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Assessment of Selected Physico-Chemical Parameters of Waste Water from a Gold Mine in Alupe Sub-County, Busia County, Kenya

Magero Denis[1*], Ondoo Kevin Omondi[1], Meng'wa Victor[2] and Wanakai Sammy[3]

1. *Department of Chemistry and Biochemistry, Alupe University. P.O Box 845–50400. Busia, Kenya*
2. *Department of Physics, Mathematics and Computer Science, Alupe University. P.O. Box 845 –50400. Busia, Kenya.*
3. *Department of Chemistry, Jomo Kenyatta University of Agriculture and Technology. P.O. Box 62,000 – 00200. Nairobi, Kenya.*

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ABSTRACT

The rise in cost of living and unemployment in the Sub – Saharan Africa has witnessed the rise of both small scale and large-scale mining activities; putting more economic pressure on families to increase their daily income. This economic hardship has led to the search for precious metals like gold and gemstones, resulting in environment degradation as mining involves digging deep into the Earth's crust in search of these minerals. This study sought to investigate the physico-chemical characteristics of wastewater from the Alupe gold mine in Busia County, Kenya. The five physical parameters investigated include: temperature, electrical conductivity, pH, turbidity and total dissolved solids. The heavy metals under investigation were: Cr, Cd, Pb, Cu, Fe, Co, Zn and Ni. Among the physical parameters, only pH and turbidity recorded values beyond the WHO permissible levels, while all heavy metals recorded values that were beyond the WHO permissible levels. Strong correlation was registered by EC – temperature, TDS – temperature, TDS – EC and TDS – turbidity. Vast majority of metal pairs recorded strong correlation ($r > 0.7$) indicating the presence of alloys and metal pair complexes. The correlational studies were conducted at 95% level of confidence ($P < 0.05$). The study recommends treatment of industrial wastes before they are released into rivers and lakes, use of improved processing technologies by industries to regulate the ever-high levels of waste generated during manufacturing and policy review that will see the implementation of environmental laws so as to curb illegal mining

*Corresponding author: Denis Magero Email: dmagero@au.ac.ke

Introduction

Approximately 37.7% of highly poisonous heavy metals get released to the environment thanks to artisanal and unregulated and unlicensed mining activities, which are normally associated with poor grade of the ore, primitive mining methods as well as low ore production (Schwartz *et al.*, 2023). For the last decade, artisanal mining has become major income source for the poor rural communities in the Sub-Saharan Africa. Mining activities lead to environment degradation as they lead to increased soil erosion, deforestation as well as erosion of woodland. This trend is expected to continue and even rise due to increase in the price of gold, lack of employment and poverty in Sub – Saharan Africa (Dzoro *et al.*, 2023).

In as much as mining greatly contributes to social and economic growth of nations, it has led to destructive long-term environment and public health concerns. Mining activities have greatly contributed to environment pollution, mainly through the release of toxic carcinogenic metals such as nickel and hexavalent chromium into water bodies.

The volume of solid waste that mining generates is such that only 1% of the extracted ore is beneficial, with 99% being dumped as waste. Due to this, several alternatives to mining have been sought, with the use of microorganisms in gold extraction being the most prominent in some parts of Africa. This use of microorganisms in mining is referred to as biomining and the bacterial used in this situation being the iron and sulphur oxidizing species, chemolithotrophic and acidophilic species, as well as *Sulfolobus metallicus Acidithiobacillus (At.) ferroxidans, (L.) ferriphilum At. thioxidans, Leptospirillum and L. ferroxidans, Sulfobacillus acidophilus* which have all found wide applications in the extraction of gold in different regions round the globe (Fashola *et al.*, 2016).

The wide range of heavy metals released into water bodies and soil due to gold mining include: Lead (Pb), Chromium (Cr), Nickel (Ni), Copper (Cu), Mercury (Hg), Arsenic (As) and Cadmium (Cd). The mentioned metals are linked to a number of diseases such as cancer and Alzheimer's disease and hypertension (Fagbenro *et al.*, 2021). Pollution by heavy metals also leads to water scarcity as it places restrictions on water use (Ondoo *et al.*, 2019). Transition metals find use in small concentrations as part of vitamins and other important minerals, but when humans are repeatedly exposed to heavy metals, it leads to bioaccumulation. When transition metals bioaccumulate in the human body, associated risks such as inhibition of DNA repair by Cadmium, nervous system breakdown by Mercury and reduced intelligent in children exposed to Mercury may occur.

Some heavy metals such as Arsenic, Mercury, Cadmium and Lead have no use in the body system of humans (Bello *et al.*, 2019). Land encroachment and illegal gold mining by neighboring Uganda have been taking place in Alupe Sub County, Busia County, for over a decade leading to air pollution, environment degradation and water pollution. The heavy machines used for mining purposes have caused cracks in buildings around Alupe therefore endangering lives. Due to this menace, lawmakers in the Sub County have called on both the County and National governments to secure the area and stop unlawful mining and streamline the gold mining industry to enable the Kenyan government acquire benefits from gold mining (Namwalo, 2023).

Materials and Methods

Study Area

Alupe Sub-County is located at latitude 0° 29' 48'' (0.49677) North and longitude 34° 7' 54'' (34.13176) East; in Busia County, Teso South constituency. It has an altitude of 1,164 metres (3,819 feet) above sea level. The climate of the region is tropical rain forest. The area is home to a gold mining and metal processing factory. Small scale gold mining is also heavily practiced in Busia County, giving rise to significant land degradation, ecosystem degradation, air, sound, noise and water pollution as a result of heavy metals, smoke, particulate matter arising from the mining process. The waste water is then discharged into river Ndambuk, leading to a further increase in pollution of the river.

Statistical Analysis

All the calculations were carried out using Excel 2013 (Microsoft Office Standard). Correlational analysis between the chemical and physical parameters was performed using the Pearson's correlation (r) and the data presented in form of mean ± standard deviation (Mean ± SD). The correlational analysis was performed at $P < 0.05$ confidence level.

Sampling Methods

Waste water from a gold mining and metal processing company was collected in triplicate using random sampling method to obtain a representative composite sample. The waste water samples were stored in 500 mL polyethylene bottles, washed with 10% nitric acid and rinsed with distilled water. About 2 mL of 65% nitric acid was added to adjust the pH of the waste water to about 2.0. The physical parameters were measured on site during the sampling process. The water samples were placed in an ice filled cool box then immediately transported to the chemistry laboratory and stored at 4 °C for 24 hours to await the analysis of cations under study (Eaton & Franson, 2017).

Sample Preparation for Heavy Metal Analysis

To 100 mL of waste water sample, 10 mL of 65% HNO_3 was added in a 250 mL conical flask and the mixture heated on a hot plate until the volume reduced to about 20 mL. The digestate was cooled to 25 °C, after which 5 mL of 65% HNO_3 was added. Successive addition of HNO_3 continued at regular time intervals until the digestion process was complete. The digestate was evaporated to near dryness, after which 5 mL of 37% HCl was added and the mixture warmed before the addition of 5 mL of 5M NaOH solution. After digestion, filtration was carried out using Whatmann No. 1 filter paper and the filtrate finally transferred to a volumetric flask of 100 mL and filled with distilled water.

Analytical Procedure

Standards for heavy metals (Co, Pb, Ni, Cu, Zn, Cd, Fe and Cr) were made by serial dilution of 1000 ppm stock solutions of the respective standards. The stock solutions for the respective metals were diluted to 10 ppm solutions that were then used to obtain the working standards. Working standards for 0.1, 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 ppm were prepared by dilution of 10ppm standards. The different heavy metals in the waste water were analyzed using Shimadzu AA 6200 Flame Atomic Absorption Spectrophotometer (FAAS) at their respective analytical lines. Both samples and standards were treated in a similar manner to minimize/eliminate matrix effect (Eaton & Franson, 2017).

Results and Discussion

Physical Parameters

The physical parameters that were determined include: turbidity, total dissolved solids, electrical conductivity and pH.

Temperature

Thermal pollution comes about as a result of industries discharging waste water whose temperature is way higher than normal. Waste water temperature has the overall effect of speeding up both chemical and biochemical reactions in waste water. Temperature also increases the solubility of some salts in water and also reduce the concentration of dissolved oxygen, therefore endangering aquatic animals. If the temperature of water is extremely high, it may kill both aquatic plants and animals. The toxicity of harmful chemical compounds such as pesticides, detergents and industrial effluent increases as the temperature of waste water increases. The formation of various thermal zones due to differences in temperature in Lakes and Rivers as Jazib (2019) puts it, also increase with temperature rise.

The waste water temperature was 30.00±0.10 °C. This high temperature can be linked to use of water for washing and cooling of machines during the manufacturing process leading to high temperatures of the discharged waste water. The high temperature can also be attributed to high turbidity levels, as suspended particles tend to absorb more heat leading to an increase in water temperatures. This water is released into river Ndambuk, causing an overall increase in water temperature hence endangering aquatic lives by significantly reducing the levels of dissolved oxygen in the river.

pH

pH has several effects on water bodies, depending on whether it is high or low. Very low pH may cause respiratory infections such as tuberculosis, corrode iron pipes and cause the sudden death of aquatic organisms. On the other hand, high values of pH may result in sediment deposition and difficulties in carrying out water treatment, especially chlorination (Wang *et al.,* 2021). The recorded average pH of the waste water was 10.79±0.01 indicating high alkalinity.

This was beyond the KEBS/NEMA limit of 6.0 – 9.0 and in excess of the WHO limit of 6.5 – 8.5. The highly alkaline pH is linked to the use of highly alkaline chemicals in the mining processes and also the production of highly alkaline waste leading to elevated pH values. The pH values of water in river Ndambuk are beyond the values obtained by Gafur *et al.* (2018) during the study of metal pollution of Bone river by gold mine activities in Gorontalo, Indonesia.

Electrical Conductivity

Electrical conductivity is caused by huge amounts of dissolved salts in water. There is a strong correlation between dissolved solids and electrical conductivity as the vales for both parameters usually depend upon the levels of dissolved salts in waste water (Provin & Pitt, 2002). These ionic salts dissociate in aqueous form to form delocalized ions responsible for conductivity. Electrical conductivity values of waste water under study was recorded as 297.00±1.00 μs/cm. Dissolved particulate matter from gold mining process as well as dissolved salts from metal processing can be linked to the elevated electrical conductivity levels in the waste water. The high electrical conductivity values can also be associated with the high temperature of waste water as this increases the ability of salts to dissolve in water leading to high electrical conductivity values. However, the values of electrical conductivity from this study were below the recommended WHO limits of 5000 μs/cm.

Total Dissolved Solids

This refers to the amount of dissolved matter in water, both organic and inorganic, and takes into account both volatile and non-volatile solids. TDS values for water are indicative of anthropogenic activities such as mining, agricultural activities as well as waste discharge. The value of TDS in the waste water was recorded as 195.67±0.58 mg/L. This was below the permissible levels recommended by the WHO of 500 mg/L, signifying lack of pollution from dissolved solids.

Turbidity

Turbidity is a measure of suspended particles in water. It can be assessed on the basis of scattering effects that suspended particles have on light (Saksena *et al*., 2008). The particles responsible for high water turbidity include soil, untreated sewage, waste and water from mines and factories (Dojlido & Best, 1993). The recorded turbidity levels were given as 891.98±4.43 NTU, which was beyond the recommended WHO turbidity levels of 5 NTU.

The high waste water turbidity could be linked high presence of solid particles suspended in water from metal processing and gold mining. This is dangerous as this water gets discharged into the nearby Ndambuk river, therefore masking the disinfection of microorganisms hence increasing the dangers of infections by water borne diseases despite disinfecting drinking water.

Table 1: Concentration of Physical Parameters in Waste Water

Parameter	Concentration	WHO
Temperature	30.00±0.10	–
E.C	297.00±1.00	5000
TDS	195.67±0.58	1000
pH	**10.79±0.01**	6.5 - 8.5
Turbidity	**891.98±4.43**	5

***Bolded values are those whose values are beyond the WHO permissible limits**

Chemical Parameters

Waste water was analyzed for eight heavy metals: Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Chromium (Cr), Zinc (Zn), Lead (Pb) and Nickel (Ni).

Cadmium

Cadmium is released into the environment mainly by industries in the form of fine solid particles and causes harm to the respiratory tract. Cadmium may be introduced into the atmosphere by incinerators as fly ash (Jazib, 2019). The main source of Cadmium is metal processing and battery industries. The concentration of Cadmium recorded was 0.271±0.003 mg/L. This was above the WHO limit of 0.05 mg/L and the NEMA/KEBS permissible limits of 0.01 mg/L. The elevated concentration of Cadmium is linked to metal processing waste and waste from gold processing. The level of Cadmium recorded in this study was way lower than the levels recorded by Turek *et al.* (2019) in the analysis of heavy metals in sewage sludge.

Cobalt

Cobalt finds wide applications in the paint industry as a major constituent of pigment and driers in paint and An isotope of Cobalt, Cobalt – 60 – is an excellent source of gamma radiation hence it finds use in treatment of cancer and tumors (Johanson, 2008). The recorded level of Cobalt in this study was 0.267±0.008 mg/L. This was found to be beyond the WHO permissible levels of 0.05 mg/L. This high concentration of Cobalt in waste water can be attributed to metal processing and gold mining as mining involves digging and crushing of rocks hence leading to an increase in the concentration of metals that end up in the waste. The Cobalt concentrations recorded in this research study were higher than the levels of Cobalt reported by Bello *et al.* (2019) during the assessment of non – carcinogenic and carcinogenic health risks of exposure to heavy metals from Bagwai and Shanono artisanal gold mines in the state of Kano, in the Federal Republic of Nigeria.

Copper

Anthropogenic activities that lead to environmental pollution by copper include mining, combustion of fossil fuel, sea sprays, volcanic eruptions as well as windblown dust from different sources. In as much as copper plays a vital role in the composition of metalloenzymes, bioaccumulation of the metal in human tissues can lead to complications such as Alzheimer's disease. Copper concentration in this study was reported as 0.312±0.012 mg/L, which was way above the WHO permissible limit of 0.02 mg/L. Copper levels reported here were above the concentrations reported by Ma *et al.* (2020) in the determination of physico chemical parameters and heavy metal concentrations in food waste water.

Iron

In as much as iron forms a major part of haemoglobin in red blood cells, elevated concentrations of the metal in water may cause staining of laundry, produce bitter, metallic taste in drinking water and increases blood coagulation resulting to dizziness. This study reported iron concentrations of 47.477±0.336 mg/L which was beyond the WHO permissible limits of 0.3 mg/L. metal processing could be responsible for the elevated concentration of the metal in waste water, as iron forms alloys with several metals, notably in stainless steel. The rising concentration of the metal could also be connected to the old, rusty and corroded metallic pipes used to discharge the waste water. Iron levels reported in this study were way beyond concentrations recorded by Agoro *et al.* (2020) in the analysis of metals in sewage sludge and waste water in Cape Town, South Africa.

Chromium

With wide applications in the pigment, paint as well as pesticide industry, Chromium is among heavy metals with wide applications. The active ingredient in Chromium-based pesticides is chromate-copper-arsenate (Ilhan & Nurba, 2004). Although Chromium III is vital in the regulation of human blood sugar and blood clotting, bioaccumulation of Chromiun VI leads to complications such as liver and kidney cancer (Dayan & Paine, 2001). The gold mining site in Alupe Sub-County recorded Chromium levels in the region of 0.029±0.002 mg/L, which was beyond the WHO permissible limit of 0.003 mg/L therefore signaling pollution by Chromium; but below the KEBS/NEMA permissible 0.05 mg/L limit. The pigments and paints used to decorate the manufactured iron sheets and other metals manufactured by the factory could be responsible for elevated concentrations of Chromium in the waste water. The level of Chromium recorded here was below the levels obtained in the determination of heavy metals in sewage sludge from municipal waste water treatment plant in Poland's industrialized region (Tytła, 2019).

Zinc

The major applications of Zinc include the manufacture of pigments for use in paints (zinc oxide and zinc sulphide); wood preservation (zinc acetate) and also in the pharmaceutical industry during the manufacturing of shampoo, deodorant and sunscreen lotion for individuals with albinism (Abendrot & Kalinowska-Lis, 2018). The concentration of Zinc was 4.470±0.374 mg/L. This was slightly beyond the WHO permissible limit of the metal in waste water of 3.00 mg/L. The elevated level of the metal in waste water can be connected to the use of Zinc based paints in the surface coating of metals as well as the manufacturing and processing of Zinc based products such as iron sheets. The Zinc level in this study was higher than that obtained by Abdul-Wahab and Marikar (2012) in the determination of the effect of gold mines to the environment.

Lead

Lead-rich salts find application in pesticides, herbicides and pigments. Lead also finds use in the manufacturing of structures such as water pipes and tanks (EPA, 2001). Bioaccumulation of the metal in human tissues leads to complications such as intestinal discomfort, spinal cord and brain inflammation (Provin & Pitt, 2002). The level of Lead in Alupe waste water was 0.432±0.021 mg/L which was beyond the WHO permissible level of 0.01 mg/L and the KEBS/NEMA maximum limit of 0.01 mg/L. Waste from industrial metal processing and waste from dye/pigment processing is responsible for the high lead levels in the waste water. Corrosion from pipes which channel waste water from the metal processing factory can also be connected to the skyrocketing concentrations of Lead in waste water. Lead levels in this research study were higher than concentrations recorded by Akan (2010) in the assessment of physical and waste water chemical parameters in Maiduguri metropolis, Nigeria.

Nickel

Nickel finds combined use with other metals in the manufacturing of alloys such as stainless steel. The metal also finds use in minting coins and manufacturing machine parts used in industrial manufacturing processes such as heat exchangers. Bioaccumulation of Nickel weakens the immune system and may cause cancer through the formation of free radicals (Das et al., 2008). Nickel concentration in waste water was reported as 1.167±0.180 mg/L. This was above the WHO limit of 0.02 mg/L and the KEBS/NEMA allowable limits of 0.3 mg/L. Elevated levels of Nickel in waste water is indicative of pollution by Nickel, which could be linked to wear and tear in machine parts, corrosion of pipes and also from metal processing waste. The Nickel concentrations from this research study were lower than that obtained in Odumo *et al.* (2018) during the study of artisanal gold mining in rural Kenya.

Table 2: Heavy Metal Levels in Waste Water

Metal	Concentration	WHO
Cd	**0.271±0.003**	0.05
Co	**0.267±0.008**	0.05
Cu	**0.312±0.012**	0.02
Fe	**47.477±0.336**	0.30
Cr	**0.029±0.002**	0.003
Zn	**4.470±0.374**	3.00
Pb	**0.432±0.021**	0.01
Ni	1.167±0.180	0.02

***Bolded values are those above the WHO limits**

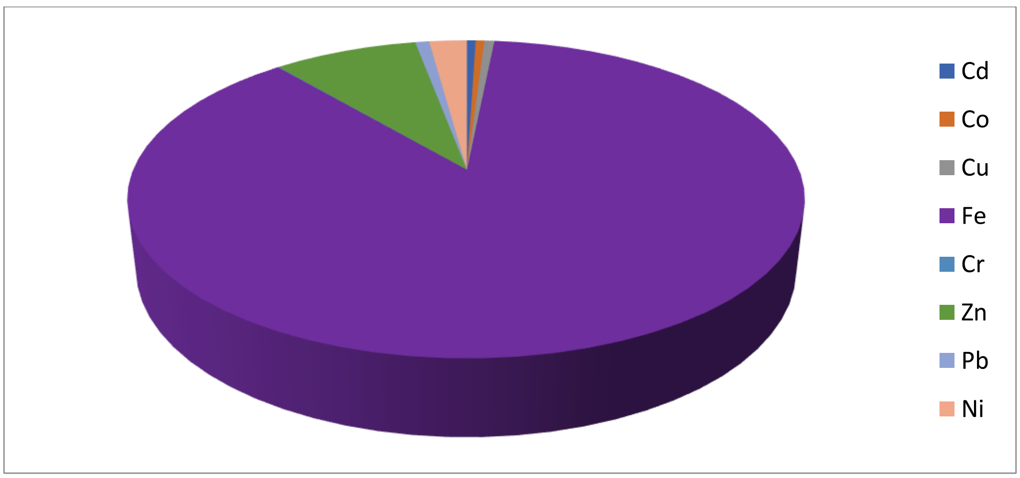

Figure 2: Pie Chart showing the Concentration of Heavy Metals in Waste Water

Correlation Studies

The joint variation between variables is usually revealed through correlational analysis of the said variables. A measure of correlation coefficient is denoted by r and its values range from – 1 to +1. Negative correlation is denoted by an r value of – 1 whereas positive correlation is denoted by an r value of +1 (Miller *et al.,* 2018).

The heavy metals under study demonstrated both weak and strong correlation. Strong correlation was demonstrated by the following metal – metal pairs: Cu – Cd (r = 0.98); Zn – Cd (r = 0.97); Pb – Cd (r = 1.00); Cu – Co (r = 0.98); Zn – Co (r = 0.97); Pb – Co (r = 1.00); Zn – Cu (r = 0.90); Pb – Cu (r = 0.98); Cr – Fe (r = 0.95); Ni – Fe (r = 1.00); Zn – Cr (r = 0.80); Ni – Cr (r = 0.95) and Pb – Zn (r = 0.95). The strong correlation demonstrated by the above metal – metal pairs is indicative of metal – metal complexes in solution form as well as alloys such as stainless steel and brass which are the major products produced by the gold mining factory.

Several metal – metal pairs also demonstrated weak correlation. They include: Fe – Cd (r = 0.35); Ni – Cd (r = 0.34); Fe – Co (r = 0.36); Ni – Co (r = 0.36); Fe – Cu (r = 0.15); Ni – Cu (r = 0.15); Pb – Fe (r = 0.36) and Ni –

Pb (r = 0.35). The weak correlation between these metal – metal pairs demonstrate the absence of metal – metal complexes. For physical parameters, a strong correlation between temperature and electrical conductivity was recorded (r = 1.0) which could be linked to the increase in ion mobility as temperature increases translating to high electrical conductivity. Temperature also affects the solubility of salts hence a rise in temperature of waste water translates to an increase in solubility of salts which leads to increased electrical conductivity.

A strong correlation was also recorded between temperature and TDS (r = 0.87) and this can be linked to increase in the solubility of salts with temperature translating to high electrical conductivity values.
TDS also showed strong correlation to electrical conductivity (r = 0.87) which could be linked to the high levels of dissolved ionic salts leading to increased electrical conductivity since these salts ionize in water to give delocalized ions which are responsible for electrical conductivity. TDS showed strong correlation with turbidity (r = 0.81) and this strong correlation may be linked to the rate at which waste water flows. As the rate at which water flow increases, turbid solid particles are disturbed and are not allowed to settle leading to an increase in both turbidity and TDS of the waste water simultaneously.

Several parameters demonstrated lack of correlation. They include: temperature and pH (r = - 0.87); electrical conductivity and pH (r = - 0.87); TDS and pH (r = -1) and turbidity and pH (r = - 0.81).

Table 3: Correlational Analysis between Physical Parameters

	Temp	**E.C**	**TDS**	**pH**	**Turbidity**
Temp	1				
E.C	1	1			
TDS	0.87	0.87	1		
pH	-0.87	-0.87	-1	1	
Turbidity	0.41	0.41	0.81	-0.81	1

***Bolded values indicate significant correlation at 95% confidence level**

Table 4: Correlational Analysis between Metal – Metal Pairs

	Cd	**Co**	**Cu**	**Fe**	**Cr**	**Zn**	**Pb**	**Ni**
Cd	1							
Co	1.00	1						
Cu	0.98	0.98	1					
Fe	0.35	0.36	0.15	1				
Cr	0.63	0.64	0.46	0.95	1			
Zn	0.97	0.97	0.90	0.57	0.80	1		
Pb	1.00	1.00	0.98	0.36	0.64	0.97	1	
Ni	0.34	0.36	0.15	1.00	0.95	0.56	0.35	1

***Bolded values indicate significant correlation at 95% confidence level**

Conclusion and Recommendations

Conclusion

The physical parameters whose levels were above the WHO levels were turbidity and pH, whereas electrical conductivity and TDS registered values that were less than the WHO allowable limits. All the heavy metals concentrations were beyond their respective WHO allowable limits, signifying pollution by heavy metals. The physical parameters that demonstrated strong correlation include: electrical conductivity – temperature, TDS – temperature, TDS – electrical conductivity and TDS – turbidity. Several metal pairs were strongly correlated and these include: Cu – Cd, Zn – Cd, Pb – Cd, Cu – Co, Zn – Co, Pb – Co, Zn – Cu, Pb – Cu, Cr – Fe, Ni – Fe, Zn – Cr, Ni – Cr and Pb – Zn. This point to the existence of metal – metal complexes and alloys in the waste water.

Recommendations

In view of the above, this study recommends the following measures to be put in place in order to mitigate pollution by industrial effluent:

i. Industrial effluent should be properly treated by taking it through primary, secondary and tertiary treatment processes so as to reduce COD and BOD to WHO permissible levels before the waste water is discharged into rivers.
ii. Heated industrial waste water should be passed through cooling ponds or cooling towers to reduce the temperature to normal room temperature before it gets discharged.
iii. Both the County and National governments should put in place policies that regulate illegal mining especially across the Kenya – Uganda border.
iv. The National Environmental Management Authority (NEMA) should put in place strict penalties that will ensure stiff penalties are passed to would be polluters.
v. Industries should embrace current processing/manufacturing technologies that aim at reducing the amount of effluent produced.
vi. Adsorbents made from local and environmentally friendly materials such as chitosan, cellulose and alginate for getting rid of anions and heavy metals in waste water should be researched further.

Competing Interests

The authors declare that no competing interests exist.

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Author Contributions

Credit (Contributor Roles Taxonomy)[25] *has been used to represent the roles played by authors in this work. The roles describe each authors' specific contribution to the scholarly output.* ***Dr. Denis Magero:*** *Conceptualization, writing – Review, Resources, and Editing, Supervision, Project administration and Funding acquisition.* ***Dr. Victor Meng'wa:*** *Writing - Review and Editing, Supervision, Project administration, and Funding acquisition.* ***Mr. Kevin Omondi Ondoo:*** *Methodology, Data Curation, Investigation, Formal analysis, Writing – Original Draft and Visualization* ***Mr. Wanakai Sammy*****:** *Formal analysis and Investigation.*

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