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Assessing the influence of horticultural farming on selected water quality parameters in Maumau stream, a tributary of Nairobi River, Kenya

Murithi M. Wilson [a,*], R.W. Michieka [a], S.M. Mwendwa [b]

[a] Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya
[b] Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box 29053-00625, Kangemi, Nairobi, Kenya

HIGHLIGHTS

- There was linear relationship between land use and water quality of the stream.
- Contamination down the stream was due to agrochemicals from nearby farms.
- Recommended policy actions include river pegging to protect the water quality.

GRAPHICAL ABSTRACT
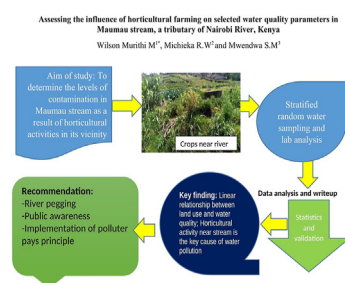
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ABSTRACT

This study aimed to determine the levels of contamination in Maumau stream as a result of horticultural activities in its vicinity. The stream was purposefully delineated into three blocks including upstream, midstream and downstream, where water samples were collected and analyzed for physicochemical attributes. Standard analytical procedures for water analysis were followed in laboratory analysis and the collected data was analyzed using Genstat software. Analyzed parameters include total dissolved solids (TDS), salinity, total suspended solids (TSS), sulphates (SO_3^{-3}), phosphates (PO_3^{-3}), nitrates (NO_3^-), fluoride (Fl^-), turbidity, chloride (Cl^-), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+) and zinc (Zn^{+2}). The results were presented in tables and a graph against WHO standards. All measured parameters showed significant differences ($p=<0.001$) among their means across the sampling sites and control. The pH did not show a clear trend from upstream through midstream to downstream. The concentrations of chloride decreased down the stream with control, midstream and downstream showing no statistical significance. Means of fluoride, magnesium, phosphates, sulphates, total soluble solids and zinc increased down the course of the stream. Increasing concentrations of the physicochemical parameters down the stream was attributed majorly to release and addition of agrochemicals to the stream from the nearby farms. A lucid knowledge of the nexus between land use and water quality was recommended as a prime management implication. In conclusion, the water quality of Maumau stream is being degraded by horticultural activities along the stream. Key policy actions including river pegging should be adopted to protect the water quality.

* Corresponding author.
  E-mail address: williemwangie@gmail.com (M.M. Wilson).

1. Introduction

It is over 20 years since the turn of the new millennium but the availability of clean water remains an acute challenge in various nations including Kenya. The issue of water quality degradation is prevalent in agrarian economies, and also in countries with a shortage of water resources (Kannel et al., 2007; Thotagamuwa and Weerasinghe, 2021; Debels et al., 2005). Surface waters continue to be contaminated by a diversity of anthropogenic materials which result to complex contaminant mixtures, presenting a major environmental challenge (De Baat et al., 2020; Bernhardt et al., 2017; Walker et al., 2019; EEA, 2018). The imbalance between human-induced water pollution and recovery from the contamination presents a real ecological disadvantage.

The chemical composition of stream waters is a key indicator of water quality, controlled by the background geochemistry of the water, climatic conditions and anthropogenic influence (Batheria and Jain, 2016). Studies have observed a degrading transformation of the hydrochemical integrity water as a result of anthropogenic pressure from activities such as horticultural production in the vicinity of streams (Wu et al., 2021; Arenas-Sánchez et al., 2021; Ghazaryan et al., 2020; Gesels et al., 2021; Alshehri et al., 2021; Zakaria et al., 2021).

Water for domestic, agricultural and industrial use is majorly from surface sources, with its quality and quantity correlating to consumers needs. Anthropogenic impacts result to significant deterioration and variation in water quantity (Peters, 2000; Parfenova, 2010). The anthropogenic influence on stream water manifests itself in fluctuations in the hydrologic regime, volume of flow and variations in ionic composition of the water upon analysis. For instance, increase in TSS and ions from human sources can disrupt the natural processes of self-purification in stream water. Toxic compounds such as pesticides and biphenyls in surface waters can reduce the metabolic activity of many aquatic life (Aktymbaeva, 2004). Irrigation with water with high electrical conductivity could result to limited economic returns that cannot justify the farmers investments (OECD, 2012a; OECD, 2012b).

Horticultural production in the world is on the raise (FAO, 2016), with the rapid growth attributable to land expansion, innovations of novel and disease-resistant crops, intensive use of agrochemicals and agrarian technologies. In horticulture, water pollution occurs when fertilizer inputs are applied at rates higher than the recommended amounts, therefore the soil is unable to fix them or are exported from the soil profile. Chemical compounds are widely used to prevent losses from diseases, pests and weeds (Schreinemachers and Tipraqsa, 2012), but on the other hand they pollute the water. The negative influence of pesticides use affects biodiversity up the trophic levels in the like of biomagnification and eventual poisoning, especially when farmers use hazardous formulations.

Water pollution is a major global threat that undermines economic, physical and environmental growth. Sustainable Development as envisaged in the 2030 Agenda acknowledges the importance of water quality with set targets. Sustainable Development Goal number 6, target 3 aims to improve water quality by pollution reduction, elimination of dumping, minimization of release of hazardous compounds, cutting the proportion of untreated wastewater to half and increasing recycling and safe re-use substantially across the globe (United Nations, 2016). The current study is therefore motivated by these targets, and aims to identify the presence of contaminants in Maumau stream and consequently Nairobi River and to derive policy recommendations to protect the water from pollution.

2. Materials and methods

2.1. Study site and design and sampling

Maumau stream is one of the tributaries of Nairobi River in Nairobi County, Kenya (Figure 1). Horticulture farming is practiced along the stream including vegetable cultivation, which creates a huge effect on water quality along the stream. The land use is characterized by smallholder farms subjected to intensive horticultural exploitation and consequently increased addition of fertilizers and pesticides. The stream was purposely delineated into three sampling blocks including upstream, midstream and downstream, meaning that the sample points were expected to show differences based on spatial location and nearby activities. This technique is known as Stratified Random Sampling, where the
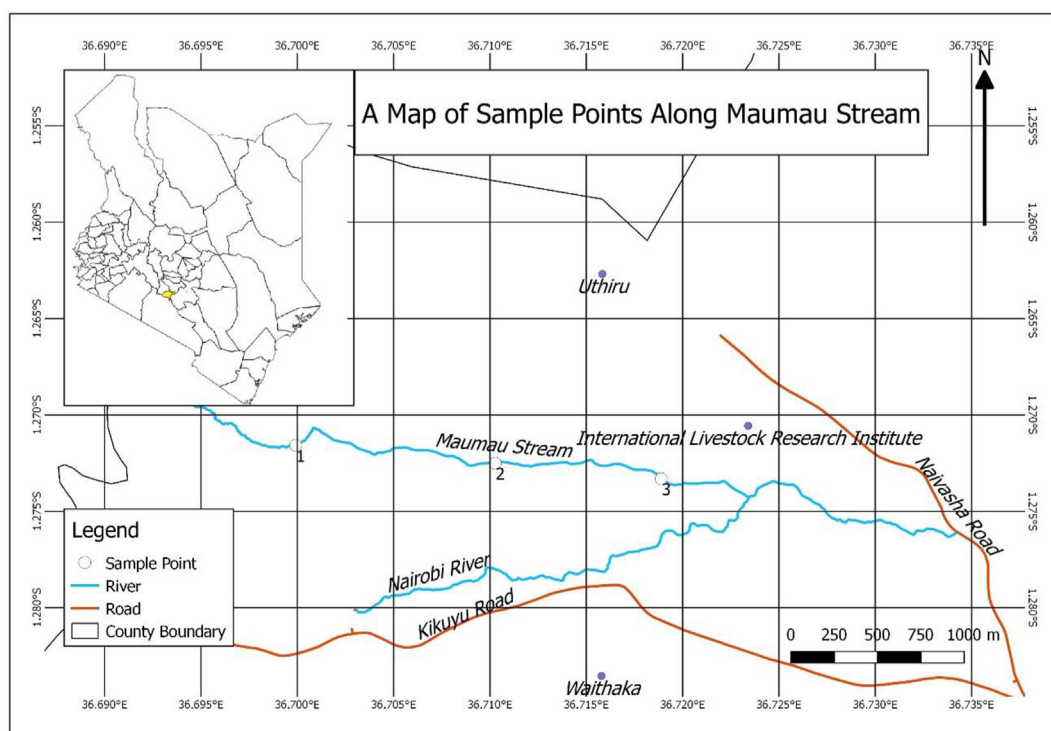

Figure 1. Study area map showing the sampling points.

sampling location is spatially subset into the delineation strata, in this case the stream section. Random sampling was applied to each stratum (upstream, midstream and downstream). The assumption was that these strata are strongly related to the target water quality parameters. This technique was also used by Mwendwa et al. (2019) and Mwendwa et al. (2020) as a delineation strategy in designating Soil Mapping Units (SMUs) to guide in land evaluation for crop suitability and soil classification respectively in Upper Kabete area, Kenya. Environmental variability which could affect the results was assumed to be negligible given the relatively short course of the stream and the same agroclimatic zone (ACZ III) along the stream course. This agroclimatic zonation is sub-humid according to Jiitzold and Kutsch (1982). Water samples were taken in the morning hours during the dry season (Month of March), therefore they did not have the discrepancies which could come as a result of different sampling times.

In each block (stratum), ten (10) composite water samples were taken into clean bottles using a water sampler and stored in cooler boxes for transportation to the laboratory. Compositing included collecting 5 water samples into a clean bucket, mixing thoroughly then taking about 500 ml of sample. Temperature measurements were taken onsite using a thermometer. Since the three sampling areas were along the stream, they were treated as blocks during data analysis. The experimental design was therefore a Randomized Complete Block Design (RCBD). The four treatments included Upstream, Midstream, Downstream and Control (WHO limits). The study area was selected because it is a typical representation of most agricultural zones in Kenya in the light of horticultural practices compromising water quality. Also, the subject stream leads to Nairobi River, which is the main river of the Nairobi River Basin.

2.2. Water quality analysis

The thirteen water quality parameters including total dissolved solids (TDS), salinity, total suspended solids (TSS), sulphates (SO_3^{-3}), phosphates (PO_3^{-3}), nitrates (NO_3), fluoride (Fl^-), turbidity, chloride (Cl^-), magnesium (Mg^{+2}), sodium (Na^+), potassium (K^+) and zinc (Zn^{+2}) were selected because they are the most common physicochemical water pollutants in all degraded water sources in the world. They are key components of most pesticides and fertilizers that are used in horticultural production. Turbidity, Phosphates and Sulphates were analyzed using the calorimetric technique under 880 nm. The pH was measured using a glass electrode pH meter according to Ingram (1994). Potassium, Sodium, Magnesium and Zinc were analyzed using the Atomic Absorption Spectrophotometer (AAS). Total Suspended Solids (TSS) were analyzed using the evaporative technique.

2.3. Data analysis

The three delineations were assumed to be the treatments during analysis. This enabled the elucidation of variation of the measured parameters in the light of spatial locus along the stream. The data was analyzed using Genstat 14th Edition to investigate the variation of means of measured parameters in upstream, midstream and downslope against the WHO limits. The test statistic used was the F-value which uses Analysis of Variance (ANOVA) as the statistical test. A value less than 0.05 at 95% confidence interval is indicative of statistical significance among the context means.

3. Results and discussions

All measured parameters showed significant differences (p=<0.001) among their means across the sampling sites and control. The pH did not show a clear trend from upstream through midstream to downstream, with the highest value observed in the upstream and the lowest in the midstream. The highest temperature was observed in the downstream and the lowest in the midstream, with means across the sampling locations having values exceeding the control. Concentrations of chloride

decreased down the stream with notably very high value in the upstream. The control, midstream and downstream were not statistically significant. Means of fluoride, magnesium, phosphates, sulphates, total soluble solids and zinc increased down the course of the stream. These data are presented in Table 1 and Table 2 and illustrated in Figure 2. Values of most of the physicochemical parameters increased down the stream due to release and addition of agrochemicals to the stream from the olericulture farms. Increase in temperature down the stream can be attributed to increased addition of the metallic ions and anions that absorb heat in water.

Significant levels of chloride especially in the upstream could reduce water quality and also interfere with osmoregulation in aquatic organisms. The decreasing chloride content down the stream can be attributed to addition of drippings with clean water into the stream. This observation is consistent with findings of Hunt et al. (2012), who attributed decreasing chloride content to dilution down the stream. Increase in fluoride concentrations down the stream can be attributed to the absence of runoff to the river which could have otherwise caused dilutions, indicating that during the dry season, the stream flow is mainly from groundwater containing more fluoride ions. Fluoride dissolution and availability seems to have correlated with the high pH of the water, indicating that the dissolution of fluoride influenced the pH. This finding is consistent with the observations Kitalika et al. (2018), who observed a linear correlation when comparing fluoride and pH trends in rivers of Mount Meru, Tanzania. The soils of the study area especially near the mouth of the stream (Kabete area) are predominantly Nitisols that have their genesis in trachytic parent material (Mwendwa et al., 2020). Trachytes contain high fluoride content and this could also explain the presence of fluorides in the water. Increasing concentration of fluorides down the stream can also be due to the use of herbicides along the stream.

This study observed significant patterns in the levels of magnesium as it increased from headwaters to downstream. Previous research has also shown increase in physicochemical content in urban vicinities across the world, where the distance downstream can predict ion concentrations. This increasing magnesium trend from upstream to downstream is attributable to increase in salts of human origin downstream because of urbanization, majorly due to impervious surfaces and degraded sewage systems. This observation is in agreement with the findings of Bhatt and McDowell (2007), who attributed increasing magnesium content in water downstream to increasing anthropogenic activity. Kaushal et al. (2014) also concluded that the hydrologic regime in urban environments can significantly be altered by extensive storm flows and leaking pipes. Drainage structures could have additionally enhanced the transport of road salt and products of weathering process from sources including impervious surfaces, into stream, an argument in agreement to observations of Elmore and Kaushal (2008) and Kaushal et al. (2014).

Nitrates decreased down the stream and this can be attributed to addition of the clean water that dripped and converged to the stream. The genesis of nitrate in the samples can be traced to the use of fertilizers, septic systems and manure leachates. Increasing phosphates down the stream can be attributed to increasing use of fertilizers and other human activities along the stream as phosphorus is a key component in fertilizers, manure, sewage waste and industrial effluent. Increase in phosphates in stream water are known to accelerate process of eutrophication, with their source mainly from runoff during irrigation practices. Bank erosion occurring during the rainy periods could also have transported phosphorous contents from the stream banks and adjacent land into the stream. These observations are consistent with findings of Neal et al. (2005) who noted increasing phosphate content down the stream.

The high potassium content notably in downstream is beyond the World Health Organizations' standards of quality water of 10 mg/L. Application of potassium based foliar fertilizers could have caused the increased potassium concentrations. Increasing concentration of sulphates down the stream can be attributed to use of fertilizers in the vicinity of the stream. This finding is supported by findings of Juan et al.

Table 1. Means and significance of analyzed parameters.

Treatments	PH	Temp.	Cl	Fl	Mg	NO_3	PO_4	K
Control	7.5a	20a	250a	1.5c	50c	50b	40d	10a
Upstream	8.273c	22.08c	2098.9b	0.4029a	0.91a	60.05d	0.15a	12.65b
Midstream	7.514a	20.52b	160.5a	0.4441ab	0.99a	57.16c	0.33b	10.16a
Downstream	7.963b	25.47d	84a	0.5132b	1.85b	6.56a	0.57c	14.58c
LSD	0.1712	0.3217	563	0.05537	0.2594	1.198	0.04295	0.761
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Table 2. Means and significance of analyzed parameters continuation.

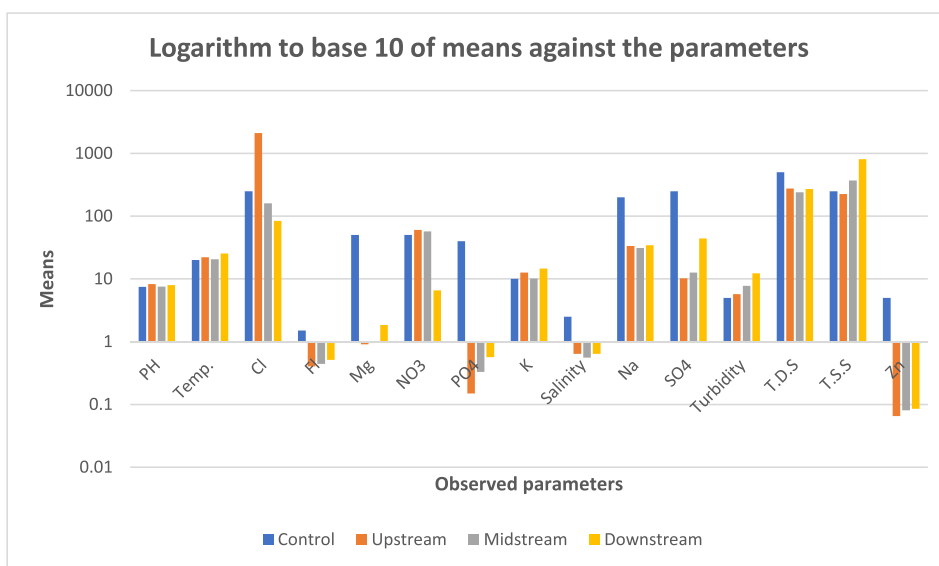| Treatments	Salinity	Na	SO_4	Turbidity	TDS	TSS	Zn
Control	2.5c	200c	250c	5a	500c	250a	5c
Upstream	0.641b	33.53b	10.22a	5.74a	274.5b	225.5a	0.065a
Midstream	0.558a	31.21a	12.65a	7.77b	239.6a	368.3b	0.081b
Downstream	0.637b	34.27b	44b	12.32c	270.9b	806.5c	0.085b
LSD	0.01529	0.722	4.834	1.021	6.86	65	0.01014
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Figure 2. A plot of means of observed parameters in the sample locations.

(2020), who concluded that most sulphates and nitrates in water have major sources in fertilizer use and degraded sewerage systems. There was also part of the stream where wastes from the car wash joined the downstream which can explain the increasing trend along the stream course. Increasing turbidity down the stream is indicative of increasing concentration of metallic elements, anions and alluviation caused by siltation from the cultivated land as a result of the destroyed riparian environment.

Dissolved solids in the stream could have emanated from anthropogenic sources including fertilizer use. Water having total dissolved solids is hard because of high content of calcium and magnesium and can signify the presence of elevated concentrations of hazardous trace elements in the groundwater. Increasing zinc concentration down the stream could be due to increased application of the zinc containing foliar chemicals especially in the midstream and the downstream where there was fruit vegetable cultivation, such as the chilies and the capsicum. Inorganic materials could have become suspended due to runoff, erosion and re-suspension from seasonal water flow.

On ecological and management implications, water quality degradation remains a key issue in the world, whereby surface waters including streams are under serious threat of pollution (Chaudhry and Malik, 2017; Mul et al., 2015). Water quality is influenced by both stochastic and human factors, which render it less useful, especially for drinking purposes (Matshakeni, 2016). The anthropogenic activities may include agriculture and urbanization and are among the key drivers of land use change within a watershed, having a strong influence on the quality and quantity of water sources (Gyamfi et al., 2012; Li et al., 2014; Khan et al., 2017; Olusola et al., 2018). One of the most paramount management implications is the identification of the correlation between the land uses and water quality. A lucid understanding of the nexus and entanglement between land use and water quality will go a long way in minimizing the pollutant loads in water bodies. This suggestion is consistent to the input of Ding et al. (2015), who noted that most pollutants in water sources emanate from the land uses. Appraising the quality of surface water would be crucial in offering guidelines to maintaining a safe and healthy environment that supports harmonious

ecosystem functioning in the face on increased demand for portable water.

From a global perspective, pollution is the major cause of water quality deterioration. Eutrophication remains the most serious water quality problem on major lakes and rivers, therefore jeopardizing marine life. This phenomenon is usually a result of high loads of mainly phosphates and nitrates, which substantially lower the useful utilization of the water. The effect of unclean portable water is a major concern to many nations because of the dangers of water-borne diseases. Clean drinking water could play a vital role in the reduction of infant mortality by ensuring good child health and survival (Vidyasagar, 2007).

4. Conclusions and policy recommendations

Most of the parameters in this study increased down the stream indicating that horticultural farming has great influence on the water quality. It is therefore advisable to cultivate with caveats so as to protect the water quality. River pegging is recommended to create a clear riparian zone. Planting trees that do not drain water away especially indigenous species to give a cover is encouraged. The trees should have a root system that can aid in trapping the leaching chemicals. Farmer education to abstain from use of chemicals in times of continued rains since they will be washed and drained to streams is a viable approach to maintain water quality. This use of indigenous knowledge is envisaged in Rio Declaration principle number 22. Farmers can also be encouraged to embrace smart agriculture so as avoid excess use of chemicals and fertilizers, the excess of which translates to pollutants. The use of biological control of pest and weeds could be a panacea to water quality deterioration and environmental degradation. Practical approaches to curb the stream pollution include but not limited to: the implementation of polluter pays principle, restrictions on direct discharge of pollutants into water sources, limits on sale of hazardous products, consensus on location the location of farms with respect to stream course, inspections and penalties to violations.

In economic terms, pollution control could include taxation to polluters and payments based on the intensity of land use. It could also entail public awareness to teach residents the economic advantages of adopting good agricultural practices. Environmental management concepts can be included in early school curriculum as a form of persuasion in raising environmental awareness. Identifying pollution hotspots including overstocked and horticultural farming areas can assist in prioritizing combat interventions.

Declarations

Author contribution statement

Wilson Murithi M: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Michieka R.W: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mwendwa S.M: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

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