUST laboratory for Applied Science. Titration was used to determine dissolved oxygen in the water samples brought from the Muenene River. Six samples namely WS1, WS2, WS3, WS4, WS5, and WS6 were tested. All the samples were fixed by adding a series of reagents that formed an acid compound. This was then titrated with a neutralizing compound that resulted in colour change. The colour change is called the “endpoint” which coincides with the dissolved oxygen concentration in samples. Dissolved oxygen analysis was done to determine the health or cleanliness of Munene river, and the level of decomposition occurring in Muenene River.

The list of reagents used:

- 2ml Manganese sulphate
- 2ml alkali-iodide-azide
- 2ml concentrated sulfuric acid
- 2ml starch solution
- Sodium thiosulfate

A lot of caution was observed during the process.

The following procedure was followed:

i. Carefully filled a 200ml glass Biological Oxygen Demand (BOD) stoppered bottle brim-full with sample water.
ii. Immediately added 2ml of manganese sulphate to the collection bottle by inserting the calibrated pipette just below the surface of the liquid.
iii. Added 2ml of alkali-azide reagent in the same manner.

iv. Stopped the bottle with care to be sure that there was no air introduced. Mixed the sample by inverting several times. Brownish-orange clouds of precipitate or floc appeared and settle down, mixed the sample by turning it upside down several times and let it settle again.
v. Added 2ml of concentrated sulphuric acid via pipette held just above the surface of the sample. Carefully placed the stopper and inverted several times to dissolve the floc. At this point the sample was fixed and stored for 8 hours. As an added precaution, squirt distilled water on the stopper, and cap the bottle with aluminium foil and a rubber band during the storage period.
vi. In a glass flask, titrated 200ml of the sample with sodium thiosulfate to a pale straw colour. Titrated by slowly dropping titrant solution from a calibrated pipette into the flask and continually stirring or swirling the sample water.
vii. Added 2ml of starch solution to form a blue colour.
viii. Continued slowly titrating until the sample turns clear. As this experiment reached the endpoint, it took only the drop of titrant to eliminate the blue colour.
ix. The concentration of dissolved oxygen in the sample is equivalent to the number of millilitres of titrant used. Each ml of sodium thiosulfate added in steps 6 and 8 equals 1mg/l dissolved oxygen.

Biological Oxygen Demand (BOD)

The leachate samples were kept in the refrigerator before laboratory analysis. The 200ml samples of water were measured for the initial and final reading. The other 200ml of water received some sodium thiosulphate in the burette and 2ml of starch solution as an indicator and then titrated. The 6 samples were then placed in the dark cupboard for 5 days and shown the following readings on the day 5.

Multi-Parameter Brand 40HQD

A PCS-Testr 35 Multi-Parameter was used to measure the Physico-chemical parameters insitu. The muliti-parameter measured the pH, Electrical conductivity (EC), and Total Dissolved Solids (TDS). These parameters were measured on the wastewater in Munene River at the 6 sample collection points. That was done traversing Munene River from the upstream to downstream selected sampling sites. The results were collected for each sampling point for the three (3) physico-chemical parameters.

Atomic Absorption Spectrometry

In direct aspiration atomic absorption spectroscopy, samples were aspirated and atomized in a flame. A light beam from a hollow cathode whose cathode was made of the element to be determined was directed through the flame into a monochromatic and onto a detector that measured the amount of light absorbed. Absorption depended upon the presence of free unexcited ground state atoms in the flame. Since the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample. This principle is the basis of atomic absorption spectroscopy. The technique generally is limited to metals in solution or solubilised through some form of sample processing. This technique was used for determination of iron, copper, zinc, cadmium, nickel, manganese, chromium, calcium, Magnesium and lead from samples. The addition of lanthanum will overcome the phosphate interference in the magnesium, calcium and barium determination. Similarly, silica interference can be eliminated by addition of calcium.

Below is a standard that was used for heavy metals during the use of Atomic Absorption Spectrometry in the laboratory.

Table 1: Standards for heavy metals

Element	Standard
Zn	1ppm
Pb	1ppm

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Cr	5ppm
Mn	5ppm
Ni	10ppm
Mg	10ppm
Cl	20ppm
Cu	20ppm
Fe	10ppm
Cd	1.0ppm
Cu	1.0ppm

Spectrophotometry

The Spectrophotometer was used to measure the nutrients of phosphate, nitrates, sulphates, and ammonia. This was done after processing the samples in the laboratory. The standard measurements were collected before the actual results.

The following wavelengths as shown by the table below were observed:

Table 2: wavelength for the nutrients

Nutrient	Wavelength
Phosphate	890nm
Sulphate	Gravimetric method
Ammonia	415nm
Nitrate	410nm

The spectrophotometer was used to analyse the heavy metals with the following wavelengths for each heavy metal as shown below:

Table 3: Wavelengths for heavy metals

Element	Wavelength (nm)
Zinc (Zn)	213.9
Cadmium (Cd)	228.8
Nickel (Ni)	232
Chromium (Cr)	273.9
Iron (Fe)	248.3

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Manganese (Mn)	279.5
Copper (Cu)	324.8
Lead (Pb)	283.3

Data analysis

The initial data analysis was done using SPSS and Principal Component Analysis (PCA) was instituted for further statistical treatment of data.

Ethical Issues

The researchers sought permission to conduct the study from the Health Services Director, Mutare City. Clearance to conduct the study was granted by the National University of Science and Technology research board.

RESULTS

Physic-chemical parameters

The physical chemical parameters that the researchers measured were the pH, electrical conductivity, total dissolved solids and the salinity of the wastewater from the Muenene River. The physic-chemical parameters were obtained insitu using the Multi-meter.

The following results were obtained insitu.

pH

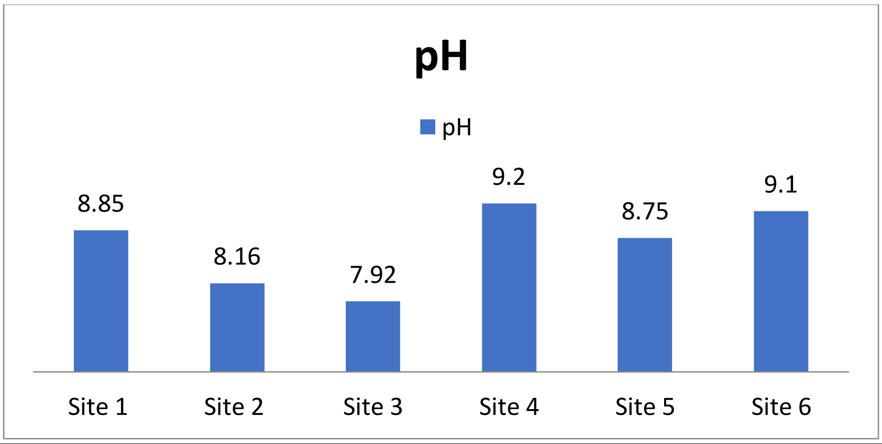

Fig 1: pH results for W/Samples

As depicted in fig 1, the pH obtained was between 7.92- 9.2 on all the (6) six sampling points. The sampling site 3 recorded the lowest pH levels of 7.92 and all other sampling points exceeded that level.

Electrical conductivity

Table 1: **Electrical Conductivity**

Site	Electrical conductivity
Site 1	37.2 mS

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Site 2	967 μS
Site 3	3.20mS
Site 4	2.74mS
Site 5	2.60mS
Site 6	2.49mS

The electrical conductivity for all sampling sites was obtained, with site 2 having 967micro Sievet per centimetre (μS) followed by site 1, which is the control with $37.2\ mS$ Site 3 recorded $3.20\ mS$ and the rest were all below 3 mS but above 2 mS. Site 1 had the highest level of electrical conductivity of $37.2(\mu S)$.

Total Dissolved Solids (TDS)

Site 3 of the sampling point recorded highest levels of total dissolved salts of 2.24ppt (parts per thousand). Site 4, Site 5 and Site 6 recorded high levels of Total Dissolved Solids (TDS) as compared to Site 1 and Site 2. The levels of TDS were degreasing from 2.24ppt to 1.75ppt along the Muenene River.

Table 3: **Results for Total Dissolved Solids**

Site	Total Dissolved Solids
Site 1	26.6ppm
Site 2	685ppm
Site 3	2.24ppt
Site 4	1.94ppt
Site 5	1.81ppt
Site 6	1.75ppt

Salinity

Table 4 salinity Results in mg/l

Site	Salinity
Site 1	24.2ppm
Site 2	418ppm
Site 3	1.42ppt
Site 4	1.22ppt
Site 5	1.14ppt
Site 6	1.10ppt

Salinity was measured and it showed that site 3 recorded significant high levels of 1.42ppt. Sites 4, 5 and 6 were gradually decreasing along the Muenene River. Sites 1 and 2 had very low levels of salinity.

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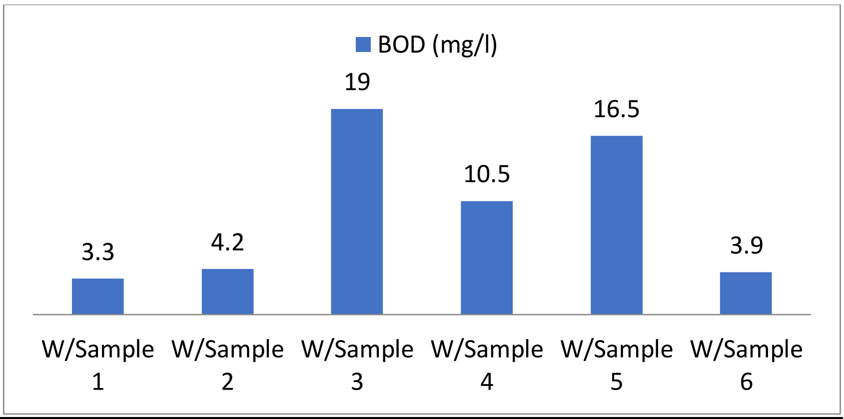
(BOD)

Table 5: A BOD_5 results on the day 5.



The Biological Oxygen Demand (BOD) which determines the relative oxygen requirements of wastewaters, with the results shown above in table 5, W/Sample 1, W/Sample 2, and W/Sample 6 were all below 10mg/l. W/Sample 3 recorded the highest level of BOD. That was followed by W/Sample 5 that recorded 16.5mg/l. W/Samples 1, 2, and 6 were all below 10mg/l.

Nutrient status

Nitrate and Ammonia

As depicted in fig 5 for Nitrate and Ammonia, in leachate, Nitrate (NO_3) was not detected in W/Sample 1, Nitrate levels obtained was recorded at 0.1315mg/l, which was from control sampling point. W/Sample 3, Nitrate levels obtained was 0.1749mg/l followed by W/Samples 4, 5, and 6. On all these sampling points they were all below 1mg/l. comparing with[18], the parameter was not measured or indicated but on[19] standard for clean or portable water, it was regulated that Nitrate should not exceed 0.1mg/l. however, all the sampling points results obtained were slightly above 0.1mg/l with minute mg/l.

Ammonia (NH_3) results obtained shown that all the sampling points have NH_3 detected. W/Sample 3 indicated the highest levels of ammonia with 7.722mg/l and was followed by W/Sample 5 with 6.2275mg/l, the least amount of ammonia was detected on W/Sample 6, which was the last sampling site and W/Sample 1 which was also the control with 1.500mg/l as shown in fig 5 below. In comparing with the[21], leachate sample, W/Samples 3,4,5, and 2 are all in the Red Zone since they were all above the recommended levels of 1.5mg/l in the standard for effluent discharge regulation of Zimbabwe. W/Sample 1 and W/Sample 6 are all in yellow zone.

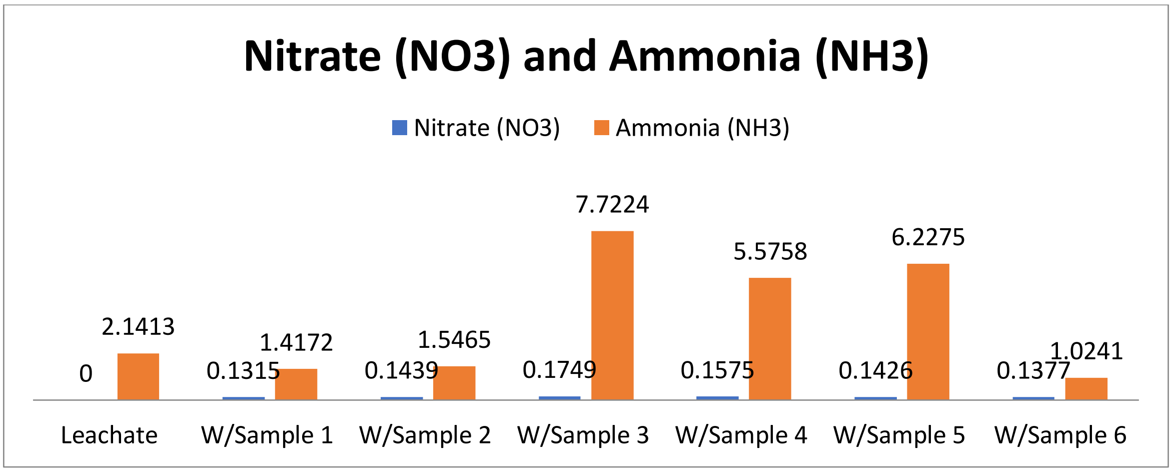


Fig 5: Results for Nitrate and Ammonium

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Sulphate

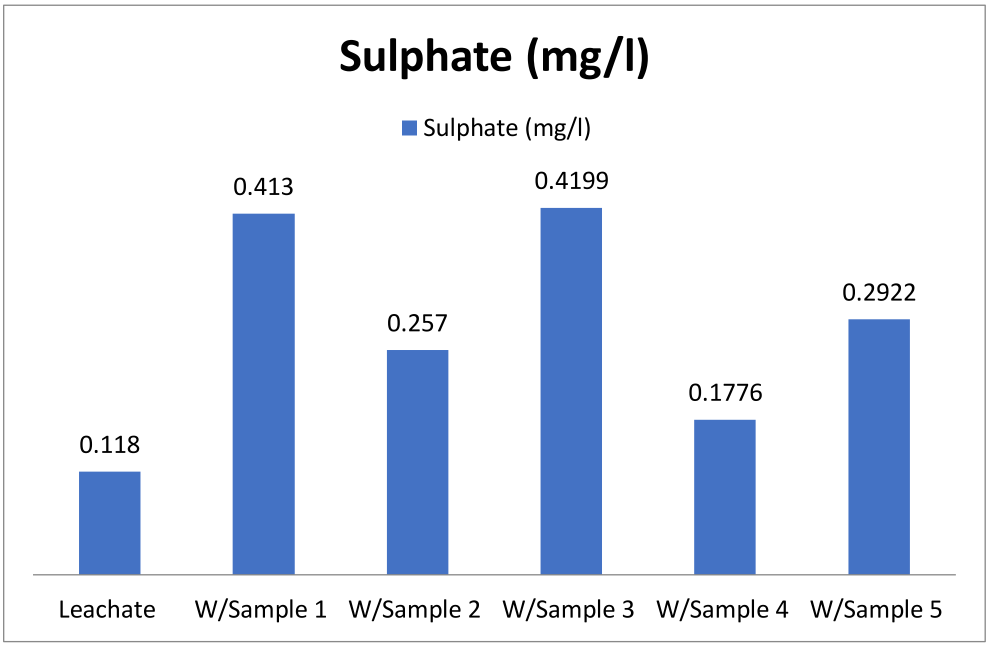

Fig 6: **Results for sulphate in wastewater and leachate**

According to the results for sulphate obtained above in fig 6, W/Sample 3 obtained 0.4199mg/l which was higher than other sampling points. This level was followed by W/Sample 1 which was the control with 0.413mg/l. Sulphate was also detected in the leachate sample with 0.118mg/l being the least value was obtained as compared to other W/sampling points.

Phosphate

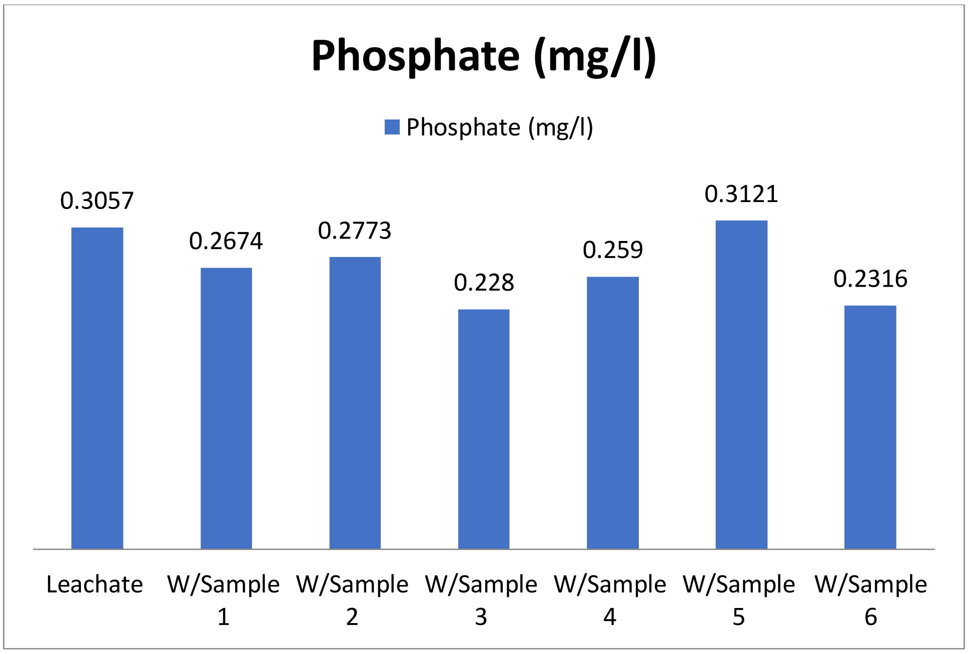

Fig 7: **Phosphate results obtained**

As illustrated in fig 7, phosphate was detected in all the W/Samples and Leachate sample. Phosphate was most detected in W/Sample 5 with levels 0.3121mg/l as compared to other W/Sampling points. W/Sample 3 where the water and leachate meet as shown in the picture 2, with the values 0.2280mg/l. However, according to the[18] all the results obtained were all in the blue zone, which is the recommended ≤0.5mg/l.

Heavy Metals

Lead (Pb)

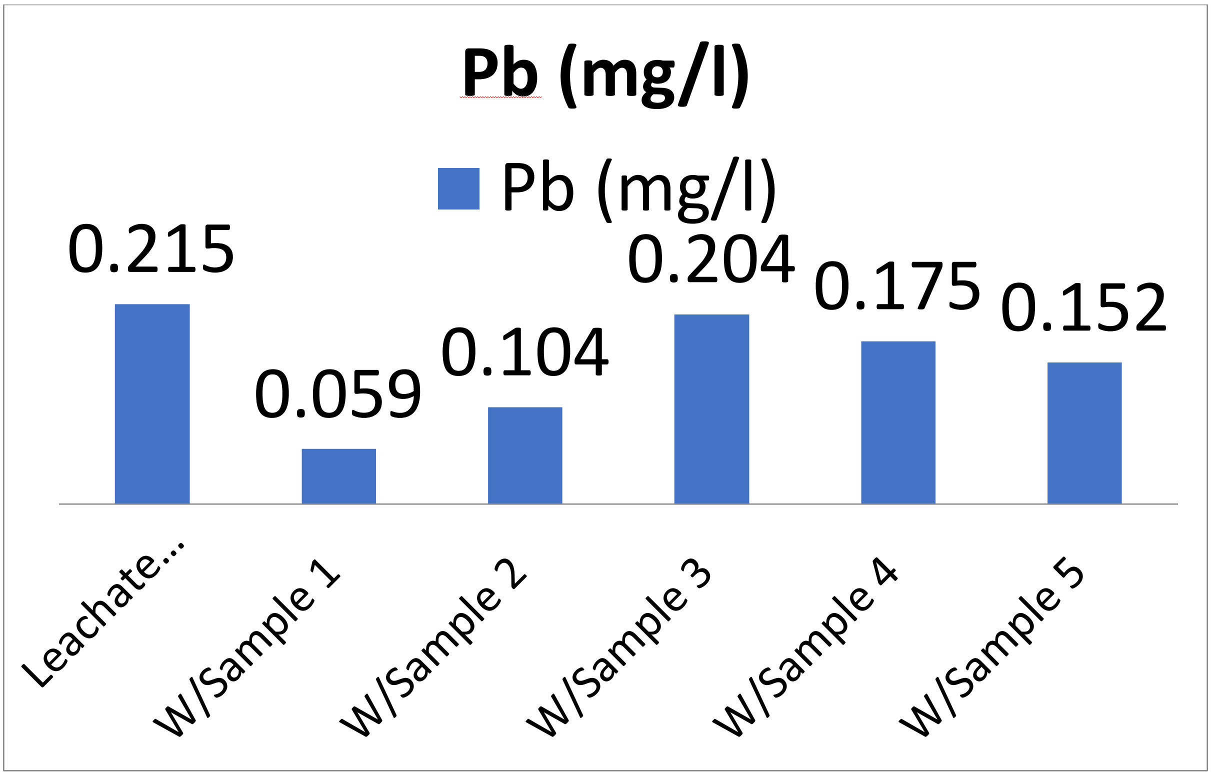

Fig 8: **Results for Lead (Pb)**

According to the results presented on the above fig 8, lead was detected in all the 6 W/Sample points and in the leachate sample. In the leachate sample 0.215mg/l was detected and was found to be within the yellow range of the[19] on effluent discharge regulations. From W/Sample 1, the levels of lead (Pb) were increasing along the River Muenene from the Mutare City dumpsite that is from 0.059mg/l of W/Sample 1 to W/Sample 6 with 0.196mg/l. At W/Sample 3, the level of Lead (Pb) was very high and thus where the leachate and water actually mingle. On W/Sample 1 was less than 0.1mg/l because it was a control. W/Sample 2, 4.5 and 6 were all in the green range zone, of which W/Sample 3 is in the yellow zone of the[21].

Chromium (Cr)

Table 6: **Chromium results**

Sample type	Cr (mg/l)
Leachate sample	0.015
W/Sample 1	ND
W/Sample 2	ND
W/Sample 3	ND
W/Sample 4	ND
W/Sample 5	ND
W/Sample 6	ND

As shown in the above table 6, chromium as one of the heavy metals also important, it was not detected in all W/Samples 1,2,3,4,5 and 6. Small amounts of chromium were only detected in the leachate sample.

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ZINC (Zn)

Table 7: Zinc results

Sample type	Zn (mg/l)
Leachate sample	0.033
W/Sample 1	ND
W/Sample 2	ND
W/Sample 3	0.005
W/Sample 4	0.012
W/Sample 5	ND
W/Sample 6	ND

ND – Not Detected

The table 7 above indicate the results for zinc and above 42.85% of the sampling points W/Samples 1, 2, 5 and 6, zinc was not detected at all as indicated by ND. The zinc was only detected in the leachate sample, W/Sample 3 where the water and leachate meet, W/Sample 4 a distance away from the sampling point where water and leachate meet. In leachate sample, zinc levels detected was 0.033mg/l and it was within the blue zone. In W/Sample 3, 0.005mg/l was obtained and it was also in the blue zone of the[22] that governs that zinc parameters should not exceed 0.3mg/l.

Iron (Fe)

Below is fig 9 which shows that iron was detected or found in all the sampling points along the Muenene River and in the leachate sample from the dump site. The point at which water and leachate meet, W/Sampling 3 recorded the highest amount of iron (Fe) with a reading of 110.8mg/l and followed by leachate sample that received a reading of 92.4mg/l. W/Sample 2 received the least recording of 0.84mg/l though it was sited just beside the dumpsite. Iron levels recorded in the leachate sample and in the W/Sampling points 3, 4, 5 and 6 fell in red zones according to the[18] for effluent discharge regulation since all the levels obtained were above 8mg/l except in the W/Samples 1 that falls in the green zone and W/Sample 2 with 0.84mg/l which falls in the blue range.

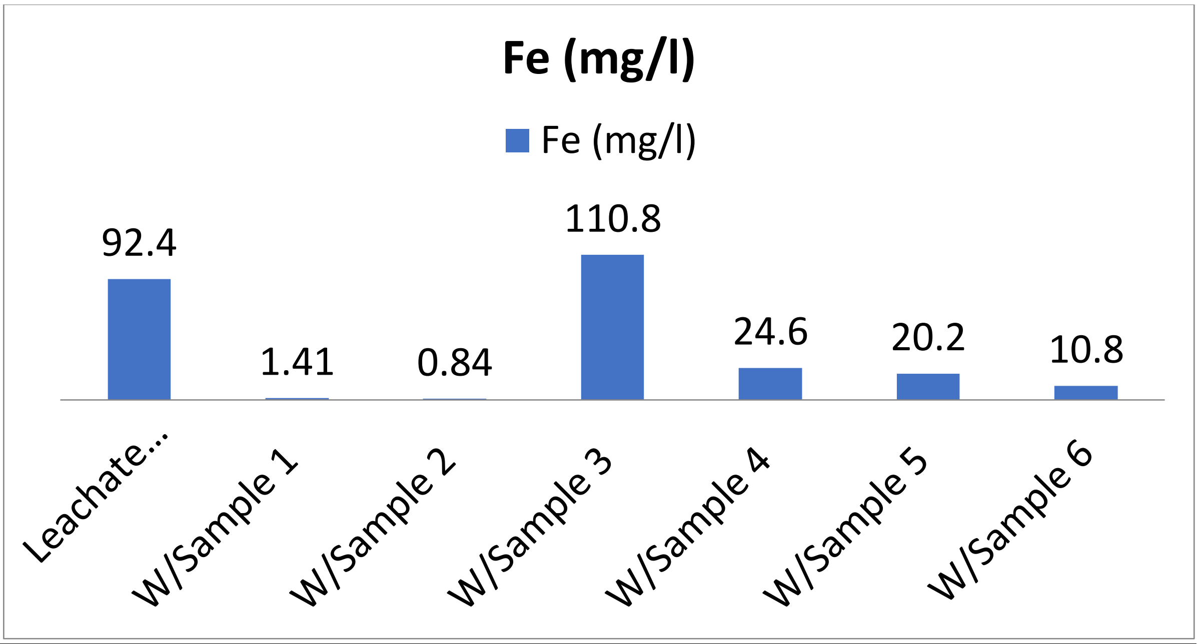


Fig 9: Iron (Fe) results obtained

Copper (Cu)

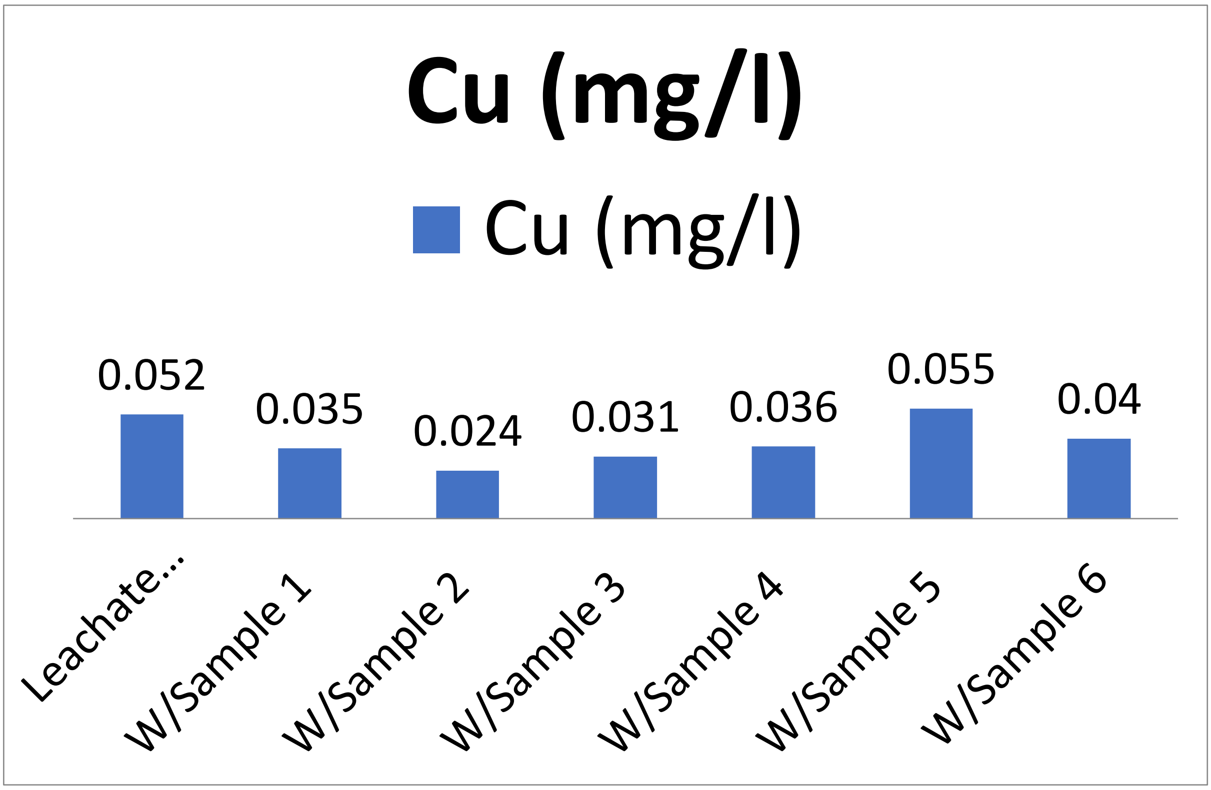


Fig 10: **Copper (Cu) results**

As depicted in fig 9, above, copper (Cu) was detected in all the 6 W/Samples including in the leachate sample. According to the[18], effluent discharge regulations, all the sampling points' results were within the blue range or zone since they were all below ≤1.0mg/l. the values obtained were 0.035mg/l, 0.024mg/l, 0.03mg/l, 0.036mg/l, 0.055mg/l and 0.040mg/l for W/Sample 1, W/Sample 2, W/Sample 3, W/Sample 4, W/Sample 5 and W/Sample 6 respectively.

Manganese (Mn)

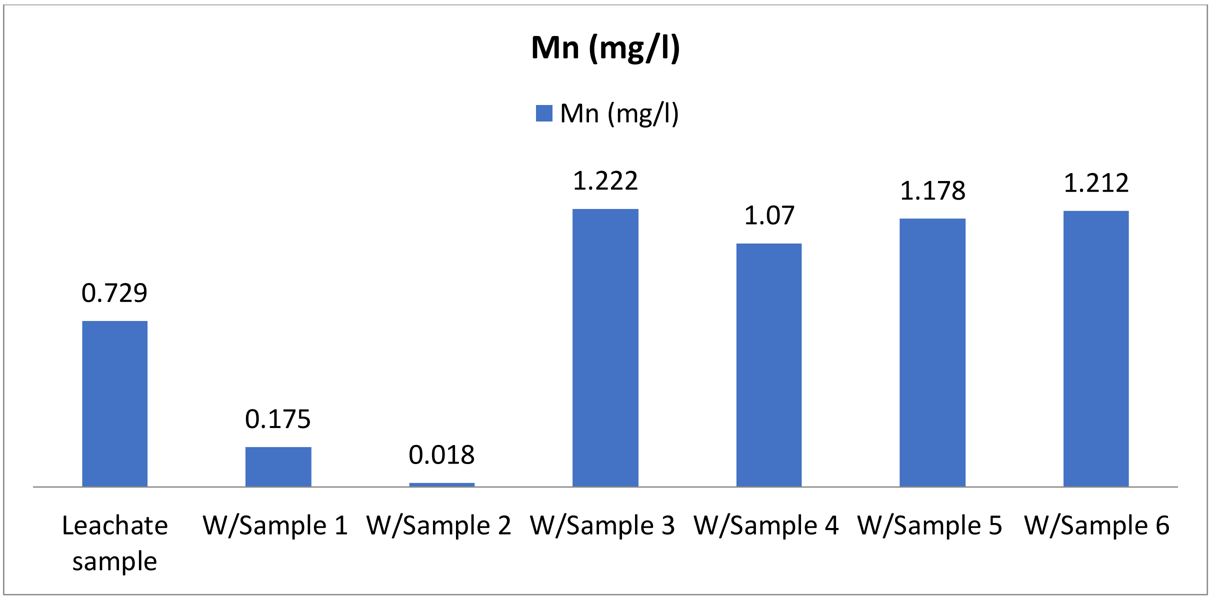


Fig 10: **Manganese (Mn) results**

As shown in fig 10 above, manganese was also detected in all the W/Sampling points and in the leachate sample. In the leachate sample and in W/Samples 1, and W/Sample 2, the results were below 1mg/l. In

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

W/Samples 3, 4, 5, and 6, the mg/l obtained were above 1mg/l. Therefore, comparing with the[21], on effluent discharge, leachate sample was found to be in the red range with results more than 0.5mg/l as regulated in the instrument. W/Sample 1 was in the blue range with 0.1, as the control and together with W/Sample 2, were all in the blue range with 0.018mg/l. W/Sample 3, 4, 5, and 6 were in the red zone with 1.222mg/l, 1.070mg/l, 1.178mg/l, and 1.212mg/l respectively since they were all above 0.5mg/l as regulated in the[18].

Cadmium (Cd)

Table 8: **Results obtained on Cadmium**

Sample type	Cd (mg/l)
Leachate sample	0.030
W/Sample 1	ND
W/Sample 2	ND
W/Sample 3	0.020
W/Sample 4	0.013
W/Sample 5	0.007
W/Sample 6	0.002

ND – Not Detected

The table above shows the results on Cadmium found in all sampling points. It was not detected in W/Sample 1 and W/Sample 2 of which W/Sample 1 is the control and W/Sample 2 is just beside the open dump site. Cadmium was detected in the leachate ranging 0.030mg/l. from the point where leachate sample was sampled, the levels of cadmium was going down gradually downstream . W/Sample 3, where the leachate meets the water and flow downstream recorded 0.020mg/l, 0.013mg/l was for W/Sample 4, 0.007mg/l was for W/Sample 5 and W/Sample 6 recorded the least amount of cadmium of 0.002mg/l. According to[21], the leachate sample and W/Sample 3 were in the green colour or range since it is above 0.01mg/l and 0.020mg/l respectively. The sampling points W/Samples 4, 5, and 6 all falls in the blue range or colour

Nickel (Ni)

Table 9: Results for Nickel (Ni)

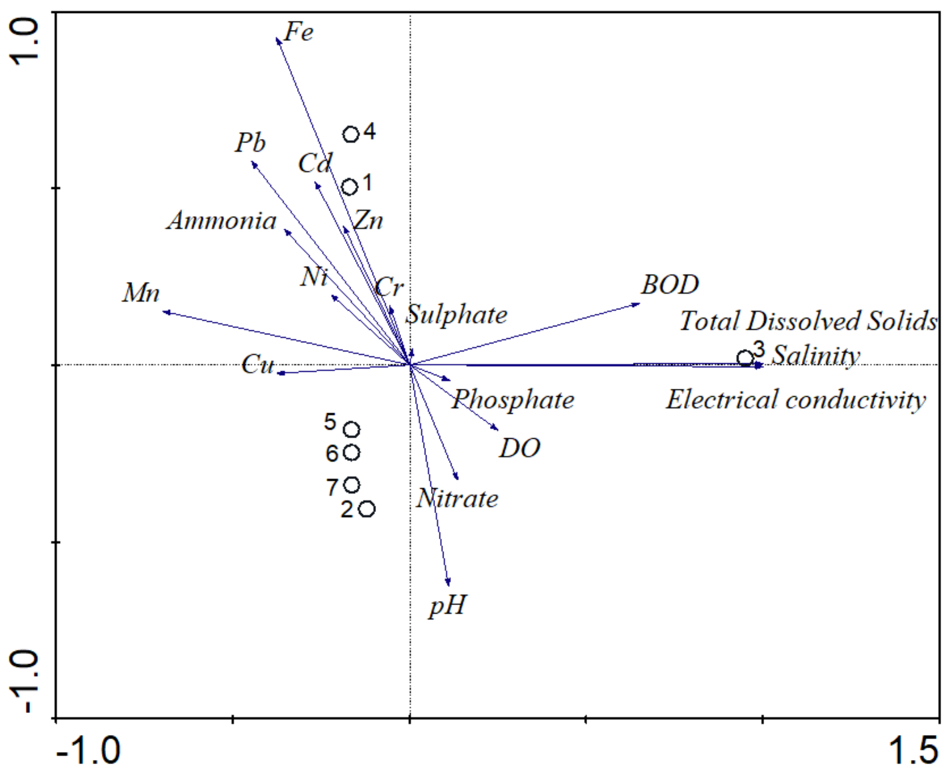
Sample type	Ni
Leachate sample	0.03
W/Sample 1	ND
W/Sample 2	ND
W/Sample 3	ND
W/Sample 4	0.02
W/Sample 5	0.01
W/Sample 6	ND

ND – Not Detected

As shown in the table 9 above, Nickel was not detected in 57.1% of the sampling points for wastewater. It was detected in leachate sample with 0.03mg/l, W/Sample 4 with 0.02mg/l and W/Sample 5 with 0.01mg/l. It was not detected W/Sample 1 which is the control, W/Sample 2, 3, and W/Sample 6. Comparing with[21], on effluent discharge regulation, leachate sample, W/Sample 4, W/sample 5 were all in the blue zone of the statutory instrument.

Principal Component Analysis

For the physico-chemical parameters, the characteristic values were large in terms of pH, salinity and dissolved oxygen. These parameters had eigen values that are greater than 1 hence they are prevailing in the first quadrant and related sampling sites. The Kaiser criterion states that latent roots greater than 1 have to be considered. In this case and in line with heavy metals, Fe, Pb, Cd, Zn, Cr, Ni, Mn and copper had higher eigen values as vividly depicted in the scree plot. These explain the most prevailing variability in the sampling points for this particular study. Paying particular attention to the nutrient status of the study area, ammonia is having very significant variability among other nutrients.



Axes	Site 1	Site 2	Site 3	Site 4	Total variance
Eigenvalues:	0.991	0.008	0.001	0.000	
Cumulative percentage variance of species data:	99.1	99.9	100.0	100.0	1.000

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

DISCUSSION

Physic-chemical parameters

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) were found to be high in the sampling points WS2 and WS 1.Levels were above the permissible levels according to[19]. This was cemented by[7] who asserted that high TDS levels suggested the presence of high levels of suspended matter and high dissolved organic matters in the waste stream.

pH

The pH levels were above the neutral level, which strongly indicates that the wastewater was alkaline since it was between 7.92-9.2. The SW3 recorded the lowest pH of 7.92 because that was the same point where the wastewater and leachate mix and flow into Muenene River. The high pH levels indicate low solubility where the solubility generally decrease with increasing pH due to the precipitation of metal ions as insoluble hydroxides at values of high pH[23].

Electrical conductivity

In the three (3) sampling points the EC was not detected. Even in the[19] of effluent discharge regulation, the EC was not above the permissible levels since it was shown that the result ranged in blue zone. [24] concurs with the results, suggesting that the low levels of E.C obtained may be due to dilution. Conductivity is an important and fast method that measures the total dissolved ions and is directly related to total solids and is affected by temperature[25]. The warmer waters have higher values of the conductivity. The water temperature is also a significant parameter that controls the inborn physical qualities of the water[25].

Salinity

Highest amount of salinity was only obtained at site 2 with 418ppm and Site 1 with 24.2ppm whereas the rest of the sites were below 1.5ppt. [26]asserts that this elevated value is probably caused by the salt in the Pliocene Quaternary clay-sandy deposits and high evaporation in this zone.

Biological Oxygen Demand (BOD)

Results show that the sampling points SW3, SW5 and SW4 were having values above the[18] standards. Therefore, high BOD levels reflected the high level of non-biodegradable organic matter[25]. Also, according to[10], a high value of BOD provides a quick dash board of a dicey situation that may metamorphose or trigger environmental anarchy. The least values of BOD indicate least organic pollutants[27]. That was shown by the least values obtained on sampling point SW1, SW2 and SW6. The results were comparable with that reported (1.26-2.81mg/l from the Dhamra estuary and (1.20-12.20mg/l reported from the river Chambal in Kota City Area, Rajasthan[13].

Nutrient status.

Phosphate

Based on the results of the study, phosphate at sampling point SW5 was much higher as compared to other sampling points. Even the leachate sample result on phosphate was lower than the SW5 with a reference value of 0.3121mg/l. Phosphate is a limiting nutrient in the environment since it governs the growth of living organisms. The levels of phosphate were high and this eventually may lead to eutrophication of Muenene River[13]. These phosphates may originate from natural dissolution of soil compounds and organic matter decomposition from a dump site as well as from anthropogenic activities, such as domestic effluents, animal excrement and fertilizers[27]. This is evidenced by the agricultural activities near the Mutare city dumpsite such as rearing of cattle and maize production which also involves use of fertilizers which may then have access to Muenene River through run off.

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

Nitrate

As depicted in fig 5, nitrate was not detected in the leachate sample. It was detected in the all the 6 WS samples in very low levels. Nitrate was stipulated in the S.I 6 0F 2007. In the[18] guidelines for portable water standards, where it was indicated that the parameter should be ≤0.1mg/l, the results obtained in WS1 - WS6 were all slightly above the[19] permissible levels for portable water. According to[12] nitrogen which usually exists in water bodies as nitrate is a key ingredient in fertilizers. Excess amounts of bioavailable nitrogen in marine systems lead to eutrophication and algae blooms[13]. However, it is with regards to the key role nitrates play in water quality determination that its assessment has been undertaken in this study. The presence of nitrate may be the result of waste disposed of at the dumpsite[26]. Thus, contamination of the water bodies with chemicals from the dumpsite is very likely to occur. This is because wastes from agro-based industries which may contain nitrates are not segregated before disposal and are likely to find their way into the river[27].

Ammonia

Ammonium results were above the limited permissible levels of [21] on effluent discharge regulation and[19] standards on portable water quality. The occurrence of high ammonia levels in both the leachate and surface water samples emanate from conversion of organic nitrogen from animal excrement and fertilizers[27].

Heavy Metal Status

Iron (Fe)

The iron (Fe) levels were found to be very high in all the sampling points including leachate sample. The results shown that the Fe was above the permissible levels of both the[18] and [19] with the highest amount of Fe recorded in the SW3. The lowest amount of iron was in SW2. Presence of scrap metal that was corroding explains the brown dark colour of the leachate which is a product of oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with humic acid [24]and[25].

Lead (Pb)

The levels of Pb were high in all the sampling points. Lead in the environment is mainly particulate bound with relatively low mobility and bioavailability. Pb does, in general, not bioaccumulate and there is no increase in concentration of the metal in food chains [26]. In the leachate it was found to be very high (0.215mg/l and WS3 with 0.204mg/l. In all the standards, [18] and[19], the values were found to be above permissible levels except in SW1 which was a control. The level of Pb in the leachate indicates the disposal of lead batteries, lead based paints, plastics, and pipes at the site[24]. Presence of Pb in the water may be due to the discharge of industrial effluents from petroleum production[27]. Pb may also come from lead-acid batteries, plastics and remnants, lead foil such as bottle closures, used motor oils and discarded electronic gadgets including televisions, electronic calculators and stereos where leachates from waste dumpsites may find their way into the rivers [27].

Copper (Cu)

Cu was detected in all the sampling points,namely, WS1, WS2, WS3, WS4, WS5 and WS6. However, the results obtained were within the permissible levels of [19]≤1.0mg/l. All the results obtained were within the range of 0.0mg/l. water quality range for copper for which there is no health or aesthetic effects is 0.0□g/lto 10.0□g/l[27]. The copper is toxic to plants. For fisheries, the level for which there are no adverse effects on early life stages of some species ranges from 2.0□□/l to 60.0□□/l [11]. Therefore, the levels of copper in Muenene River pose no threat to the environment and human health.

Manganese (Mn)

Manganese (Mn) was detected in all the sampling points. The leachate sample and WS1 and WS2`s results were below 0.5mg/l. However, the leachate sample was found to be in the red zone as also echoed by[21] on effluent discharge regulation. Sampling points WS3, 4, 5 and 6 were in the red zone of S.I 6 of 2007. Manganese occurs in surface waters that are low in oxygen and often does so with iron and when oxidised in aerobic waters, the oxides builds up in distribution causing several discolouration above 50.0□□/l [25]. The presence of Mn may be due to discharge from industrial facilities or as leachate flow from landfills. High values of Mn may be as a result of pollution from manganese dioxide cells for which the nation has no controlled methods of disposal. The metal may also come from other sources such as domestic wastewater and sewage sludge disposal[27].

Cadmium (Cd)

Cadmium was not detected in WS/1 and WS2. The levels of cadmium were high in leachate sample collected at the dumpsite and its levels decreased from SW3 downstream. The results were from 0.030 to 0.002mg/l. The leachate levels of 0.030mg/l and SW3 where the leachate and water meet indicated green range, which is a warning range according to[18]. But according to[19] samples WS3, 4, 5, were all above the recommended levels. Therefore, people down Muenene River who might be using the water are exposed to the metal. Chronic exposure to the metal produces a wide variety of acute and chronic effects in mammals similar to those seen in humans[13]. According to[13], even though the values obtained are low, cadmium is known to be one of the most toxic elements with reported carcinogenic effects to humans. High concentration of Cadmium has been found to lead to chronic kidney dysfunction[26]. Cadmium may bio accumulate at all levels of aquatic and terrestrial food chain. Cadmium contamination in surface water bodies could be attributed to the discharge of contaminants including nickel-cadmium batteries[27].

Zinc (Zn)

As indicated by table 4, zinc (Zn) was not detected in 42.85% of the sampling points except in the leachate sample and WS3 and WS4. However, none of the results obtained exceeded the permissible levels for both the[21] for effluent disposal regulations in Zimbabwe and[19] for portable water permissible levels. [24] also discovered the similar results where zinc (0.943mg/l) was in the permissible levels of for drinking water. Similar results were also obtained by [30] where the author mentioned that zinc levels were below the detection levels in all the water samples at various sites.

Chromium (Cr)

Cr was only detected in the leachate sample with a value of 0.015mg/l. Within all other sampling points WS1 - WS6, Cr was not detected at all. The detected amount of Cr in the leachate was even at the recommended permissible levels of[18] for effluent discharge regulations, though it was not measured in the[19] for portable water standards. According to[24] the presence of Cr in the leachate sample indicates the disposal of considerable amounts of steel at the site.

Nickel (Ni)

Ni was not detected in 57.1% of the sampling points. In the three (3) samples namely leachate sample, WS4 and WS5, the values obtained were in the normal range as indicated by[21]. [24]detected Ni (0.773mg/l) in excess and this can be attributed to the disposal of batteries at the site. Therefore batteries that are being disposed at Mutare City dumpsite from the battery industries and car servicing companies within Nyamakate industry are a cause for concern.

CONCLUSION

The physic-chemical parameters of the water indicate that untreated leachate and unsegregated solid waste leads to pollution of water. Total dissolved solids (TDS) were found to be high in the sampling point WS2 and WS 1 and were above the permissible levels . The pH levels were above the neutral level, which strongly indicates that the wastewater was alkaline since it was between 7.92-9.2. In the three (3) sampling points the EC was not detected. Highest amount of salinity was only obtained at site 2 with 418ppm and Site 1 with 24.2ppm whereas the rest of the sites were below 1.5ppt. Results show that the sampling points SW3, SW5 and SW4 were having values above the[18] standards. Based on the results obtained in the experiment, phosphate at sampling point SW5 was much higher as compared to other sampling point. On nutrients such as ammonia, phosphate, nitrates were found to be above the permissible levels and that may possibly result in pollution of the Muenene River. The heavy metals include Fe, Pb, Mn and Cd were found to be above permissible levels in terms of S.I 6 of 2007 for wastewater discharge regulations in Zimbabwe. Zn, Ni and Cr were detected but were at normal range that is not harmful to the environment. With reference to the results obtained, the water quality was unsatisfactory due to elevated levels of the concentrations phosphorus, ammonia, and the biochemical oxygen demand ratio (BOD).

RECOMMENDATIONS

Based on the research outcomes, and the findings of this study, the study, therefore, recommends that strict legal action should be taken against any firms and individual that constitutes environmental indiscipline, while concrete drainage systems should be constructed to ensure the free flow of water. Effective waste management through the proposed modern sanitary landfill should be adopted to ensure environmental sanitation, with effective public awareness of the potential hazardous environmental impacts of poor waste management. More also, environmental agencies for waste management should be well-trained and equipped with relevant waste technology. These recommendations are congruent to[28]

Key messages

- Nutrients such as ammonia, phosphate, nitrates were found to be above the permissible levels, subsequently leading pollution of the Muenene River.
- The heavy metals like Fe, Pb, Mn and Cd were found to be above permissible levels in terms of S.I 6 of 2007 for wastewater discharge regulations in Zimbabwe.
- Zn, Ni and Cr were detected but were at normal range that is not harmful to the environment.
- The leachate generated from dump site finally flows into a stream used to irrigate vegetables and fruits by unsuspecting farmers.
- The water quality analysis revealed unsatisfactory results due to the elevated concentrations of phosphorus, ammonia, and the biochemical oxygen demand ratio (BOD).

ACKNOWLEDGEMENTS

The authors would like to express heartfelt and special thanks to the Director of Health Services, Mutare city for granting permission to conduct the study.

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