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The Impacts of Solid Waste on Ground and Surface Water Quality in Kisii Municipality, Kenya

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Abstract
Leachate flow from urban municipal dumpsites into surface and groundwater sources poses significant risks to urban populations who rely on these water sources. Accumulation of contaminants can lead to high pollutant levels, potentially toxic to users. In Kisii Town, River Nyakumisaro and improved groundwater wells are the primary sources of potable water for residents. The aim of this study was to assess the impact of municipal solid waste disposal on water quality in these urban sources. The study specifically focused on comparing pollutant levels in wells and streams with KEBS drinking water guidelines and NEMA effluent discharge standards, examining the seasonal effects on water pollution, and investigating the correlation between pollutant levels and distance from the dumpsite. Water samples were collected from four wells and the stream during both dry (August) and wet (September to early October) seasons in 2015. The surface water samples were taken from two points upstream and downstream (400m and 800m), and well samples were collected directly from taps. Analysis included physicochemical parameters such as temperature, pH, electrical conductivity, and nitrate (NO3-), alongside trace metals (Pb, Cd, Zn, Mn) and bacteriological analysis. Results showed that levels of electrical conductivity, manganese, zinc, lead, cadmium, nitrate, and E. coli in the water samples exceeded KEBS/NEMA standards, indicating potential health risks. The total coliform count was found to be higher than 1600 counts/100ml, posing a pathogenic health threat. Seasonal effects were evident, with increased pollutants during the wet season due to higher solubility of organic materials and runoff. The pollutant levels had a negative correlation with distance from the dumpsite, with downstream concentrations lower, possibly influenced by industrial activities. The findings highlight the need for periodic water quality assessments and regulations regarding safe distances for well placement near dumpsites.

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I. Introduction

The rapid development of the 20th century transformed many rural communities into urban centers, bringing with it a host of environmental challenges. Among these, solid waste management has emerged as a pressing global issue, particularly in rapidly growing cities. The 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro highlighted the problem, emphasizing the need to reduce waste and promote the reuse and recycling of materials. Despite these international efforts, many developing countries continue to struggle with effective waste management due to increasing urban populations and insufficient infrastructure.

In Africa, solid waste disposal often takes precedence over water quality concerns, with urban growth contributing to the generation of harmful toxic substances. This situation is exacerbated by a lack of infrastructure to handle the volume of waste produced. In Kenya, common waste disposal methods include open dumping, incineration, composting, and landfilling, with open dumping being the most prevalent due to its low cost. However, this practice frequently overlooks geological and hydrogeological factors, resulting in environmental degradation. The indiscriminate dumping of waste, including toxic substances, has led to serious consequences such as water pollution, disease outbreaks, flooding, and unsightly waste accumulation, posing significant health risks to urban populations.

Statement of the Problem

Rapid urbanization and population growth in Kisii Town have led to increased solid waste generation, overwhelming existing waste management systems and endangering crucial water resources. The close proximity of groundwater wells and River Nyakomisaro to the Nyambera dumpsite raises significant environmental and public health risks due to leachate contamination. Despite the urgency, limited empirical studies have assessed the extent of this pollution. This study sought to fill that gap by evaluating pollutant levels in surface and groundwater sources against KEBS and NEMA standards to guide policy and promote safe water use. Previous studies by Ogendi (2022) and Kerich & Fidelis (2020) highlighted the deteriorating water quality of River Nyakomisaro due to anthropogenic activities, underscoring the need for systematic monitoring and improved waste management to protect water sources in Kisii Municipality.

Objectives of the study

The main objective was to determine the effects of solid waste on ground and surface water quality in Kisii County, Kenya. Specific research objectives were to establish;

i) The levels of pollutants in the wells and stream water as compared to guidelines provided by Kenya Bureau of Standards for drinking water and NEMA effluent discharge guidelines.
ii) The effects of seasons on wells and stream water pollutants levels
iii) The correlation between levels of pollutants in wells and surface water with distances from the dumping site.

Hypotheses

i) There is no significant difference in levels of pollutants in ground water and surface water from the guidelines set by Kenya Bureau of Standards (KEBS, 2006) and NEMA, 2012.
ii) Seasons have no significant effect on ground water and surface water quality
iii) There is no significant correlation between levels of pollutants with distances from the dumpsite.

Conceptual framework

The conceptual framework is based on the relationship between leachate generation and the quality of the surface water and the ground water. The solid waste management elements are the basis of waste management practices of achieving environmental health. The management of solid wastes at the dumping sites with time, solid waste characteristics and other intervening factors were significant in correlation to the quality of the surface and ground water. Figure 1.1 shows the conceptual framework.

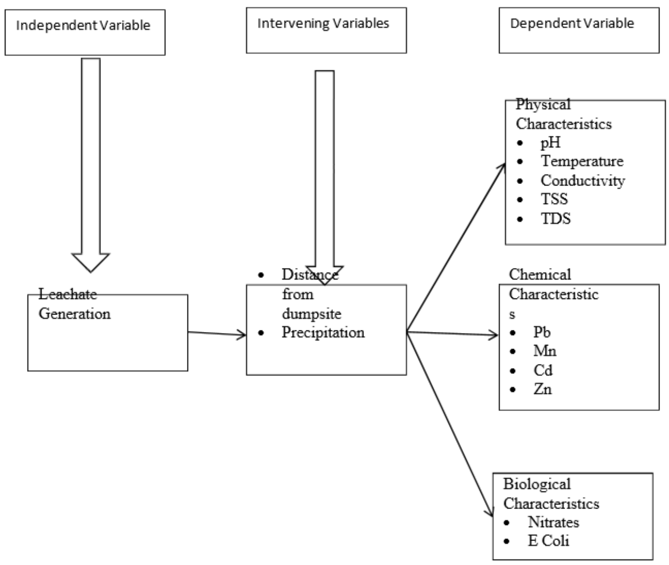


Figure 1.1: Conceptual framework (Source: Author)

II. Literature Review

Groundwater Supplies

Groundwater, found in the pores and fractures of rocks and sediments beneath the Earth's surface, originates from rainfall or snow that percolates through the soil into underground systems. It eventually resurfaces through wells, streams, lakes, or oceans and is widely used for domestic, agricultural, and industrial purposes due to its broad availability, low cost, and relatively high quality, often requiring minimal treatment compared to surface water (Morris, 2003). Globally, nearly half of the population depends on groundwater for drinking water, and in Africa, approximately 75% of the population relies on it for water supply. In arid countries like Libya, Tunisia, Namibia, and Botswana, groundwater serves as the primary or sole source of potable water (UNEP, 2010; WWAP, 2012)

Pollution of Groundwater and Surface Water

Groundwater vulnerability to pollution is influenced by the interplay of geological and hydrological factors, with certain combinations posing greater risks than others (Dimitriou, 2008). Aquifers are hydraulically connected to the land surface through pore spaces, and those that readily receive water—and thus contaminants—from the surface are considered more vulnerable. The quality of groundwater is determined by the amount of contaminants reaching the aquifer, the time it takes them to travel, and the natural capacity of the geological system to attenuate pollutants, which varies depending on soil and rock type as well as the nature of the contaminants (WHO, 2006). Effective prevention or control of groundwater and surface water pollution thus requires a thorough understanding of the aquifer's vulnerability and the human activities affecting the area.

Effects of Municipal Solid Waste on the Environment

Uncontrolled municipal solid waste dumping poses significant environmental and public health risks, particularly to urban residents living near dumpsites. These risks include pollution of water sources, contamination of food, air and land degradation, and harm to vegetation. Poor waste disposal practices contribute to environmental degradation, ecosystem disruption, and increased public health hazards (UNEP, 2005; Abdus-Salam et al., 2011). Many dumpsites are poorly located near residential areas and wetlands without proper technological safeguards, making them susceptible to releasing pollutants through leachates into water bodies and harmful gases into the air (Kulikowska & Klimiuk, 2008). Over time, unmanaged and aging dumpsites severely impact terrestrial, aquatic, and aerial environments, with several water resources becoming hazardous to both humans and ecosystems (Moh, 2012; Odukoya et al., 2000).

Effects of Pollutants on Health

Pollutants in water, particularly heavy metals and microbial contaminants, pose significant health risks when concentrations exceed safe thresholds. While water naturally contains trace elements like zinc, calcium, and magnesium, elevated levels of heavy metals such as lead, cadmium, mercury, and arsenic can cause serious health conditions including kidney damage, neurological disorders, anemia, high blood pressure, and reproductive issues (Sangarika et al., 2010; GSADH, 2005). These metals often enter water systems through industrial activities, waste incineration, and landfill leachate. Acidic water (low pH) exacerbates the toxicity of these contaminants by increasing their solubility and reactivity (Moh, 2012). In addition to chemical pollutants, microbial pathogens like *Escherichia coli* (E. coli), often derived from untreated sewage, serve as indicators of fecal contamination and can cause gastrointestinal illnesses and, in vulnerable populations, more severe health outcomes like methemoglobinemia or "blue baby syndrome" (Butt & Iqbal, 2007; Osu & Okoro, 2011). Thus, monitoring and managing these pollutants is critical to protecting public health.

Water Quality Standards and Guidelines

Water Quality Standards and Guidelines are designed to safeguard public health and protect aquatic ecosystems by regulating acceptable contaminant levels in water sources. These standards, established by individual countries, are based on global frameworks such as the WHO Guidelines for Drinking-Water Quality (GDWQ), which address physical, chemical, and microbiological parameters and are regularly revised through scientific consultations (WHO, 2006; 2011). Although not legally binding, the GDWQ provide a basis for countries to develop context-specific regulations suited to their environmental, socio-economic, and cultural conditions. Developed nations have generally achieved higher compliance with these standards, while developing countries like Kenya are still improving their regulatory frameworks. Kenya has localized the WHO guidelines through the Kenya Bureau of Standards (KEBS) and the National Environment Management Authority (NEMA), whose effluent discharge limits were used in this study to assess the physico-chemical and biological quality of water.

Potential Health Effects of contaminated surface water flow and groundwater

Landfilling, while globally recognized as a controlled waste disposal method, often fails to prevent contamination of surface and groundwater due to poor construction practices and lack of proper lining, allowing leachate from decomposing organic waste to seep into surrounding water sources (Butt & Ghaffar, 2012; Longe & Balogun, 2010). This leachate infiltration poses significant environmental and health risks, particularly to vulnerable populations like children and the elderly (Mor et al., 2006). Contaminated water can transmit a range of waterborne diseases, including diarrhea, cholera, typhoid, hepatitis, and blue baby syndrome, particularly when high nitrate levels are present. Additionally, toxic substances such as benzene—a known carcinogen—and lead can cause severe health issues, including neurological damage, developmental problems in children, and pregnancy complications (Butt & Iqbal, 2007). Preventing groundwater contamination at the source remains the most effective strategy for protecting public health.

Challenges of urban solid waste management

Urban solid waste management is deeply influenced by public attitudes and awareness regarding waste handling practices, including segregation, recycling, and willingness to support waste management services. Effective solid waste management (SWM) relies on community participation and a societal approach, yet in many settings, this involvement is minimal (Zurbrugg, 2003). In Kisii Town, for instance, the management of waste is particularly challenging due to its status as a commercial and transit hub for neighboring counties and countries. Waste generated in areas like markets, hotels, and bus parks is disposed of at the Nyambera municipal dumping site, which falls under the Daraja Mbili zone. However, this site struggles with unmanaged and aging waste that includes household, commercial, industrial, and institutional sources (MCK, 2013). The waste composition includes both organic (food, garden waste) and inorganic materials (construction debris), which slow down decomposition and increase the accumulation of contaminants (Ahmed & Ian, 2012).

Impacts of Solid Waste Management

Improper SWM poses serious threats to land and water resources, with leachate being one of the most toxic by-products. It contaminates surface and groundwater, endangering communities that rely on these sources for drinking and domestic use. Due to limited natural dilution, leachate impacts persist, requiring environmental control measures for sustainable management. The depth and age of waste in landfills directly affect leachate toxicity, with older and deeper waste layers producing more concentrated contaminants (Ahmed et al., 2012; Asadi, 2008). Over time, leachate evolves to contain high chemical and biological oxygen demand (COD and BOD), and its composition changes as organic materials decompose and inorganic elements remain stable (Chiang et al., 2001).Leachate forms through complex physical, chemical, and biological processes influenced by waste type, landfill geology, and climate (Kjeldsen et al., 2002). Its composition includes a mix of organic and inorganic components, posing significant challenges for developing countries with underdeveloped waste management systems (Tatsi & Zouboulis, 2002). Key ions found include calcium, magnesium, sodium, and chloride, which contribute to toxicity (Christensen et al., 2001). Trace elements like cadmium, lead, chromium, and zinc are common and hazardous due to their toxicity and persistence in the environment (Jorstad, 2006). While the concentration of heavy metals in leachates is often low, even minimal levels can severely contaminate groundwater (Ehring, 1983). Their mobility is affected by pH, redox potential, and the chemical environment within the landfill. Dissolved organic matter in leachate includes complex substances like fulvic and humic acids, whose concentrations are monitored through physico-chemical indicators such as TDS, TSS, and coliform counts (Kjeldsen & Christophersen, 2001; Jorstad, 2006).

III. Materials And Methods

This study used a descriptive survey design. Creswell (2002) describes descriptive survey design is being cheap, easy and effective to conduct. The descriptive survey design enabled the researcher to gather information, summarize and interpret them for the purposes of clarification (Orodho, 2004).

The initial reconnaissance survey within Kisii Municipality near Nyambera Municipal Dumping site found a total of four wells and one river. The wells close to the dumping site were purposively selected both upstream and downstream. The stream was equally sampled along the wells and close to the dumping site, This sampling method was adopted because of its flexibility. It also allowed for experience and decision making ability of the investigator (Orodho, 2004). The area was chosen due to regular use of these water sources for domestic purposes.

The choices of the sampling points were determined by the direction of flow and their proximity to the sampled wells and nearness to the surface leachate flow from the dumping site. The collection of samples from wells and the surface water was done during the dry season of August, September and early October 2015 and the rainy period of late October, November and December 2015.

A total of four (4) sampling points and four wells were selected at equidistance both upstream and downstream (Figure 3.1). The surface water samples were collected at an average of 30cm deep in both seasons. For each season three samples were taken from each of the four sampling points making a total of 24 surface water samples collected in the two seasons.

The surface water samples were collected in 1.5 litre water bottles. The bottles were first cleaned with 10% Nitric acid and rinsed with distilled water and then rinsed three times with the sampled water at the sites. Samples for the wells were filled in the 1.5 litres of sample bottles direct from the tap after sterilization of the sampling equipment. Each sampling container was corked after filling with sampled water using lids and kept in a cool box for transfer to Kenya Industrial Research and Development Institute (KIRDI) laboratories in Kisumu for analysis.

In-situ Measurements

The Physical parameters; Temperature, Electrical conductivity, pH were determined in the field immediately after collection. The pH was measured using Jenway model 3100 pH meter. Electrical Conductivity was determined using conductivity meter Jenway model 4076 and both of them had automatic temperature compensation.

Sample Digestion

The water samples were thoroughly shaken in their plastic containers to obtain homogenous sample. A volume of 100 ml of the sample was measured using a 100 ml volumetric flask and transferred to a conical flask; 5 ml of concentrated nitric acid was then added. The mixture was heated slowly on a hot plate and evaporated to about 20 ml ensuring that the water did not boil. A further 5 ml of concentrated nitric acid was added and the beaker was covered with a watch glass while heating continued. Nitric acid continued to be added until the solution appeared light coloured and clear. Lastly, 2 ml of concentrated hydrochloric acid was added and heated slightly to dissolve any remaining residue. Few drops of hydrogen peroxide were then added to ensure complete digestion had taken place. The solution was filtered and the filtrate was transferred to a 100 ml volumetric flask to cool and the filtrate was made up to the mark with distilled water (Radojovenic and Bashkin, 2006).

Preparation of stock solutions and standards

Zinc stock solution and standards

Zinc stock solution (100 mg/l) was prepared by dissolving 0.289 g of zinc nitrate salt in 300 ml of distilled water and then made up to 1 litre of solution using distilled water. A working zinc standard solution (20 mg/l) was made by diluting 20 ml of the stock solution to 100 ml of solution. The calibration graph was made using solutions with the following concentrations; 0.5, 1, 1.5, 2, and 2.5 mg/l of zinc.

Manganese stock solution and standards

Manganese stock solution (100 mg/l) was prepared by dissolving 0.10 g of manganese metal powder in 10 ml of concentrated hydrochloric acid mixed with 1 ml of concentrated nitric acid. A 10 ml of nitric acid was then added and the solution finally diluted to 1000 ml with distilled water. A working manganese standard solution (20 mg/l) was made by diluting 20 ml of the stock solution to 100 ml of solution using distilled water. The calibration graph was made using solutions with the following concentrations; 0.5, 1, 1.5, 2 and 2.5 mg/l of manganese.

Lead stock solution and standards

Lead stock solution (1000 mg/l) was prepared by dissolving 1.59 g of lead (II) nitrate in 500 ml of distilled water and then made up to 1 litre of solution using distilled water. Through serial dilutions, standard working solutions of lead of 1, 2, 3, 4 and 5 mg/l were made which were used to generate a calibration curve for lead.

Cadmium stock solution and standards

Cd stock solution (1000 mg/l) was prepared by dissolving 0.275 g of Cd nitrate salt in 500 ml of distilled water and made up to 1 litre of solution using distilled water. A working Cd standard solution (10 mg/l) was made by diluting 10 ml of the stock solution to 100 ml of solution with distilled water. The calibration graph was drawn using concentrations; 0.2, 0.4, 0.6, 0.8, and 1.0 mg/l of Cd solutions.

Method of Validation

The digestion method and atomic absorption spectroscopy analysis were validated by recovery method. 1g of randomly selected soil powder was spiked with three different concentrations of heavy metals one at a time (1.0, 1.5, 2.0 ppm) each run in with the AAS machine. This was followed by the digestion of the spiked samples and determination of metal concentration using AAS. Blank or un spiked samples were digested through the same process and analyzed by same AAS. The amount that was recovered after digestion of the spiked samples was used to calculate % recovery (Al- weher, 2008). A mean recovery of the matrix was evaluated at 95% confidence level (Borosova *et al.*, 2002).

Sample analysis

Buck scientific (210 VGF) flame atomic absorption spectrophotometer machine was used in this analysis. Its parameters were set according to the specifications given in the manufactures manual including lamp current and fuel system of air/acetylene flame. The AAS machine had a picking meter that indicated when the optimum conditions had been realized. Its optimization was automatic. The elements and their wavelength (nm) of analysis in air acetylene flame were at 283.3, 278.5, 213.8 and 228.3 for Pb, Mn, Zn and Cd respectively.

Data analysis and presentation methods

Data on the level of pollutants in the wells and stream water was analyzed using descriptive statistics to obtain means. Correlation analysis was performed through cross- tabulations to determine the relationship between the level of pollutants in the surface water and wells as compared to the seasons and distances between the wells and the dumping sites. The Data was analyzed using Statistical Package for Social Sciences (SPSS) computer software version 20.

IV. Results And Discussions

Levels of pollutants in the wells and stream water as compared to guidelines provided by KEBS for portable water

pH

The ground and surface water pH for wet and dry seasons were measured (Table 4.1 and 4.2). The results in Table 4.1 shows that the mean pH in stream water ranged from 7.43 to 7.44 during dry season and 7.32 to 7.34 during wet season and were slightly alkaline. Table 4.2 indicates that the mean pH in wells during dry (7.45) and wet (7.34) seasons did not show a wide variation. The mean pH during the study was within the guidelines and in acceptable range. The pH value indicates a neutral to alkaline leachate which suggests a methanogenic stage. This concurs with findings of Khateeb (2013) who observed that at this stage significant quantities of pollutants such as ammonia are consistent with such pH value.

Table 4.1: pH Values for the Four Sampling Points on the Stream Measured during the Dry and Wet Seasons

Sampling points

Season	**Month**	S_1	S_2	S_3	S_4
Dry	August	7.43	7.44	7.45	7.47
	September	7.46	7.43	7.44	7.42
	Early October	7.43	7.45	7.43	7.42
	Mean	7.44	7.43	7.43	7.43
Wet	Late October	7.33	7.34	7.31	7.37
	November	7.36	7.33	7.32	7.32
	December	7.33	7.35	7.33	7.32
	Mean	7.34	7.34	7.32	7.33

Table 4.2: pH Values for the Four Wells Measured during the Dry and Wet Seasons

Sampling points

Season	**Month**	W_1	W_2	W_3	W_4
Dry	August	7.47	7.47	7.47	7.47
	September	7.42	7.42	7.42	7.42
	Early October	7.46	7.46	7.46	7.46
	Mean	7.45	7.45	7.45	7.45
Wet	Late October	7.33	7.34	7.35	7.37
	November	7.36	7.33	7.34	7.32
	December	7.33	7.35	7.33	7.32
	Mean	7.34	7.34	7.34	7.34

Water Temperature

The measured temperatures in both surface water and wells during the wet and dry season are given in Table 4.3 and Table 4.4. The average measured temperatures were higher during the dry season as compared to the wet season. This is due to a lot of heat generated naturally from the sun that heats the water bodies during dry season in Kisii highlands during such period (MCK, 2013). In both surface water and wells, the temperatures ranged between 18.9^{0}C to 24.6^{0}C.

Table 4.3 Temperature Values for the Four Sampling Points on the Stream Measured during the Dry and Wet Seasons

Sampling points

Season	**Month**	S_1	S_2	S_3	S_4
Dry	August	21.6	21.7	21.7	21.9
	September	21.7	21.8	21.8	21.9
	Early October	21.8	21.9	21.9	21.9
	Mean	21.7	21.8	21.8	21.9
Wet	Late October	18.8	18.8	18.8	18.8
	November	18.9	18.9	18.9	18.9
	December	18.9	18.9	18.9	18.9
Mean		18.9	18.9	18.9	18.9

Table 4.4: Temperatures Values for the Four Wells Measured during Dry and Wet Seasons
Sampling points

Season	Month	W_1	W_2	W_3	W_4
Dry	August	21.3	21.4	21.6	24.5
	September	21.4	21.5	21.7	24.6
	Early October	21.5	21.6	21.8	24.7
	Mean	21.4	21.5	21.7	24.6
Wet	Late October	18.8	18.8	18.8	18.8
	November	18.9	18.9	18.9	18.9
	December	18.9	18.9	18.9	18.9
Mean		18.9	18.9	18.9	18.9

Electrical Conductivity of Water

The electrical conductivity (EC) for wet and dry seasons as compared to KEBS guideline is presented in Figure 4.1 and 4.2. The location of the wells (W1, W2, W3, W4) and sampling points (S1, S2, S3, S4) on the surface water was -800, -400, 400 and 800 respectively from the dumpsite. The negative sign indicates upstream while positive indicates downstream from the dumping site.

The results in Figure 4.1 and 4.2 indicate that Well 3 (166*us/ml*) and sampling point, S3 (193*us/ml*) which are adjacent and located nearest to the dumpsite downstream had the highest electrical conductivity during wet season. All sampling points other than S1 had relatively high electrical conductivity as compared to the KEBS guidelines. This is likely because S1 was located furthest upstream from the dumpsite implying less inorganic dissolved solids like nitrate, sulphate and phosphate anions or cations like sodium, magnesium and iron. This is consistent with result found by Mohammed (2011) at Minna, Niger state of Nigeria where groundwater conductivity was higher than WHO guideline.

Figure 4.1: Electrical Conductivity for the Four Sampling Points along the Stream Measured during the Dry and Wet Seasons (2015)

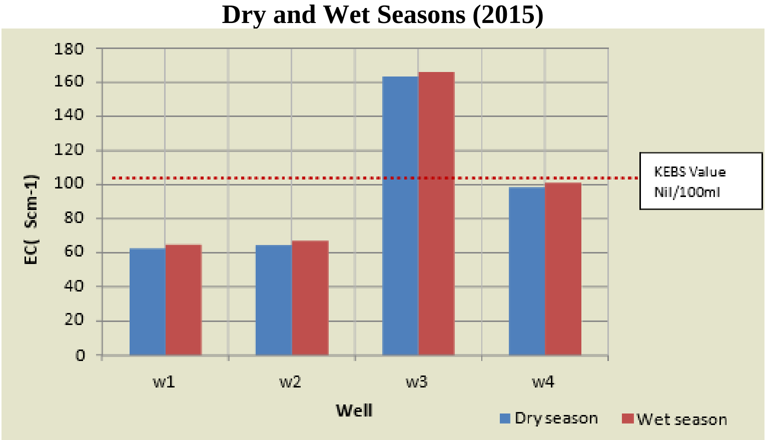
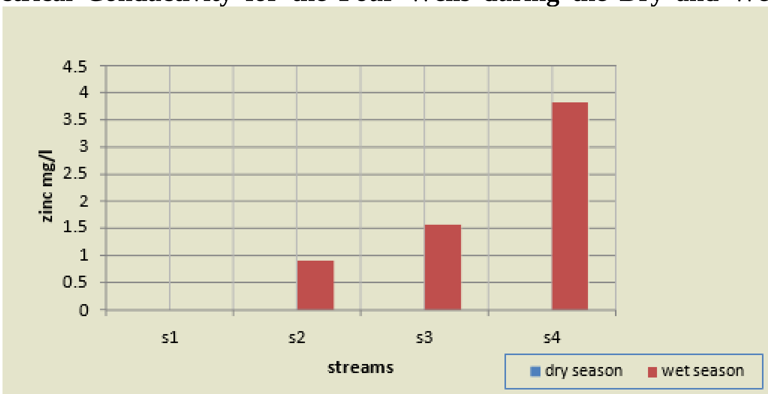


Figure 4.2: Electrical Conductivity for the Four Wells during the Dry and Wet Seasons (2015)



Zinc (Zn) Concentration levels

In this study the mean Zn concentration levels in surface water for all the sampling sites are presented in Figure 4.3. Measured values were detected only during the wet season in three sampling points; S2, S3 and S4. The zinc concentration increased from S2 (0.91 mg/l), S3 (1.57mg/l) to S4 (3.83 mg/l). The concentration of Zn in the downstream sampling points exceeded the recommended limit of 1.5 mg/l levels recommended by KEBS. The concentration of Zn increased downstream probably due to gradual accumulation from the municipal wastes and that from the dumping site. When Zn metal is dumped haphazardly in the landfills, the resulting leachate percolates into the groundwater or is washed into the streams thus causing water pollution. This finding concurs with Damodharan (2013) who noted that among other sources of Zn into aquatic ecosystems include urban runoff and municipal sewages.

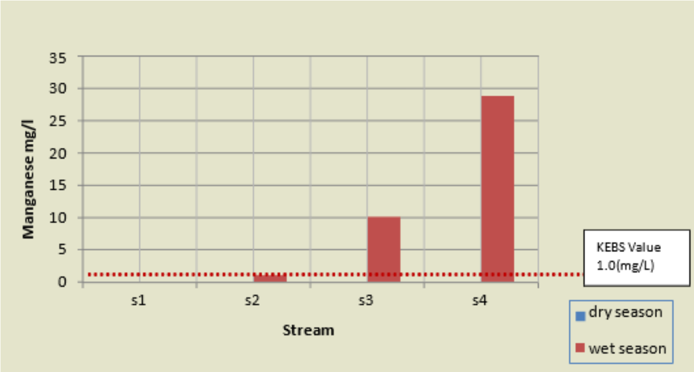


Figure 2.1: Zinc Levels for the Four Sampling Points on the Stream Measured during Dry and Wet Seasons (2015)

Manganese (Mn) Concentration Levels

Measured values were detected only during the dry season in three sampling points; S2, S3 and S4. The results in Figure 4.4 indicate higher levels of manganese (10.10 and 28.93) for wells S3 and S4 respectively than the recommended guideline (1.0 mg/l) during the dry season while S2 indicated a similar value to the recommended guideline. Only well S2 registered slightly similar concentration (1.01) to the guideline. The mean Mn concentration ranged from 1.01 mg /l at sampling point 2 to 28.93mg/l in sampling point 4. The high levels observed at sampling point S4 could probably be due to industrial activities in the Kenya Industrial Estates (KIE) next to the sampling point. In all the sampling sites the mean Mn concentration levels in surface water was found to be higher than that recommended limit of 1.0 mg/l for Mn in drinking water (KEBS, 2012).

This finding is consistent with Ziemacki *et al.* (1989) that Mn gets into the aquatic ecosystems from industries manufacturing dry-cell batteries, glass, and fertilizer and in leather and textile.

Manganese concentration levels over the recommended levels are of concern. At levels exceeding 1.0 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. The ill effects of manganese in human via inhalation include neurotoxin causing ataxia, co-ordination impairment, anxiety, dementia and involuntary movement similar to Parkinson's disease (Ziemacki *et al.*, 1989).

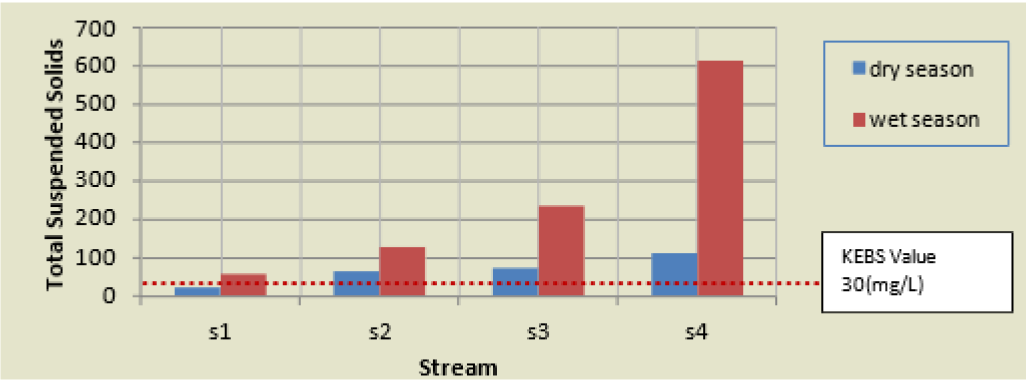


Figure 4.3: Manganese Levels for the Four Sampling Points on the Stream Measured during the Dry and Wet Seasons (2015)

Lead (Pb) concentration levels

The mean measured concentration levels of Lead for wet and dry seasons were not detected (ND) indicating that it is not present. This finding contradicts many recent studies in Kenya that indicate higher Pb concentration levels. For example Oyoo-Okoth *et al.* (2010) found mean Pb levels ranging from 0.26 - 0.99 mg/l in Lake Victoria. Also, Muiruri *et al.* (2013) recorded lower and higher mean Pb levels at different sites (ND -

0.047 mg/l) in surface water of Athi River tributaries. Other studies in Kenya that have recorded higher mean Pb levels include open waters of Winam gulf (0.2 mg/l), River Nyando (0.19 mg/l), and 0.015 mg/l in River Sondu Miriu (Tole and Shitsama, 2003). Ochieng *et al.* (2007) obtained higher mean Pb levels ranging 0.025 - 0.563 mg/l in surface water of five Rift valley Lakes. Ochieng *et al.* (2008) recorded Pb concentration levels of 0.006 - 0.048 mg/l in Lake Kanyaboli, Kenya. Studies carried out by Olatunji and Osibanjo (2012) also recorded higher mean Pb levels (0.02 - 0.04 mg/l) in surface water of River Niger, Nigeria.

Cadmium (Cd) concentration levels

The measured levels of cadmium in surface water and for wells during the wet and dry seasons were not detected (ND). This suggests that there is little contamination from municipal waste. Cadmium contamination from sources such as cadmium containing batteries and plastics, or cadmium-plated steel and electronic wastes is low at the Nyambera dumpsite. The releases could be carried and deposited on areas far from the source. Cadmium has toxic effects on skeletal system, the respiratory system and the kidney. It can also cause disruption of biosynthesis of hemoglobin (Jorstad, 2006). It is also carcinogenic. The results imply that cadmium is not a life threat in both the surface and wells in the study area.

Total Suspended Solids (TSS)

The results of measured levels of total suspended solids (TSS) are given in Figure 4.5. There was higher concentration levels recorded during the dry season as compared to the wet season. Other than the sampling site S1 that is furthest upstream all other sampling points recorded higher values than the recommended KEBS guidelines of 30 mg/l. The values of TSS during the dry season increased downstream probably due to gradual accumulation from the municipal wastes and that from the dumping site. Suspended material is a major pollutant carrier. Organic pollutants, toxic heavy metals, nutrients and pathogens are found in composites of suspended matter. The type of suspended matter determines turbidity and transparency of water. This finding agrees with Lang'at (2009) who found higher concentration levels of TSS from tea farms in Kericho, Kenya.

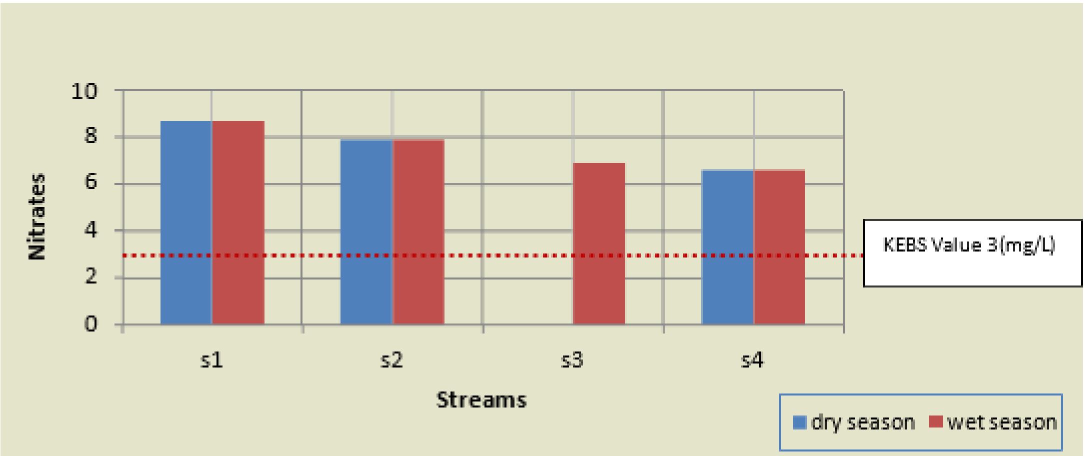


Figure 4.5: The Graph of Total Suspended Solids for the Four Sampling Points on the Stream Measured during the Dry and Wet Seasons

Dissolved Nitrates

The results in Figure 4.6 show that all the sampling points of the stream recorded higher levels (ranging from 6.6-8.7 mg/L) of nitrates than the recommended KEBS guidelines of 3.0 mg/l in both the wet and dry season but was not detected during the dry season in S3.

The measured levels of dissolved nitrates for wells during the wet and dry seasons against the recommended KEBS guideline limit of 0.005 mg/l were not detected (ND). This concurs with WHO (2004) that high concentration of nitrate cause ground and surface water pollution by increasing their nutrient levels. When nitrates in domestic water exceed the thresholds, it can result to illnesses like methemoglobinemia (blue baby syndrome) in children and nitrosamine in adults. The toxicity of nitrates comes from the natural reduction of nitrates to nitrites by gastric enzymes in human system.

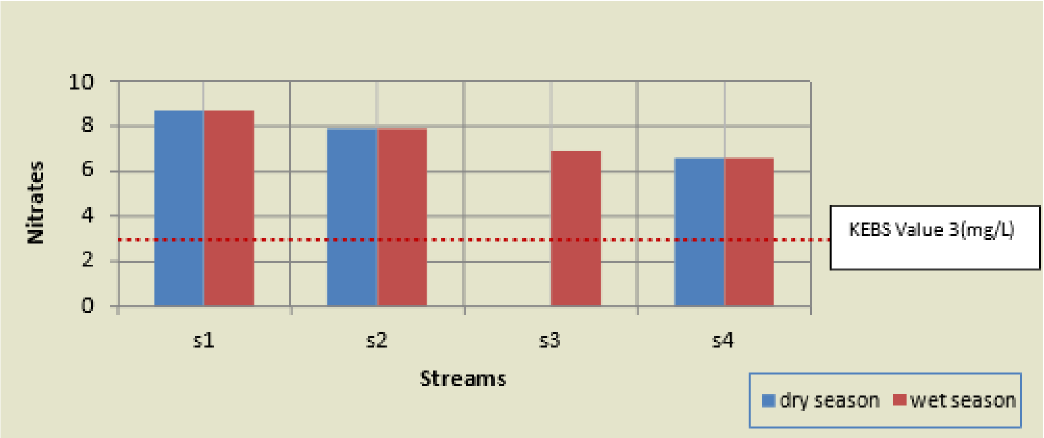


Figure 4.6 The Graph of Nitrate Values for the Four Sampling Points on the Stream Measured during the Dry and Wet Seasons

Total Coliforms

The levels of Total coliforms counts in surface water and wells were very high both in the wet seasons and dry seasons in all the samples; all exceeding 1600 mgl-1 as compared to the KEBS guidelines of nil/100ml. The presence of *Escherichia coli.forms* in drinking water is reflected through biological indicators like the total coliforms. The *Escherichia coli.forms* originates from intestinal tract of warm blooded animals and usually an indicator of the presence of pathogens in water. Their presence in drinking water is of great concern because of the many diseases they may cause to human beings. This finding is consistent with Butt *et al.* (2007) that total coli forms may not necessarily be harmful to human; however Environmental Protection Agency (EPA) considers them useful indicators of the presence of pathogens.

Effects of wet and dry seasons on wells and stream water pollution.

The study sought to find out whether the wet season (rainfall of 16.7 mm) and dry season (rainfall of 0 mm) affected the levels of pollutants in the stream and wells from which samples were taken. The following subsections show how levels of pollutants differed between dry and wet seasons.

Differences in Physical Parameters in Stream Water in the Dry and Wet Seasons

Table 4.5 shows the mean levels of Physical parameters in the stream sampled during the dry and wet season and the results of the t-test used to determine whether the mean differences were statistically significant. The results of Table 4.5 reveals that the levels of total dissolved solids (TDS) were higher in the stream water during the wet season compared to the dry season although the difference was not significant (t= 1.388, p=.259). The wet season significantly affected the levels of TDS in ground water. This is by infiltrations of particles when it rains and interferences of the mico-activities carried out near the stream (Ohwoghere-Asuma & Aweto, 2013).

Similarly, the mean levels of total suspended solids (TSS) in the stream were higher in the wet season compared to the dry season but the difference was not significant (t= 1.779, P=.173). The mean pH in the stream water was lower during the wet season compared to the dry season as shown in Table 4.5 and this difference in pH was significant (t= 41.00, P=.000). The wet season had a significant effect on pH levels during the study. This might be attributed to leachate seepage as its mean showed the alkaline pH (above 7.0) in both dry and wet seasons. Table 4.1 also shows that the mean temperature in the stream water was significantly higher in the dry season than in the wet season (t= 71.035, P=.000). The mean Electrical Conductivity (EC) in the stream water was lower during the dry season compared to the wet season as shown in Table 4.5. The observed increase in conductivity during wet season in stream water can be is a resultant of infiltration effects of rain water that washes out chemicals contained in solid wastes (Butt & Ghaffar, 2012).

From the t-test results in Table 4.5, it is possible to conclude that there are differences in the levels of Physical parameters measured in the study during the dry and wet seasons as shown by the values of pH and temperature.

Table 4.5 Physical Parameters t-test Analysis for Stream

Parameter	Dry season mean	Wet season mean	t-value	p-value	N
TDS	89.25	164.75	1.388	.259	4
TSS	66.25	256.75	1.779	.173	4
pH	7.435	7.333	41.000	.000	4
Temperature	21.80	18.90	71.035	.000	4
EC	146	148	-	-	4

Differences in Physical Parameters in Wells during Dry and Wet Seasons

The mean levels of Physical parameters measured in the wells during dry and wet seasons and the results of t-tests used to determine whether the mean differences were statistically significant are summarized in Table 4.6. The results show that there was a slightly higher mean concentration of total dissolved solids (TDS) in the wells during the dry season compared to the wet season even though this difference was not significant (*t*= 1.000, *P*=.391). Infiltrations of solids particles with rain water and surface water flow interferences the TDS in ground water aquifers during the wet season (Ohwoghere-Asuma & Aweto, 2013).

The mean concentration of total suspended solids (TSS) in the wells was not detected. The results also shows that the mean temperature was significantly higher in the dry season compared to the wet season (*t*= 4.420, *P*= .021). The mean Electrical Conductivity (EC) in the wells was lower during the dry season compared to the wet season as shown in Table 4.6. The observed increase in conductivity during wet season in stream water can be attributed to flushing and infiltration effects of rain water that washed out chemicals contained in refuse (Butt & Ghaffar, 2012). The mean pH in the wells lower during the dry season compared to the wet season as shown in Table 4.6. The wet season had a significant effect on pH levels during the study. This might be attributed to leachate seepage as its mean showed the alkaline pH (above 7.0) in both dry and wet seasons.

Table 4.6 Physical Parameters t-test Analysis for the Wells

Parameter	Dry season mean	Wet season mean	t-value	p-value	N
TDS	56.075	56.000	1.000	.391	4
pH	7.45	7.34	-	-	4
Temperature	22.30	18.90	4.420	.021	4
EC	97.75	99.75	-	-	4

The Correlation between Levels of Pollutants in Wells and Surface Water with respect to Distances between the Wells and Stream and the Dumpsite

The study investigated whether the levels of pollutants in wells and the stream water differed with respect to the distance from the dumping site. Correlation analyses were done to ascertain whether significant relationships existed between the levels of pollutants and distance from the dumpsite. The following sections present the results of these analyses.

Correlations between Physical Parameters in Stream Water and Distance from Dumpsite

Table 4.7 summarizes the Pearson's correlations between the Physical parameters in the stream water and the distances of the sampling points from the dumpsite. The results show that with the exception of pH, a negative correlation was observed between the levels of each Physical parameters and the distance from the dumpsite in both the dry and wet seasons.

Table 4.7 Correlation Analysis between Levels of Physical Parameter and Distances of Sampling Points from Dumpsite

		Dry Season		Wet Season	
Parameter	N	r	p	r	p
TDS	4	-.647	.353	-.289	.711
TSS	4	-.735	.265	-.621	.379
EC	4	-.669	.331	-.669	.331
pH	4	.949	.054	.953	.047
Temperature	4	-.671	.329	-	-

Total Dissolved Solids (TDS) in Stream Water

Figure 4.7 shows the correlation of TDS during the dry and wet seasons as a function of distance from the dumpsite. The results from Figure 4.7 shows that concentrations was high in S2 located proximity to upstream dumpsite, therefore, this is a valuable indicator that there are mineralized solids from the dumping site that percolated in stream water with rain water. However, Table 4.7 shows no significant correlation between distance and level of TDS in dry season (r= -.647, P= .353) or wet season (r= -.289, P= .711). Total Dissolved Solids recorded in the stream water in the range between 72-348 mg/L were much lower than those found by Mohammed (2011) in Niger, Nigeria: 210-738.99 mg/L, and Ohwoghere-Asuma and Aweto (2013) in Delta State, Nigeria: 6.67- 765.37 mg/L.

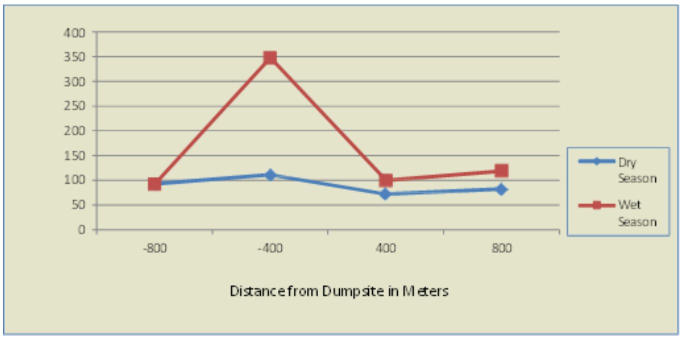


Figure 4.7 Correlation between TDS in Stream Water and Distances from Dumpsite (Dry and Wet Seasons).

Total Suspended Solids (TSS) in Stream Water

Figure 4.8 shows the correlation of TSS during the dry and wet seasons as a function of distance from the dumpsite. The results show negative correlations between levels of TSS and distance from the dumpsite in both dry and wet seasons such that the levels were generally higher downstream. Table 4.7 however shows that these correlations were not significant in both the dry season (*r*= -.735, *P*= .265) and wet season (*r*= -.621, *P*= .379).

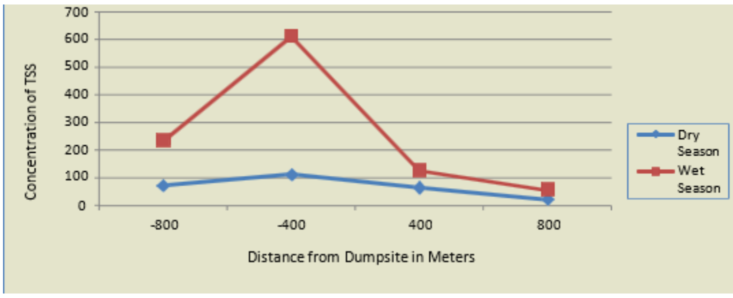


Figure 4.8 Correlation between TSS in Stream Water and Distances from Dumpsite (Dry and Wet Seasons).

Electrical Conductivity in Stream Water

Changes in electrical conductivity (EC) in stream water with respect to distance from the dumpsite are shown in Figure 4.9 (dry season) and Figure 4.10 (wet season). The results of Figure 4.9 and Figure 4.10 both reveal negative correlations between electrical conductivity and the distance from the dumpsite. Electrical conductivity along the stream declines as one moves upstream (S2 to S1). However, these correlations were not significant in either dry (*r*= -.669, *P*= .331) or wet season (*r*= -.669, *P*= .331) as given in Table 4.7.

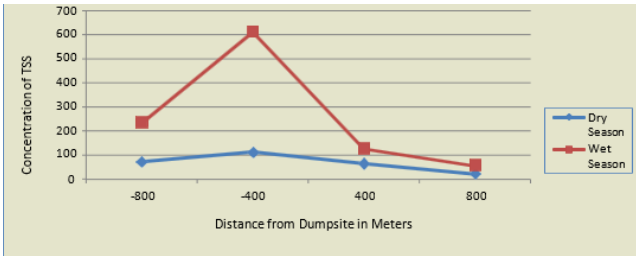


Figure 4.9 Correlation between EC in Stream Water and Distances from Dumpsite (Dry Season).

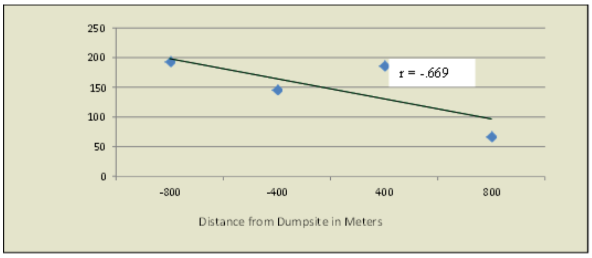


Figure 4.10 Correlation between EC in Stream Water and Distances from Dumpsite (wet Season).

pH in Stream Water

Figure 4.11 and Figure 4.12 show the correlation of pH during the dry and wet seasons as a function of distance from the dumpsite. Results of Figure 4.11 shows a positive correlation between pH and the distance from the dumpsite even though this correlation was not significant (*r*= .949, *P*= .054). Figure 4.12 shows a positive correlation that was significant (*r*= .953, *P*= .047). The only significant correlation was observed for pH in the wet season (*r*= .953, *P*= .047). The positive relationship indicates that for every increase in distances downstream from the dumping site there is an increase in pH value in stream water. The closer the sampling point to the dumping site downstream, the lower the pH value in stream water and vice versa. This can be attributed to the fact that sampling points far away from the dumping site downstream have high catchment of leachate influx than closer sampling points, an indicator of the effect of landfill on groundwater quality through seepage of leachate (Ohwoghere-Asuma & Aweto, 2013).

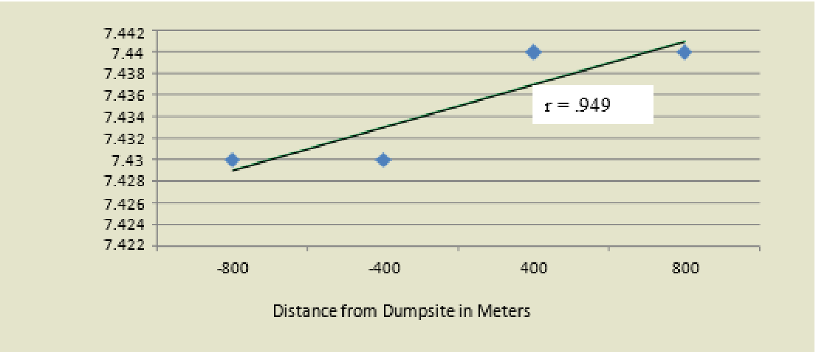


Figure 4.11 Correlation between pH in Stream Water and Distances from Dumpsite (Dry Season).

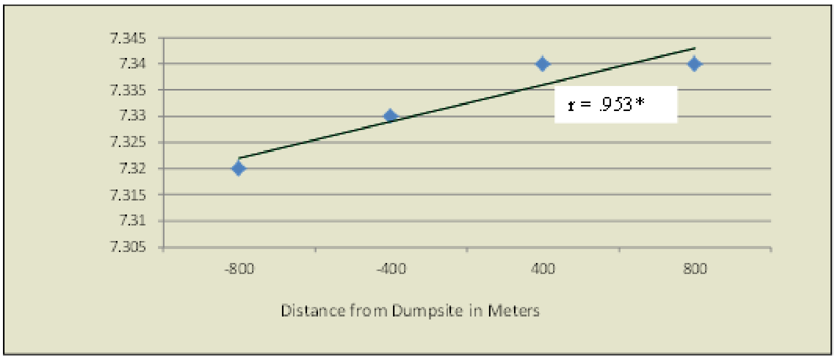


Figure 4.12 Correlation between pH in Stream Water and Distances from Dumpsite (Wet Season).

Temperature in Stream Water

The correlation between temperature in the stream water and distance from the dumpsite during the dry and wet seasons is shown in Figure 4.13 and Figure 4.14 respectively. Figure 4.13 shows that in the dry season, there was a negative correlation between temperature in the stream water and distance from the dumpsite although it was not significant (*r*= -.671, *P*=.329). Figure 4.14 however shows that the temperature was constant during the wet season.

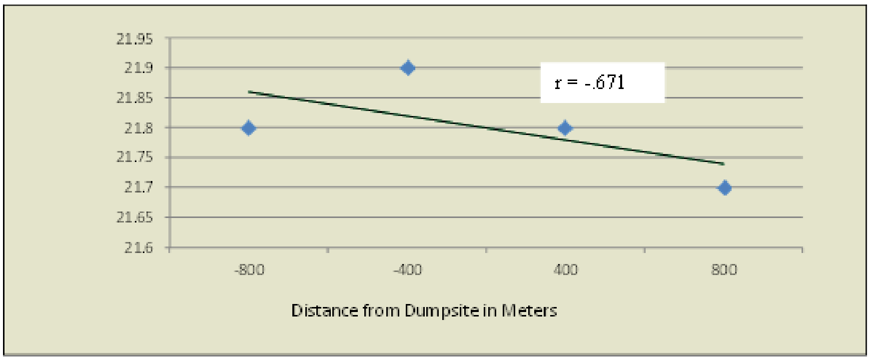


Figure 4.13 Correlation between Temperature in Stream Water and Distances from Dumpsite (Dry Season).

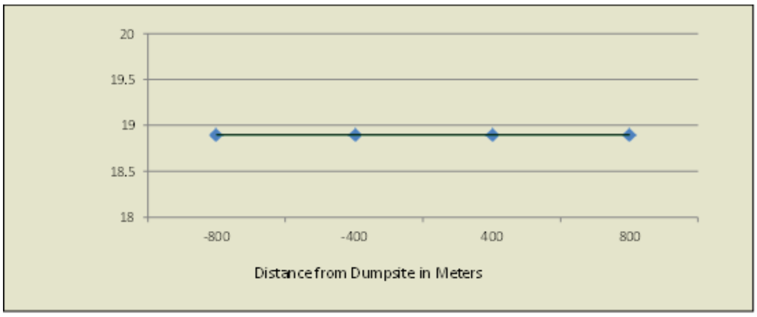


Figure 4.14 Correlation between Temperature in Stream Water and Distances from Dumpsite (Wet Season)

Correlation between Chemical Parameters in Stream Water and Distance from Dumpsite
Nitrates in Stream Water

The results of the correlation analysis between levels of nitrates in the stream water and the distance from dumpsite are presented in Table 4.8. Results shows a positive insignificant correlation of nitrate levels and distance from dumpsite in both dry season

(*r*= .862, *P*= .138) and wet season (*r*=.931, *P*= .069).		
Table 4.8 Correlation Analysis between Levels	**of**	**Chemical Parameter and**
Distances of Sampling Points from Dumpsite		
Dry Season		Wet Season

Parameter	N	r	p	r	p
Nitrates	4	.862	.138	.931	.069

Correlation between Physical Parameters in Well Water and Distance from Dumpsite

The study investigated whether there was any correlation between levels of Physical parameters in well water and distance of wells from the dumpsite. Table 4.5 contains the results of the correlation analysis. The results from Table 4.9 show that none of the physical parameters correlated significantly with the distance of the well from the dumpsite.

Table 4.9 Correlation Analysis between Levels of Physical Parameter and Distances of Wells from Dumpsite

		Dry Season		Wet Season	
Parameter	N	r	p	r	p
TDS	4	.904	.096	.903	.097
EC	4	-.914	.086	-.914	.086
PH	4	-		-	
Temperature	4	-.439	.561	-	-

Total Dissolved Solids in Well Water

Figure 4.15 and Figure 4.16 show the correlations between levels of TDS in the well water and distance of the well from the dumpsite in dry and wet reasons respectively. The results from both Figures show that the TDS levels increased as one moved from the wells downstream to the wells upstream. However, these correlations were not significant in both the wet season (*r*= .904, *P*= .096) and dry season (*r*=.903, *P*=.097).

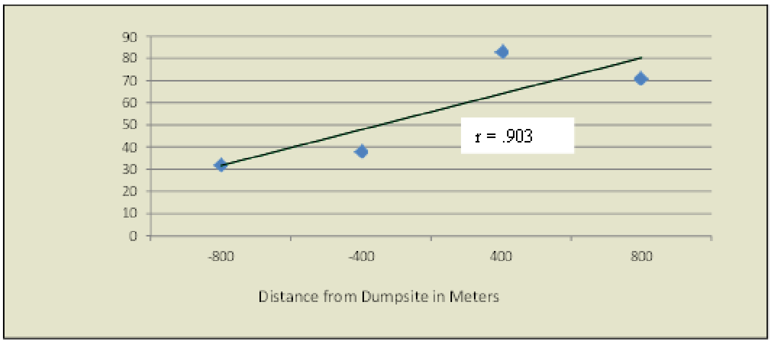


Figure 4.15 Correlation between TDS in Well Water and Distances from Dumpsite (Dry Season).

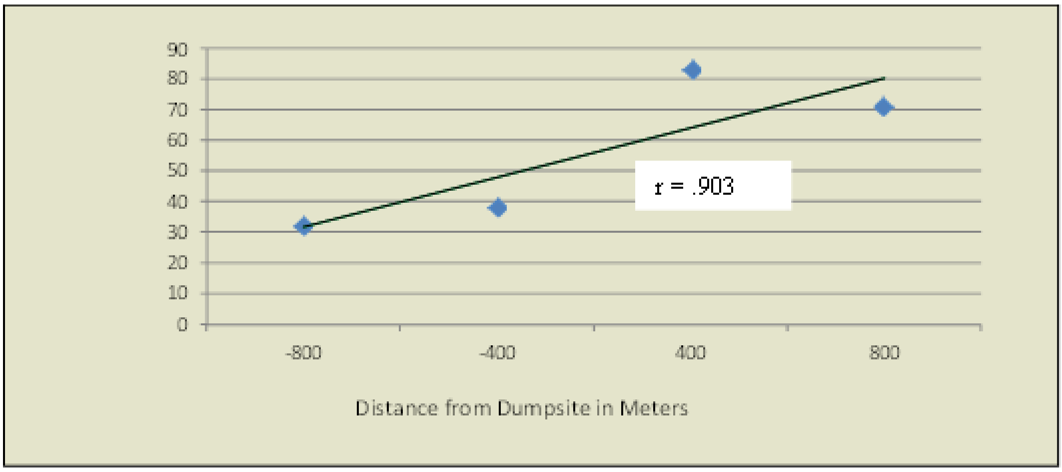


Figure 4.16 Correlation between TDS in Well Water and Distances from Dumpsite (Wet Season)

Electrical Conductivity in Well Water

Figure 4.17 and Figure 4.18 show the correlation between electrical conductivity of well water and the distance of the wells from the dumpsite in the dry season and wet season respectively. Results show that there was a negative correlation between electrical conductivity of well water and the distance of the well from the dumpsite although the correlation in both dry and wet season was not significant (*r*= -.914, *P*= .086).

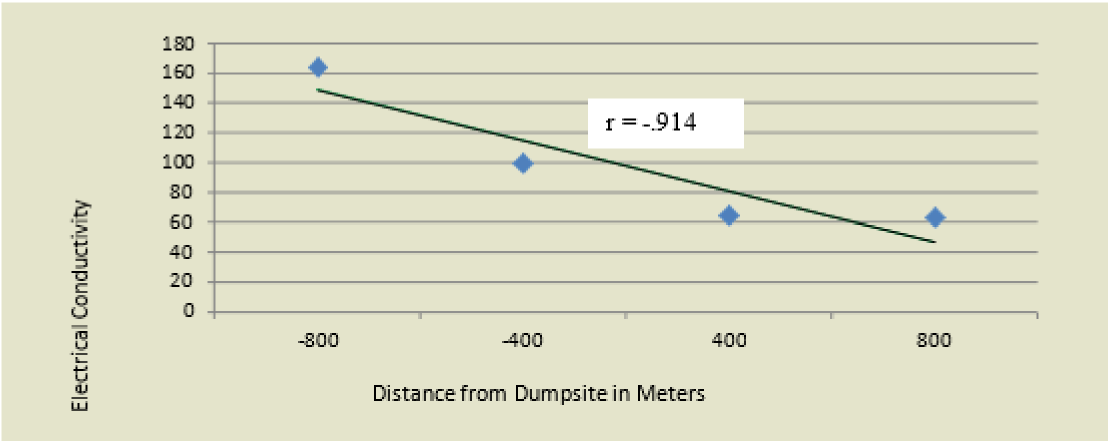


Figure 4.17 Correlation between EC in Well Water and Distances from Dumpsite (Dry Season).

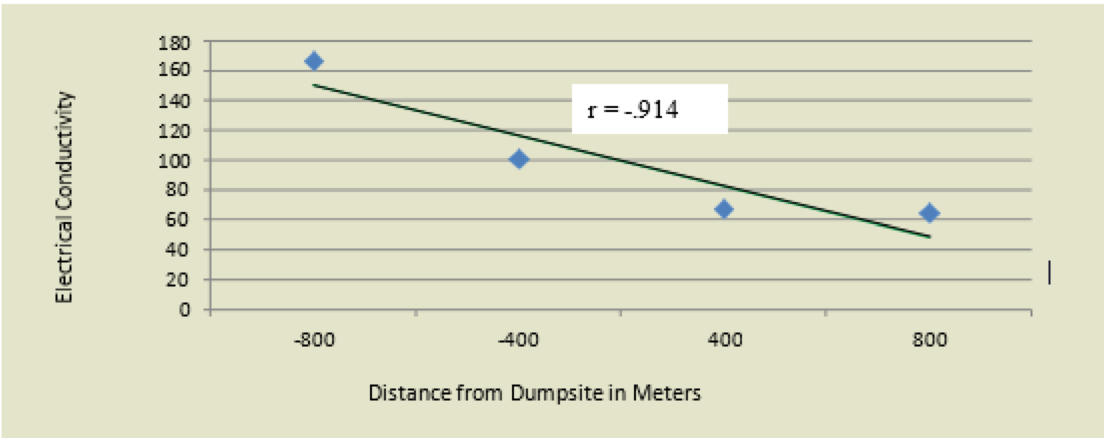


Figure 4.18 Correlation between EC in Well Water and Distances from Dumpsite (Wet Season).

pH in Well Water

Figure 4.19 shows the trend in pH in the wells during the dry season while Figure 4.20 shows the trend in the wet season. Results in both Figure 4.19 and Figure 4.20 show that the pH was the same in all the wells during the dry and wet seasons. The pH did not correlate significantly with the distance of the well from the dumpsite.

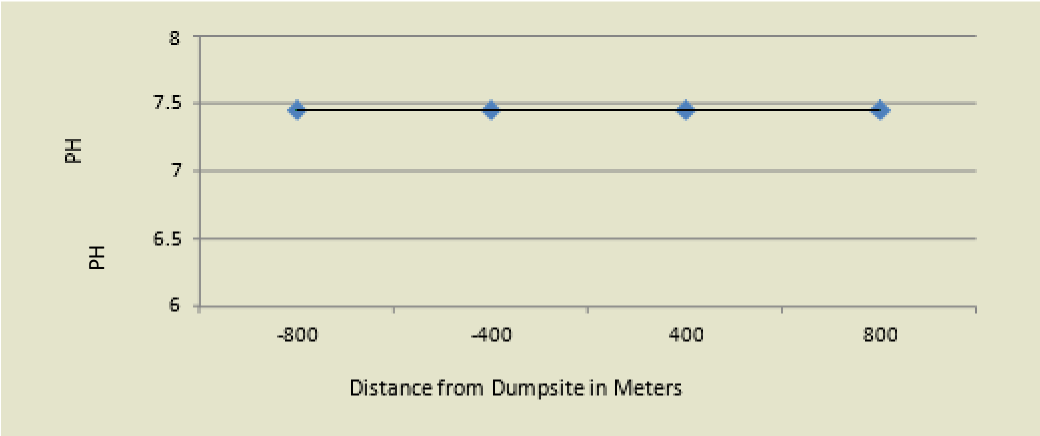


Figure 4.19 Correlation between PH in Well Water and Distances from Dumpsite (Dry Season).

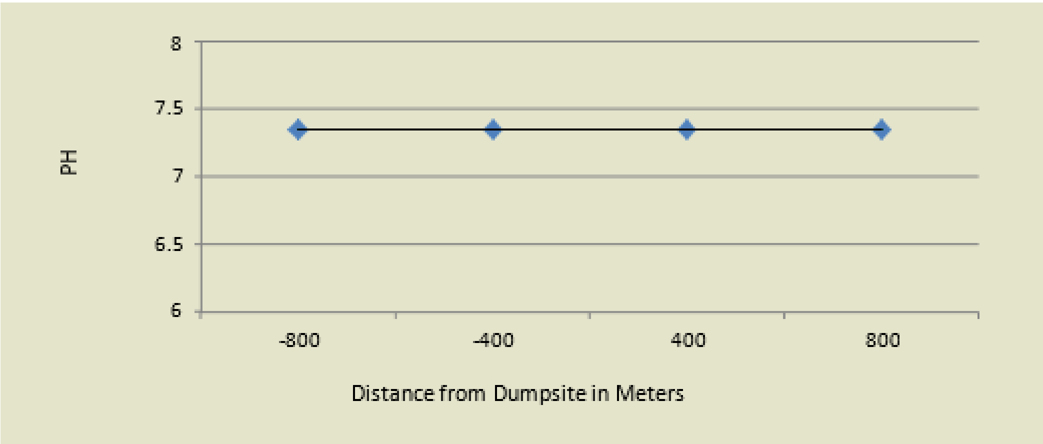


Figure 4.20 Correlation between PH in Well Water and Distances from Dumpsite (Wet Season).

Temperature in Well Water

The trends in temperature in well water in relation to distance from dumpsite in dry and wet seasons are depicted in Figure 4.21 and Figure 4.22 respectively. Figure 4.21 shows that during the dry season, there was a negative correlation between temperature of well water and the distance of the wells from the dumpsite although the correlation was not significant (*r*= -.439 *P*= .561). However Figure 4.22 shows that during the wet season the temperature remained constant in all the wells.

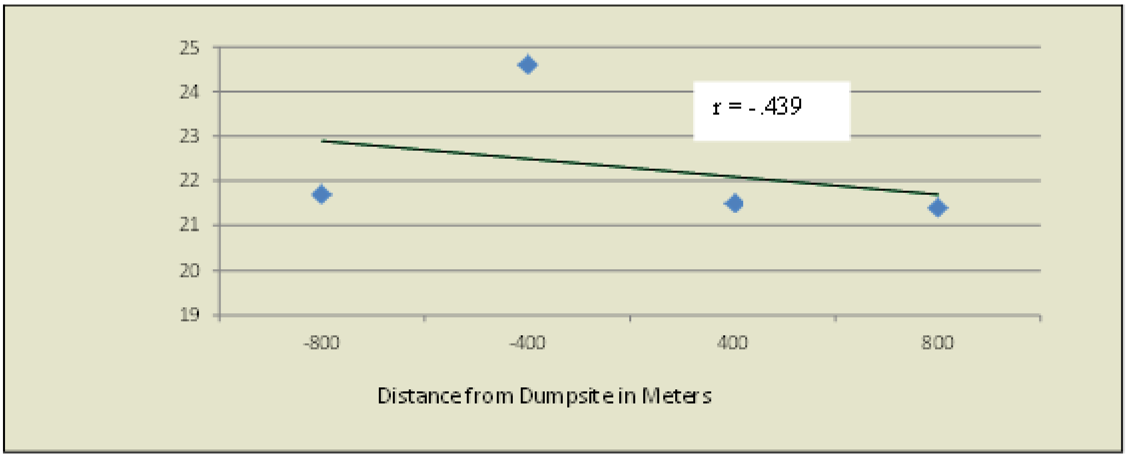


Figure 4.21 Correlation between Temperature in Well Water and Distances from Dumpsite (Dry Season).

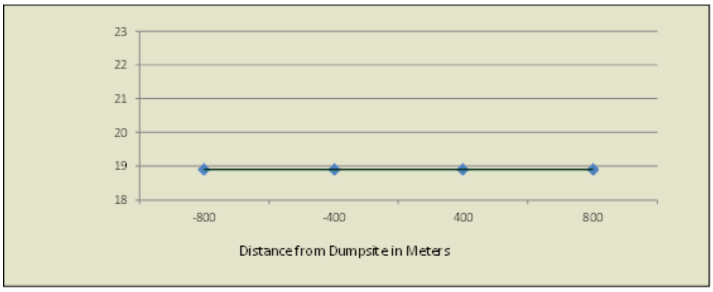


Figure 4.22 Correlation between Temperature in Well Water and Distances from Dumpsite (Wet Season).

Correlation between Chemical Parameters in Well Water and Distance from Dumpsite

Table 4.9 shows the results of correlation analysis of the concentration levels of zinc and manganese with distance of the wells from the dumpsite in the dry season. Results of Table 4.9 show that there was a negative correlation between levels of zinc in well water and distance of the wells from the dumpsite. The results were also the same between levels of manganese in well water and distance of wells from the dumpsite.

Table 4.9 Correlation Analysis between Levels of Chemical Parameters and Distances of Wells from Dumpsite in the Dry Season

Parameter	N	r	p
Manganese	4	-.655	.345
Zinc	4	-.677	.323

Manganese in Well Water

Figure 4.23 shows how the levels of manganese differed in the well water in relation to the distance of the wells from the dumpsite. Table 4.9 shows that there was a negative though non-significant correlation between the levels of manganese and distance of the wells from the dumpsite (*r*= -.655, *P*= .345). Manganese levels decreased as one moved from the downstream towards the upstream wells.

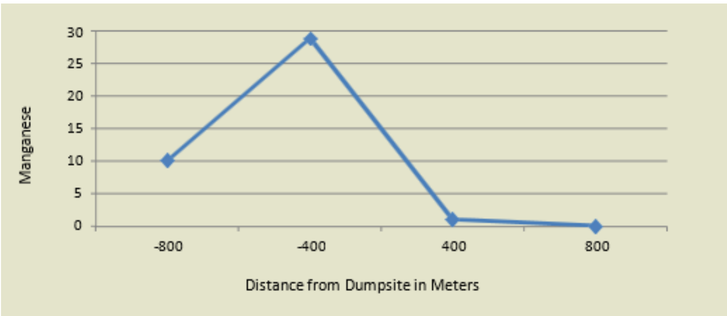


Figure 4.23 Correlation between Mn in Well Water and Distances from Dumpsite (Dry Season).

Zinc in Well Water

The correlation between zinc levels in well water and the distance of the wells from the dumpsite in the dry season are shown in Figure 4.24. As Figure 4.32 shows, zinc levels decreased as one moved from the downstream wells towards the upstream wells. However, the correlation was not significant (*r*= -.677, *P*= .323) as shown in Table 4.9.

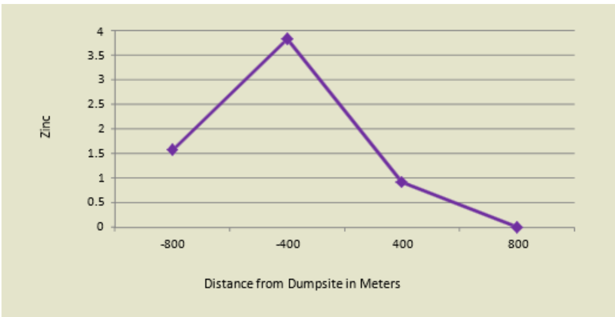


Figure 4.24 Correlation between Zn in Well Water and Distances from Dumpsite (Dry Season).

Negative correlations observed indicate disassociation of the parameters where the value of one variable can increase as the other decreases. Concentrations of measured chemical pollutants in downstream are least related between streams and well. Thus water flowing downstream had negative correlation both in Zn (*r*= -.677, *P*= .323) and Mn (*r*= -.655, *P*=.345). From the results presented in Table 4.9, during the wet season the surface water had the highest levels of Mn and Zn at sampling site 4 (28.93 mg/l, 3.83 mg/l), sampling site 3 (10.10 mg/l, 1.57 mg/l) and sampling site 2 (1.01mg,l 0.91 mg/l) respectively. During the dry season the concentration levels for Mn, Cd, Zn and Cd were not detected.

These results suggest that high levels of heavy metals pollution in the surface water of River Nyakumisaro were at site 2, 3 and 4 which represents a downstream increase. This may be due to large quantities of solid and liquid waste disposed in the river from the industrial, commercial, domestic and leachate flow from the dumpsite. There are other contributory activities including garages, carwash, agriculture and sewage flowing into the river course. This finding agrees with Oyekunle *et al.* (2013) who carried out a similar study on Speciation of Heavy Metals in Water and Sediments from Asunle River, Nigeria revealed that total heavy metals concentrations in water from different sampling sites within the river varied significantly. Sites far from the dumping site reflected the least levels of heavy metals while the highest levels were recorded in sampling points closer to dumpsite indicating a direct input of heavy metals from the dumpsite.

Leachate Analysis

Leachate analysis was done based on the NEMA recommended standards for safe discharge of liquid waste to portable water.

Table 4.10 t-test Analysis for Leachate against NEMA standards

Parameter	Dry Season Mean	Wet Season Mean	t-value	p-value	N
pH	7.50	7.93	1.753	.154	6
TDS	1563.33	2656.67	5.104*	.035	6
EC	2081.67	3350.00	1.994	.183	6
Nitrates	89.00	202.00	2.833	.101	6
Pb	0.54	0.77	2.391	.075	6
Mn	15.41	33.17	3.789	.059	6
Zn	1.84	3.26	2.978*	.041	6
Cd	0.07	0.14	1.541	.198	6

significant at .05

pH

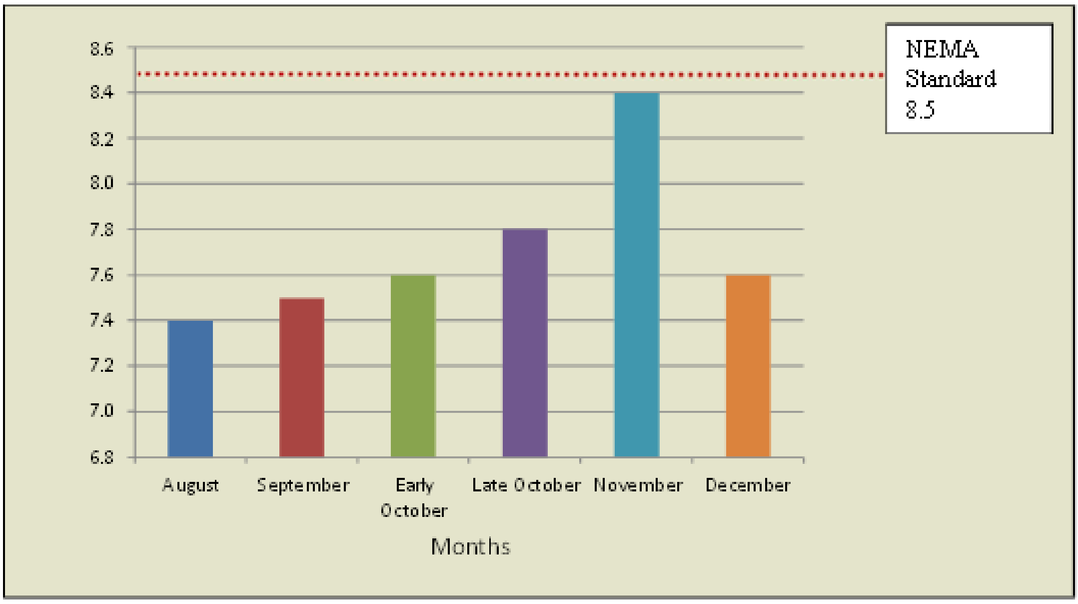


Figure 4.25 Leachete Analysis for pH.

TDS

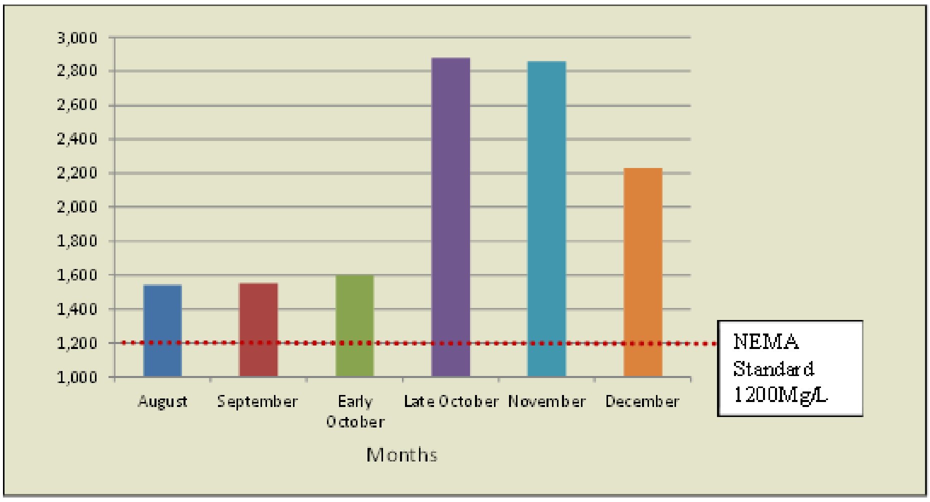
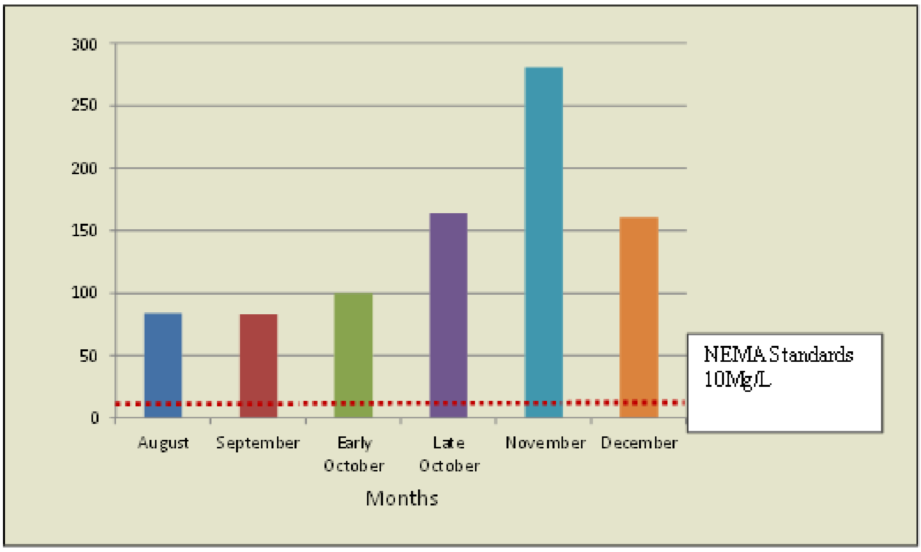


Figure 4.26 Leachete Analysis for TDS.

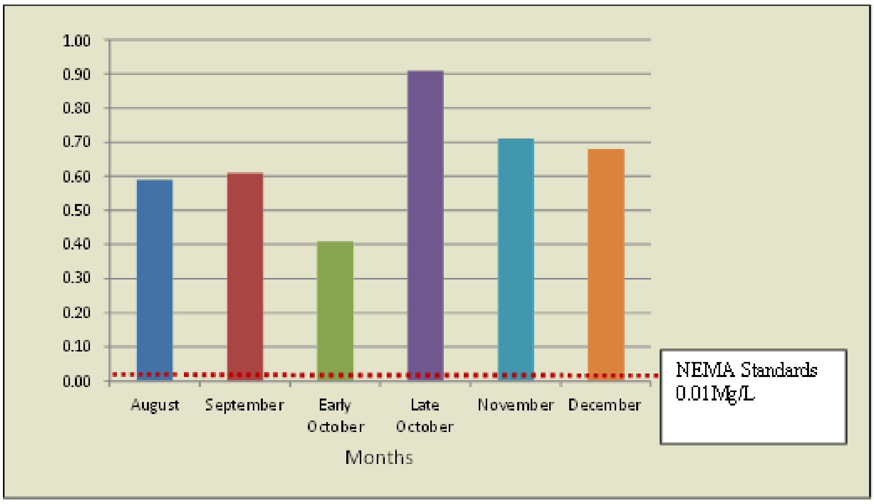
Nitrates



Figure

Leachete Analysis for Nitrates.

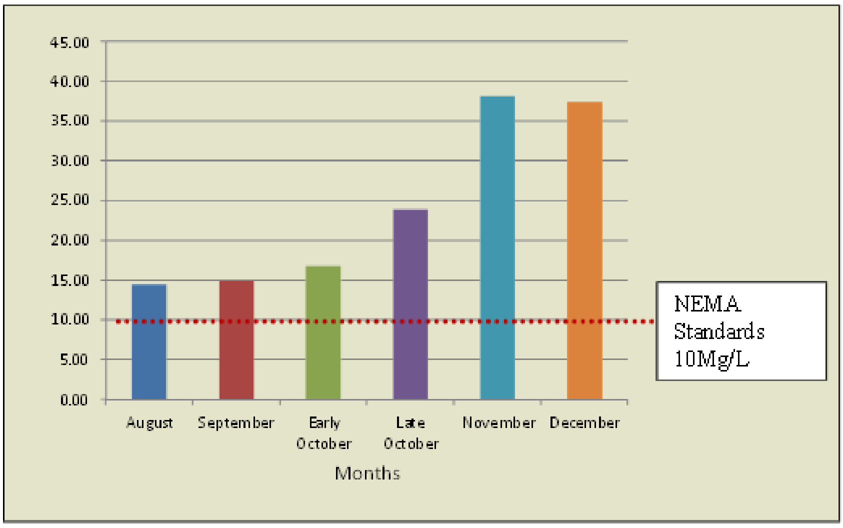
Pb



Figure

Leachete Analysis for Pb.

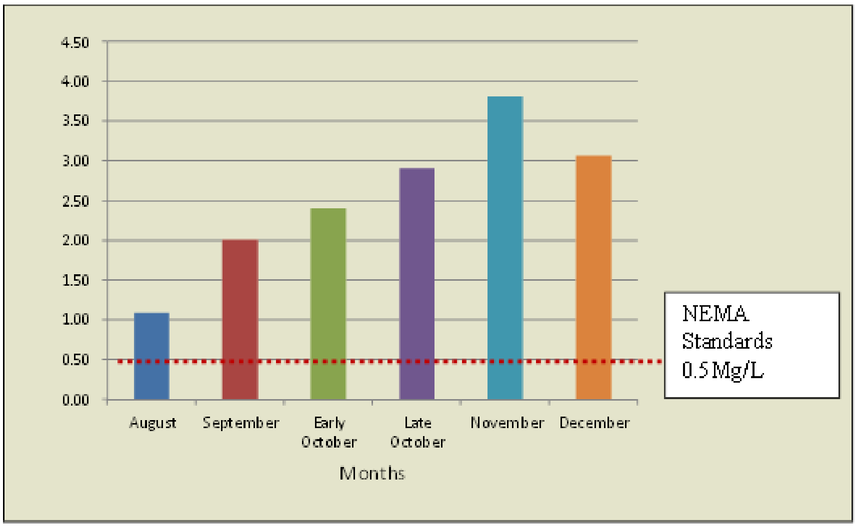
Mn



Figure

Leachete Analysis for Mn.

Zn



Figure

Leachete Analysis for Zn.

Cd

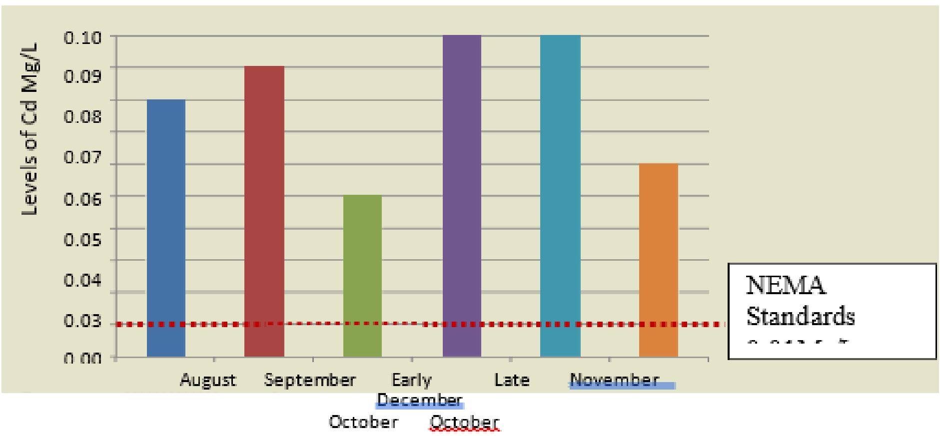


Figure 4.31 Leachete Analysis for Cd.

V. Conclusions And Recommendations

Conclusions

The study concluded that water sources near the Nyambera dumpsite in Kisii Municipality are significantly contaminated, posing a serious public health risk. Except for pH, all physical and bacteriological parameters in both surface and groundwater exceeded KEBS standards, with high bacterial loads indicating leachate intrusion. Heavy metal pollution, particularly manganese and zinc, was more pronounced during the wet season, making water unsafe for human consumption during this period. Additionally, contamination levels were found to be higher at sampling points closer to and downstream of the dumpsite, confirming that proximity to the site directly influences water quality.

Recommendations

The study recommend that management ensure access to safe and potable water in Kisii Municipality, there is a need to strengthen solid waste management at the Nyambera dumpsite by adopting proper waste sorting, appropriate disposal methods, and careful site selection informed by the area's geology and hydrogeology. The Gusii Water and Sewerage Company should improve both the quantity and quality of piped water supply to reduce reliance on potentially contaminated surface water and shallow wells. Public awareness initiatives focusing on waste avoidance, reduction, reuse, and recycling are crucial in minimizing the volume of waste reaching the dumpsite and reducing leachate formation. Additionally, regular monitoring of water sources is necessary to track pollutant concentrations and develop predictive models for assessing water safety across different seasons. Further studies should be conducted to determine the minimum safe distance between dumpsites and water sources, given that River Nyakumisaro currently presents serious health risks, particularly to vulnerable groups such as pregnant women and infants.

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