Vol. 14(9), pp. 241-249, September 2020
DOI: 10.5897/AJEST2020.2849
Article Number: 3277BE664741
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Irrigation water quality analysis of Mitheu Stream in Machakos Municipality, Kenya

Linge Kitulu[1*], Julius Kioko Nzeve[2], Fuchaka Waswa[3], Esther Kitur[1] and Douglas Shitanda[4]

[1]Department of Environmental Science and Education, School of Environmental studies, Kenyatta University. P. O. Box 43844-00100, Nairobi, Kenya.
[2]Department of Environmental Sciences, School of Environment and Natural Resources Management, Machakos University, P. O. Box 136, Machakos, Kenya.
[3]Department of Agricultural Science and Technology, School of Agriculture and Enterprise Development, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya.
[4]Department of Mechanical Engineering, School of Engineering and Technology, Machakos University, P. O. Box 136, Machakos, Kenya.

Received 29 April, 2020; Accepted 15 July, 2020

Water samples for physico-chemical, heavy metals and bacteriological analyses were collected from 4 selected points along Mitheu Stream flowing through Machakos Municipality once every month from June 2019 to September 2019. The samples were analyzed in Kenya Plant and Health Inspectorate Service and Water Resources Authority laboratories then data subjected to one-way analysis of variance to test significant differences ($P \leq 0.05$). The results were compared with World Health Organization guidelines to assess the suitability of the water for irrigation use. Results showed that the levels of the Biological Oxygen Demand and the Chemical Oxygen Demand in Mitheu Stream were higher than critical values permitted by the World Health Organization for irrigation water. Nitrates and Sulphates were within critical limits; however, Phosphates were higher than permissible limits at all the sampling points. Heavy metals concentrations for Cu, Pb, Zn and Cr were within allowable limits for irrigation water, but Cd was above the limit. Both total coliforms and *Escherichia coli* counts exceeded allowable limits for irrigation water. As such, Mitheu Stream can be considered polluted and the water unfit for irrigation farming. The Municipal authorities, working with other relevant stakeholders should take appropriate measures to mitigate stream pollution from untreated effluent discharged into the stream.

Key words: Physico-chemical, heavy metals, total coliforms, effluent.

INTRODUCTION

Although sustainable development goal 6 requires all people to enjoy clean water and reliable sanitation services by 2030 (Hounslow, 2018), access to clean water and sanitation services is still a challenge globally and particularly in Sub-Saharan African countries (Andersson, 2018; Jeong et al., 2016). The problem will

*Corresponding author: E-mail: lingekitulu@gmail.com.

only increase in tandem with urbanization pressure (Kakoi et al., 2016). Majority of the towns and cities receiving new immigrants lack efficiently functioning wastewater management systems (Silverman et al., 2013). As such substantial quantities of raw effluent are often channeled into urban streams and rivers (Abakpa et al., 2013). Such effluent is typically contaminated with bacterial, physical and chemical contaminants that pose serious risks to people and the environment if no treatment is done based on best practices (Fuhrimann et al., 2016; Putri et al., 2018).

Heavy metals and bacterial pollution are common in most streams flowing through urban areas in Sub-Saharan Africa (Zhang et al., 2016). Human exposure to these contaminants is enhanced through use of polluted stream water for irrigation farming (Qureshi et al., 2016). The danger of bioaccumulation of pollutants and the risk of ill-health is increased through consumption of crop commodities irrigated with contaminated water (Singh and Kumar, 2017; Kim et al., 2015). Kenya being a water-scarce country, irrigation farming in urban and peri-urban areas is popular and also fueled by the huge and ready market from the increasing population (Kavoo et al., 2016). The risk of diseases to both farmers and consumers of their crop commodities irrigated using water from polluted streams cannot be overemphasized (Bismuth et al., 2016). This study investigated the pollution status of Mitheu Stream within Machakos municipality with focus on physico-chemical parameters, selected heavy metals as well as bacterial counts. This stream is the main recipient of effluent discharged from the Machakos sewage treatment plant. Leafy vegetable farming is a major economic practice along the stream.

MATERIALS AND METHODS

Study area

This research study was done at various points along the Mitheu Stream located in Machakos municipality, Kenya (Figure 1). Machakos town has a population of 170,606 people (KNBS, 2019). Its sewage treatment plant is located along Mitheu Stream into which effluent is directly discharged. The treatment plant uses the activated sludge process to treat effluent. Physical observation of the treatment plant however suggests neglect, which points to poor functionality of the plant. Being a seasonal stream, Mitheu Stream water levels are maintained by seasonal rains and effluent discharged into it. Water from the stream is used for irrigation by farmers within Machakos municipality. Cases of farmer vandalizing the sewer lines to obtain enough irrigation water during the dry seasons have been observed. High demand for vegetables within the municipality has sustained the urban farming along this particular stream. Being a time-bound study, this research was conducted during the dry season with insignificant climatic variation. Unavailability of more funds did not allow a comparative analysis across seasons.

Water sampling and sample analysis

Four sampling Points (A to D) were selected along Mitheu Stream as shown in Figure 1. Sampling Point A was far downstream, while Point B was immediately downstream of the Machakos town sewage treatment plant. Point C was where the treatment plant discharge entered into the stream. Sampling Point D was upstream of the sewage treatment plant. These sampling points were selected at strategic points along the stream to compare the levels of contamination as the stream flowed downstream. Samples were collected in triplicates once every month from June 2019 to September 2019. Samples for bacteriological analysis were collected using sterilized glass bottles to avoid contamination (Hsieh, 2018), and bacteriological loads (total coliforms and *Escherichia coli*) analyzed by use of the multiple tube technique in Water Resources Authority (WRA) Laboratory in Nairobi. The total coliforms together with *E. coli* were used to estimate the quality of water in Mitheu Stream with respect to bacteriological contamination. Samples for the physico-chemical parameters, that included Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Nitrates, phosphates, and sulphates were taken using acid-cleaned 500 ml polyethylene bottles, and analyzed in WRA laboratory, Nairobi using standard procedures as described by APHA (1998). Samples for heavy metal analysis were collected in clean 500 ml polyethylene bottles, and treated with 2mls concentrated nitric acid in Machakos University Chemistry laboratory. The samples were then transported to the Kenya Plant Health Inspectorate Service (KEPHIS) Analytical Chemistry Laboratories for heavy metal analysis using inductively coupled plasma mass spectrophotometer (Agilent 7900 series ICP-MS). Five heavy metals were analyzed in stream water in this study i.e. Cd, Cu, Zn, Pb and Cr. These metals were chosen due to their high probability of occurring in substantial concentrations in municipal effluent.

Statistical data analysis

One-way Analysis of Variance (ANOVA) was used to test the significant variations ($P<0.05$) in mean concentrations of heavy metals, physico-chemical parameters, and bacterial counts in water from the four sampling points. Tukey post hoc test was used to separate means where there were significant differences among the sampling points. All the data analyses were done using Statistical Package for Social Sciences (SPSS) version 21.

RESULTS AND DISCUSSION

Physico-chemical parameters

Levels of physico-chemical parameters measured on water samples from Mitheu Stream are presented in Table 1 and Figures 2 and 3.

Chemical oxygen demand and biological oxygen demand

The Chemical Oxygen Demand (COD) for the four sampling points ranged between 189.00 ± 196.44 MgL^{-1} and 1304.00 ± 604.45 MgL^{-1} (Table 1 and Figure 2). COD was lowest downstream at sampling Point A and highest in the discharge from the sewage treatment plant (Point C) as shown in Figure 2. COD is a measure of the amount of oxygen needed to oxidize all organic chemicals in a wastewater before it is discharged into

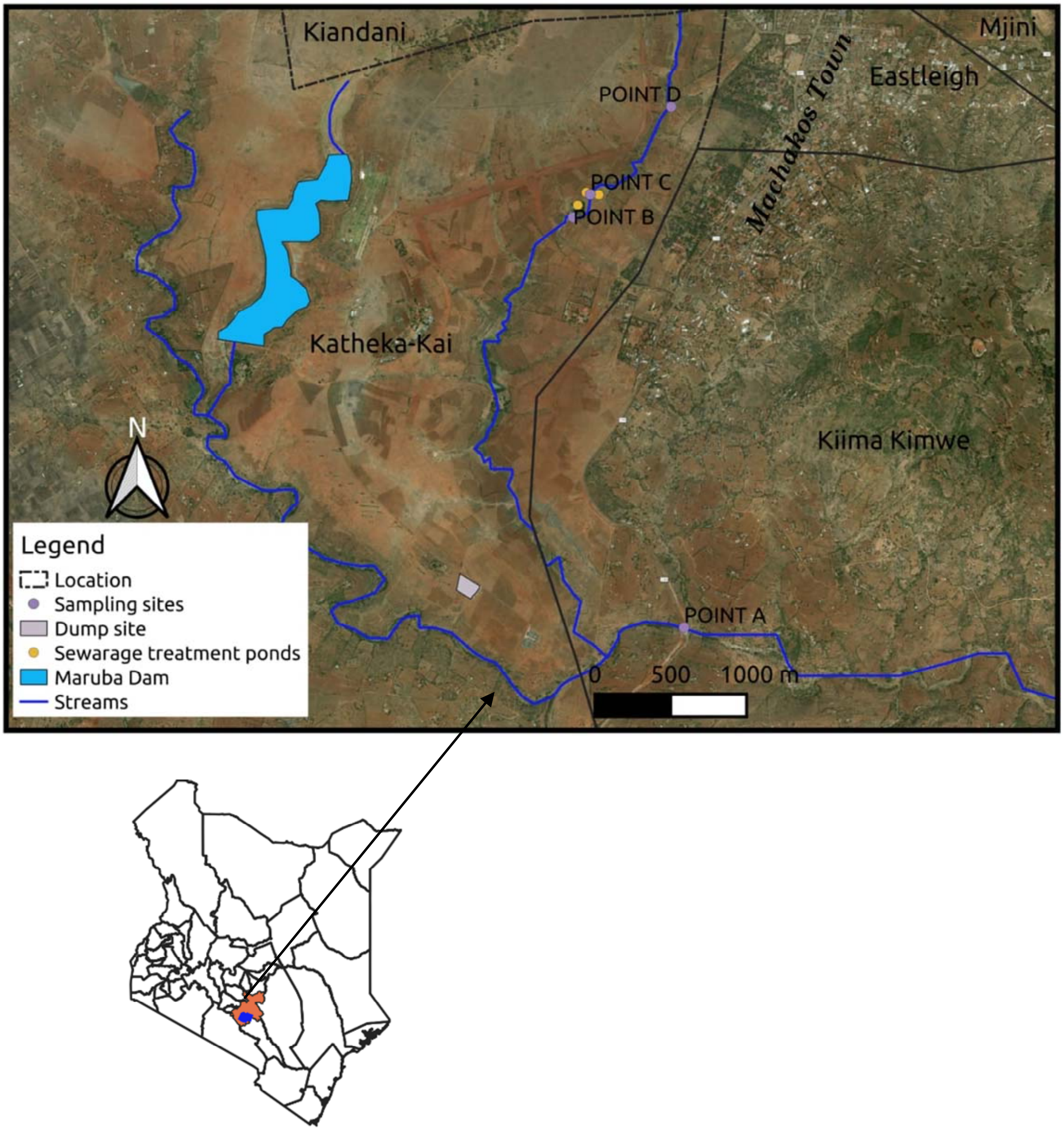

Figure 1. Map of the study area and sampling sites.

Table 1. Mean ± Standard deviations of physico-chemical parameters.

Site/parameter (MgL^{-1})	Point A	Point B	Point C	Point D	WHO limit	P-value
COD	189.00±196.44	325.50±132.94	1304.00±604.44	398.00±278.75	10.00	0.003
BOD	74.75±135.52	157.50±137.93	465.00±292.75	115.75±37.40	5.00	0.033
Nitrates	0.87±0.79	11.34±18.31	3.70±3.82	1.95±2.79	45.00	0.427
Phosphates	0.10±0.13	1.68± 2.75	0.38±0.10	1.74±2.91	0.10	0.555
Sulphates	17.21±18.25	29.92±20.96	122.31±86.87	32.59±32.61	250.00	0.035

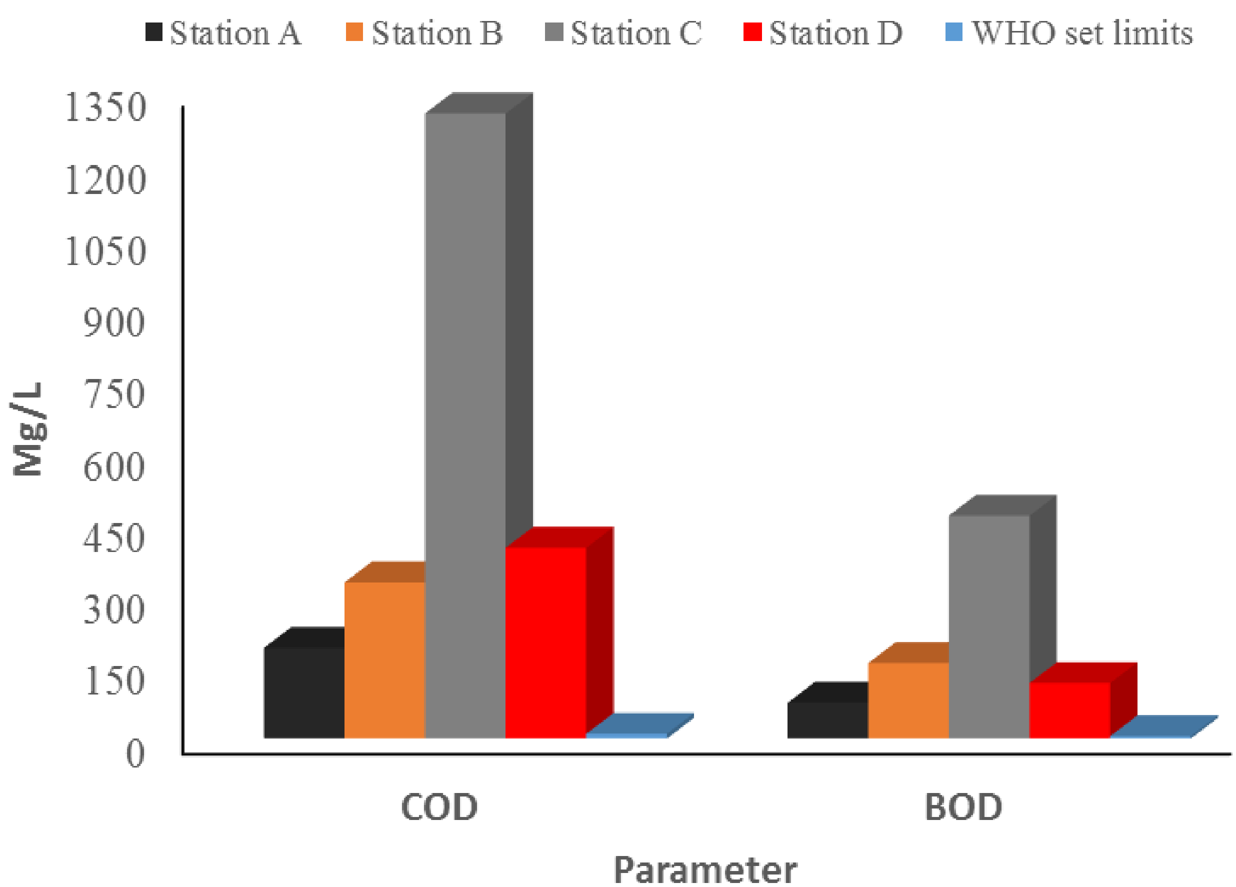

Figure 2. Levels of COD and BOD in Mitheu Stream.

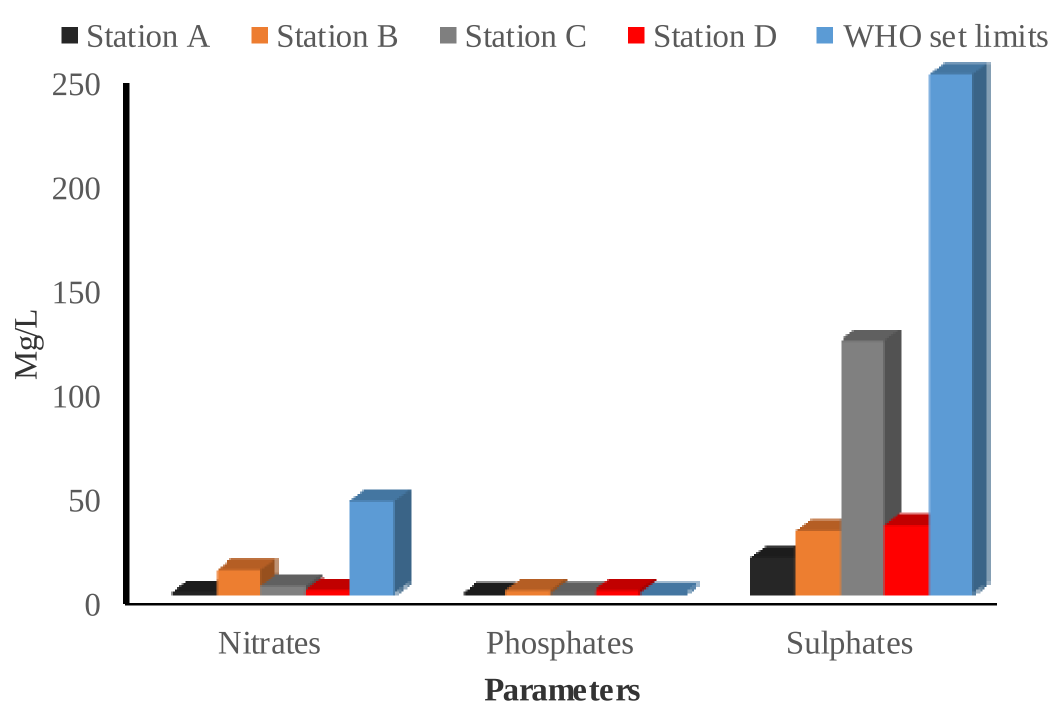

Figure 3. Levels of nitrates, phosphates and sulphates at Mitheu Stream.

water bodies (Islam et al., 2018). The significantly high levels of COD in effluent from the sewage treatment plant in Machakos town (Point C) indicated that it was not properly cleaned of the organic chemicals before being discharged into Mitheu Stream. The BOD observed was between 74.75 ± 135.52 MgL^{-1} downstream at Point A and 465.00 ± 292.75 MgL^{-1} in the sewage treatment plant discharge (Point C) as presented in Figure 2. BOD in wastewater is a measure of the oxygen needed to aerobically digest organic compounds by biological microorganisms (Mallika et al., 2017). Lower amounts of BOD signify improved efficiency of wastewater treatment plants. For this case the discharge from Machakos wastewater treatment plant had comparatively high levels of BOD implying its low efficiency in eliminating bio-organic waste. Organic chemicals were further washed into the stream from the farms alongside it. Despite this, dilution of effluent as the water flowed downstream lowered the concentrations of COD and BOD gradually from Point C to A. The COD and BOD had significant variations among the four sampling points ($P \leq 0.05$). However, Tukey's post hoc test showed that it was Point A downstream and Point C that had significant differences for both parameters. The high quantities of COD and BOD in all the sampling points were an indication the water in Mitheu Stream was not suitable for irrigation due to excessive amounts of organic chemicals. These organic chemicals pollute soils and are further absorbed by plants and transmitted to humans. The COD and BOD in Mitheu Stream were relatively high compared with those found in streams crossing Gondar town in north-west Ethiopia (Tessema et al., 2019). A comparison with the level of COD and BOD in Anko River, Assela town finds the concentration of these parameters to be relatively high in Mitheu Stream (Gebre, 2017).

Nitrates

The concentration of nitrates measured ranged from 0.87 ± 0.79 MgL^{-1} at Point A to 11.335 ± 18.305 MgL^{-1} at Point B as indicated in Figure 3. The concentration along the stream did not vary significantly ($P=0.427$). This high concentration just below the sewage treatment plant (Point B) was as a result of combination of the effluent from wastewater treatment plant and the municipal effluent getting into Mitheu Stream through broken sewer lines. Nitrates were however within WHO safe limits for irrigation water. This implied that nitrates pollution of Mitheu Stream did not pose a danger to the health of the farmers and residents of Machakos municipality.

Phosphates

High concentration of phosphates was recorded upstream at point D (Table 1 and Figure 3). The high phosphate concentration was attributed to the entry of raw effluent into the stream from vandalized sewer lines. The discharge from the wastewater treatment plant (Point C) had relatively lower concentration of 0.38±0.10 MgL^{-1}. However, this concentration was still higher than WHO recommended levels of phosphorous in irrigation water. This indicated that excessive phosphorous was not effectively removed from municipal wastewater in the treatment plant. Agrochemicals washed into the stream also could have contributed to increase in phosphorous in the stream. The concentration of phosphates did not vary significantly along the sampling sites ($P=0.555$). Phosphate concentration in three sampling points (Points B, C and D) was higher than WHO allowable limits for irrigation water. Higher phosphate content in irrigation water results to eutrophication and depletion of oxygen levels in water. Further, absorption of excess phosphates by vegetables could lead to their transmission to consumers resulting in health problems such as liver damage, muscle damage and kidney failure (Nyamangara et al., 2013). Eutrophication dries up a stream by excessive vegetative growth. Comparatively, the concentration of phosphates in Mitheu Stream was lower than levels found in a similar study in Anko River in Assela town (Gebre, 2017). The concentrations of phosphates were further found to be lower than their concentrations in a similar study in Gondar town, Ethiopia (Tessema et al., 2019).

Sulphates

The sewage treatment plant discharge (Point C) contained the highest concentration of sulphates measuring 122.33±86.87 MgL^{-1} as shown in Figure 3. The high amount of sulfur in the sewage treatment plant discharge signified its high concentration in the municipal effluent from Machakos town as well as low efficiency in the elimination of sulfur by the treatment process. The lowest concentration of sulphates (17.21±18.25 MgL^{-1}) was recorded downstream at sampling Point A and this could be attributed to dilution effect as water flowed downstream. There was significant variation between sulphates concentration in the sewage treatment plant discharge (Point C) and the rest of the sampling points ($P=0.035$). Decomposition of H_2S was responsible for the foul smell of the stream waters. The intensity of the odor is proportional to the quantity of sulphates in it. High amounts of sulphates in irrigation water lead to scaling of fruits and vegetable leaves (Lu et al., 2017). This is evident in fruits and vegetables that have visible scales. Sulphates are however not known to cause any direct health impacts to humans while present in irrigation water unless in very high concentrations that exceed 1000 MgL^{-1} (Moreno et al., 2009).

Bacteriological parameters

The highest counts of both total coliforms and *E. coli*

Table 2. Mean ± Standard deviations of Bacteria counts in water.

Site/parameter	Point A	Point B	Point C	Point D	WHO limit	P value
Total Coliforms (MPN/100 ml	4524.25±4615.32	100508.25±59895.92	180175.00±78885.08	240000.00 ± 0.00	1000	0.026
E. coli (MPN/100 ml)	1791.75±1685.87	111441.75±96477.92	151300±113913.88	229166.75±21666.50	Nil	0.125

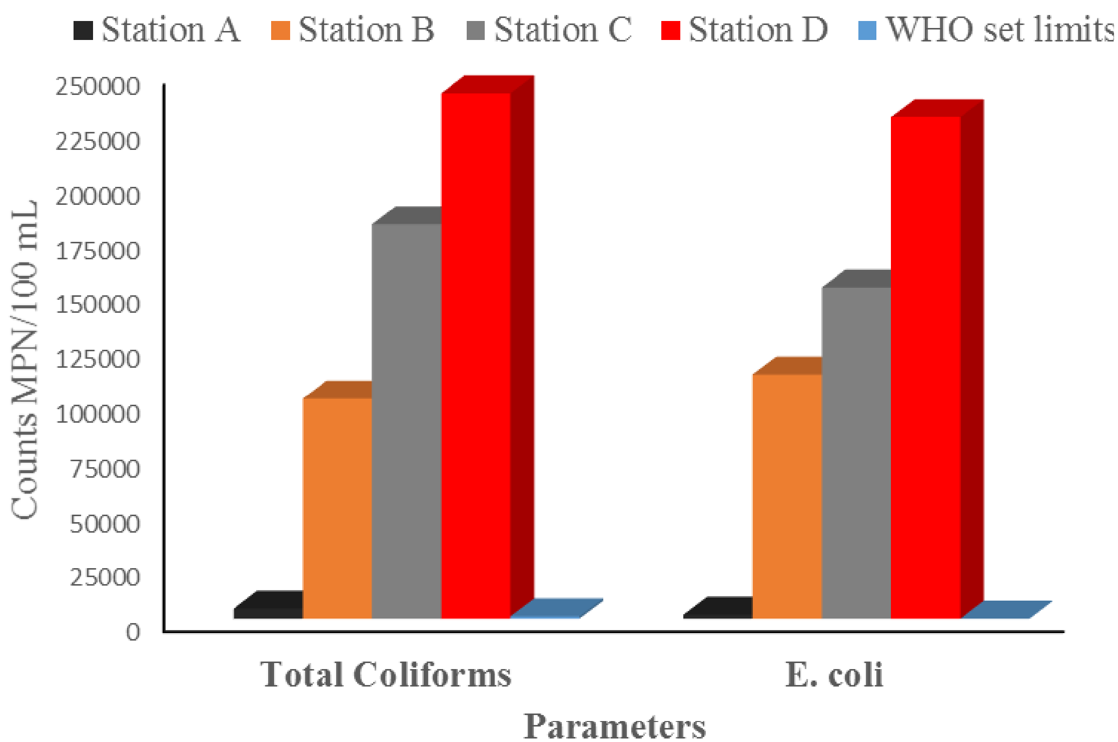

Figure 4. Bacterial counts in Mitheu Stream.

bacteria were upstream at sampling Point D at 240,000.00 ± 0.00 MPN/100 ml and 229,166.75±21,666.50 MPN/100 ml respectively (Table 2 and Figure 4).

The high bacterial counts at Point D were as a result raw effluent that entered Mitheu Stream from vandalized sewer lines. Comparatively, the downstream section (sampling Point A) had the lowest bacteria count for both total coliform and *E. coli* at 4524.25 ± 4615.316 MPN/100 ml and 1791.75 ± 1685.866 MPN/100 ml, respectively. This was as a result of dilution of effluent as water flowed downstream. Total coliform counts in the 4 sampling points were significantly varied as indicated by the P-value 0.026, however, *E. coli* counts were not significantly different (P = 0.125). The counts for both Total coliforms and *E. coli* exceeded WHO permissible limits for irrigation water. Heavy bacterial contamination against WHO set standards implies possible transmission of bacterial-carried infections to farmers either by directly handling the stream's water or the residents who consume the vegetables. *E. coli* in particular is required to be below 1 for irrigation water (Ogbonna, and Ajubo, 2017). High concentrations of the virulent strains of *E. coli* lead to diseases such as diarrhea, urinary tract infections, and crohn's disease (Agwa et al., 2013). The high bacterial contamination was due to the municipal effluent from Machakos town that is channeled directly into Mitheu Stream due to vandalism of sewer lines by farmers who farm along the stream. Additionally, it is an indication of inefficient sewage treatment system within Machakos Municipality. Municipal sewage contains fecal matter that has high bacterial content and has serious risks to human health. A similar study in Athi River in Machakos County in 2015 found a higher bacterial contamination in River Athi (Wambugu et al., 2015). A comparison with a similar study conducted in Tamale Metropolis Ghana finds the urban stream in Machakos to be heavily polluted with both total coliforms and *E. coli* bacteria (Abdallah, 2018).

Heavy metals in water

Heavy metal concentrations in Mitheu Stream are presented in Table 3. Out of these five metals, only Cd was above WHO standards for irrigation water in three sampling points. One-way ANOVA revealed that the concentrations of the metals in the respective sampling points did not vary significantly ($P>0.05$).

The concentration of Cd ranged between 0.0019±0.0015 MgL^{-1} (Point D) upstream and 0.0182±0.0275 MgL^{-1} (Point A) downstream. The high concentration of Cd downstream could be linked to usage of phosphate fertilizers in the farms along the stream that got washed into the stream. Concentrations at Points A, B and C were higher than WHO limits for irrigation water. This implied unsuitability of the water from Mitheu Stream for irrigation with regard to Cd poisoning. The concentrations of Cu, Zn and Pb were below WHO limits for irrigation water for all the sampling points. The concentration of Pb ranged from 0.0011±0.0019 MgL^{-1} at Point B to 0.0144±0.0245 MgL^{-1} at Point C. The concentration of Zn ranged between 0.0281±0.0487 MgL^{-1} at Point B and 0.1204±0.1329 MgL^{-1} at Point A. The fertilizers and pesticides used in the farms along the stream possibly contributed to the high concentration of Zn downstream. Pb concentration at Point D was higher than other sections of the stream. The most probable source of Pb upstream of Mitheu Stream was municipal effluent discharged into the stream that possibly contained Pb washed from paintings in buildings within Machakos town and vehicle garages at Machakos industrial area. Its concentration downstream of the wastewater treatment plant was below detectable limit. This indicated low susceptibility of Pb poisoning from municipal effluent in Machakos town. Cr concentration was found to range between 0.0003±0.0005 MgL^{-1} at Point A and 0.0049±0.0049 MgL^{-1} at Point D. All concentrations of Cr were below WHO limits for irrigation water. Compared with heavy metals concentrations in urban streams in a study conducted in Awash River in Ethiopia by Degefu et al. (2013) the concentrations in Mitheu Stream were lower. Similarly, concentrations of Cu, Zn, and Pb were lower compared to those of urban streams in Tamale Metropolis Ghana (Abdallah, 2018). The concentration of Cd in this study however, was slightly higher than that found in urban streams in Tamale Metropolis, Ghana (Abdallah, 2018). The potential sources of these heavy metals in Mitheu Stream were the municipal effluent within Machakos municipality and the agrochemicals (fertilizers and pesticides) used in the farms along the stream.

Heavy metals, particularly those studied in this research, have detrimental effects on stream ecosystems. They contribute to a reduction of dissolved oxygen in water and disrupt the optimum metabolic functioning of aquatic organisms such as zooplanktons, phytoplankton and fish (Lenka et al., 2018; Ghosh et al., 2015; Saha et al., 2011; Mahmoud, and Ghoneim, 2016) high concentrations of these heavy metals also interfere with the metabolic activities as well as physiological process of plants (Sayo et al., 2020). Dietary intake of heavy metals can have serious health effects on people such as damage to vital internal organs like the liver, kidneys and the brain (Mahmoud and Ghoneim, 2016; Ghosh et al., 2015; Saha et al., 2011). These negative effects give credence to the need to design appropriate pollution prevention and mitigation measures of effluent discharged into riverine systems within Machakos municipality.

CONCLUSION AND RECOMMENDATIONS

The high concentrations of COD and BOD in Mitheu Stream above WHO limits for irrigation water are a pointer to heavy organic load discharge. The sources of organic wastes need to be monitored, tracked and prevented. The high concentration of phosphates above WHO standards are an indication of poor sanitation services as well as long-term washing of agrochemicals into the stream. Phosphates are however not harmful to humans unless in extremely high concentrations. Sulphates and nitrates were within allowable limits in accordance to WHO standards for irrigation water. The high load of total coliforms and *E. coli* bacteria are an indication of poor sanitation services and their management in the municipality. The high concentration of Cd above the WHO limits for irrigation is a pointer to

Table 3. Mean ± standard deviations of heavy metals concentrations in water.

Site/parameter (MgL^{-1})	Point A	Point B	Point C	Point D	WHO limit	P-value
Cd	0.0182±0.0275	0.0118±0.0197	0.0162±0.0276	0.0019±0.0015	0.01	0.827
Cu	0.0015±0.0017	0.0011±0.0019	0.0144±0.0245	0.0040±0.0050	0.2	0.556
Zn	0.1204±0.1329	0.0281±0.0487	0.1102±0.1521	0.0308±0.0420	2	0.592
Pb	0.0024±0.0042	BDL	0.0002±0.0003	0.0289±0.0501	0.5	0.452
Cr	0.0003±0.0005	0.0031±0.0054	0.0018±0.0031	0.0049±0.0049	0.01	0.557

BDL is below detectable limit.

potential Cd poisoning through dietary heavy metal transfer. Overall, the use of this stream water for irrigation poses serious health risks to the farmers as well as residents of Machakos municipality, who are the main market for the leafy vegetables grown. The sewage treatment plant in Machakos is not operating as efficiently as would be expected. An audit of the system is needed in order to provide entry points to structural and operational changes toward best practices in effluent management. A multi-stakeholder approach is needed to develop and implement guidelines on prevention of stream pollution, urban farming and irrigation water use in such unique circumstances.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The research was funded by Machakos University through an internal research and innovation grant (Grant no. 2018/2019 FY). The authors also appreciate KEPHIS and Water Resources Authority, Nairobi for availing their laboratory facilities for analysis of samples.

REFERENCES

Abakpa GO, Umoh VJ, Ameh JB, Yakubu SE (2013). Microbial quality of irrigation water and irrigated vegetables in Kano State Nigeria. International Food Research Journal 20(5):2933.

Abdallah CK (2018). Water Quality Assessment of Irrigation Water Used by Informal Peri Urban Vegetable Irrigation Farmers: The Case of Tamale Metropolis Ghana (M. Sc. Thesis).

Agwa OK, Sito E, Ogubue CJ (2013). A spatial assessment of the microbiological and physico-chemical quality of a stream receiving raw abattoir waste. Middle-East Journal of Scientific Research 14(7):879-886.

Andersson S (2018). Environmental Communication for sustainable development in Kenya: A qualitative study focusing on solid and liquid waste.

Bismuth C, Hansjürgens B, Yaari I (2016). Technologies Incentives and cost recovery: is there an Israeli role model?. In: Society-Water-Technology pp. 253-275. Springer Cham.

Degefu F, Lakew A, Tigabu Y, Teshome K (2013). The water quality degradation of upper Awash River Ethiopia. Ethiopian Journal of Environmental Studies and Management 6(1):58-66.

Fuhrimann S, Pham-Duc P, Cissé G, Tram NT, Ha HT, Ngoc P, Winkler MS (2016). Microbial contamination along the main open wastewater and storm water channel of Hanoi Vietnam and potential health risks for urban farmers. Science of The Total Environment 566:1014-1022.

Gebre AE (2017). Assessment of Assela Town municipality waste water discharge effect on the chemical and bacteriological water pollution load of Anko River. International Journal of Water Resources and Environmental Engineering 9(7):142-149.

Ghosh D, Saha R, Ghosh A, Nandi R, Saha B (2015). A review on toxic cadmium biosorption from contaminated wastewater. Desalination and Water Treatment 53(2):413-420.

Hounslow A (2018). Water quality data: Analysis and interpretation. CRC Press.

Hsieh JJ (2018). A Comparison of the Multiple-Tube Fermentation Method and the Colitag Method for the Detection of Waterborne Coliform Bacteria.

Islam MS, Mohanta SC, Siddique MAB, Al-Mamun MA, Hossain N, Bithi UH (2018). Physico-chemical assessment of water quality parameters in Rupsha River of Khulna region Bangladesh. The International Journal of Engineering and Science (IJES) 7:73-78.

Jeong H, Kim H, Jang T (2016). Irrigation water quality standards for indirect wastewater reuse in agriculture: A contribution toward sustainable wastewater reuse in South Korea. Water 8(4):169.

Kakoi B, Kaluli JW, Ndiba P, Thiong'o G (2016). Seasonal Variation Of Surface Water Quality in the Nairobi River System. In: Scientific Conference Proceedings (No. 1).

Kavoo DM, Ali SH, Kihara AB, Kosgei RJ, Tweya H, Kizito W, Tauta CN (2016). An assessment of water sanitation and hygiene (wash) practices and quality of routinely collected data in Machakos County Kenya. East African Medical Journal 93(10):43-46.

Kenya National Bureau of Statistics (KNBS). (2019). 2019 Kenya Population and Housing Census Volume I: Population by County and Sub-County.

Kim NH, Hyun YY, Lee KB, Chang Y, Rhu S, Oh KH, Ahn C (2015). Environmental heavy metal exposure and chronic Kidney disease in the general population. Journal of Korean

Medical Science 30(3):272-277.

Lenka JL, Lepzem NG, Mankilik MM, Dafil RP (2018). Heavy metal contamination in selected cruciferous vegetables grown in Jos Nigeria. International Journal of Current Research in Chemistry and Pharmaceutical Sciences 5(4):26-34.

Lu XM, Chen C, Zheng TL (2017). Metagenomic insights into effects of chemical pollutants on microbial community composition and function in estuarine sediments receiving polluted river water. Microbial Ecology 73(4):791-800.

Mahmoud EK, Ghoneim AM (2016). Effect of polluted water on soil and plant contamination by heavy metals in El-Mahla El-Kobra Egypt. Solid Earth 7(2):703-711.

Mallika S, Umamaheswari R, Krishnamoorthy S (2017). Physico-Chemical parameters and bacteriological study of Vaigai River Water Madurai district, Tamilnadu, India. International Journal of Fisheries and Aquatic Studies 5(1):42-45.

Moreno P, Aral H, Vecchio-Sadus A (2009). Environmental Impact and Toxicology of Sulphate.

Nyamangara J, Jeke N, Rurinda J (2013). Long term nitrate and phosphate loading river water in the Upper Manyame catchment Zimbabwe. Water SA 39(5):637-642.

Ogbonna DN, Ajubo TA (2017). Assessment of the impact of municipal sewage disposal on the water quality in Obio/Akpor LGA Rivers State. International Journal of Geography and Environmental Management 3(1):13-22.

Putri M, Lou CH, Syai'in M, Ou SH, Wang YC (2018). Long-Term River Water Quality Trends and Pollution Source Apportionment in Taiwan. Water 10(10):1394.

Qureshi AS, Hussain MI, Ismail S, Khan QM (2016). Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater. Chemosphere 163:54-61.

Saha R, Nandi R, Saha B (2011). Sources and toxicity of hexavalent chromium. Journal of Coordination Chemistry 64(10): 1782-1806.

Sayo S, Kiratu JM, Nyamato GS (2020). Heavy metal concentrations in soil and vegetables irrigated with sewage effluent: A case study of Embu sewage treatment plant Kenya. Scientific African e00337.

Silverman AI, Akrong MO, Amoah P, Drechsel P, Nelson KL (2013). Quantification of human norovirus GII human adenovirus and fecal indicator organisms in wastewater used for irrigation in Accra, Ghana. Journal of Water and Health 11(3):473-488.

Singh UK, Kumar B (2017). Pathways of heavy metals contamination and associated human health risk in Ajay River Basin, India. Chemosphere 174:183-199.

Tessema H, Sahile S, Teshome Z (2019). Bacteriological and Physicochemical Profile of Water Samples Collected from River and Stream Water Basins Crossing Gondar town North West Ethiopia. Journal of Academia and Industrial Research (JAIR) 8(2):21.

Wambugu P, Habtu M, Impwi P, Matiru V, Kiiru J (2015). Antimicrobial susceptibility profiles among *Escherichia coli* strains isolated from Athi River water in Machakos County, Kenya. Advances in Microbiology 5(10):711.

Zhang Z, Juying L, Mamat Z, QingFu Y (2016). Sources identification and pollution evaluation of heavy metals in the surface sediments of Bortala River Northwest China. Ecotoxicology and Environmental Safety 126:94-101.