EFFECTS OF FARMING PRACTICES ON THE LEVELS OF TURBIDITY, NITRATES, AND PHOSPHORUS IN RIVER RUPINGAZI IN EMBU WEST SUB COUNTY, KENYA

Quentin A.M. Ngati[1], Adiel M. Magana[1], Justin M. Nyaga[2]

[1]Department of Environmental Studies, Chuka University, P.O.Box 109-60400, Chuka, Kenya.

[2]Department of Biological Sciences, University of Embu, P.O. Box 6 - 60100, Embu, Kenya.

Email of corresponding author: qngati@gmail.com

Abstract

River Rupingazi catchment in Embu West Sub-County of Kenya has recently undergone unchecked rapid land use change from natural vegetation to urbanization and agriculture with varying farming practices. Effects of land-use changes on water quality in this catchment is not well documented. This river is primary source of livelihood for about 116,700 inhabitants in the sub county. An ecological survey was carried out to determine the effect of farming practices on the levels of turbidity, nitrates, and phosphorus in the 24 km reach of River Rupingazi. A transect walk along was used for dividing the reach into 7 zones. These include the; Main Tea zone, Tea zone, Tea/Coffee zone, Coffee zone, Mixed Farming zone, Town zone, and Livestock zone. Four major farming practices prevalent across the seven zones are the growing of perennial crops, perennial cover crops and non-perennial crops, and constructed soil conservation structures. Triplicate water samples were randomly collected at the entry and exit of each zone and tested for turbidity, nitrates and phosphorous. One-way ANOVA at $P < 0.05$ was used for data analysis using Statistical Package for Social Scientists (SPSS) software. There were no statistically significant differences in mean values of turbidity ($P = 0.067$), nitrates ($P = 0.281$) and phosphorus ($P = 0.189$) in water at the seven study sites. Furthermore, it was established that main farming practices in the study area influenced the levels of study parameters. Combination of the soil and water conservation structures and perennial crops in the Main Tea and Coffee zones resulted to lower levels of turbidity, nitrates, and phosphorus in the study reach. Tea/Coffee zone with a combination of cover crops and soil and water conservation structures recorded the lowest levels of turbidity, nitrates and phosphorous in the river water. Zones with non-perennial crops had comparatively higher level of the measured parameters. It is therefore recommended that combination of various land use practices should be applied to improve the water quality parameters particularly in the riparian buffer strip of upper regions of rivers where bank have steep gradient.

Keywords: Land use, farming practices, Turbidity, Nitrates, and Phosphorus levels in water

INTRODUCTION

Land use change has been shown to greatly influence the drainage characteristics of a basin (Gossweiler et al., 2019). An increase in the proportion of drained areas, direct exposure to surface runoff through reduction of vegetative cover among other land use characteristics in a catchment concurrently increase nitrogen (N), Phosphorus (P), silt and organic carbon concentrations in the water flowing into rivers. Briassoulis (2020), (Zou et al., 2020) & Finer et al., (2021) lists some of the major land use types as forest, grassland, cropland, residential, or commercial. However, these are broad categories of land use types that require more details on the physical and natural patterns like the kind of farming practices i.e. in crop land- perennial or non-perennial crops, to have a complete description of land use (Meyer & Turner, 1994), in order to adduce their unique effects on nutrient flow into rivers. According to Tong et al. (2002), there is a substantial relationship between the N and P levels in river water and the type of farming practice. However, Lintern et al. (2018) observed that our knowledge on relationship between various farming practices and their respective effects on water quality is currently insufficient.

Agriculture is among the leading causes of river water pollution globally (Evans et al., 2019). The primary source of N and P in runoff is farmland of which mainly is in the form of nitrates (NO_3) and soluble phosphates (PO_4^{3-}-P). Extensive use of N and P rich fertilizer to boost production in the farmland with large portion of the nutrients going to a waste through runoff has played a major part in nitrates and phosphorus finding their way into river water (Cui et al., 2020). For example, P is mostly carried to rivers via runoff and erosion, whereas leaching of P is often little due to the limited solubility of phosphates in soils (Smil, 2000). Particulate organic matter makes up 75–90% of the P carried by runoff water from farmed land (Sharpley et al., 1995). These particulate matter rich in N & P nutrients in the form of suspended solids such as clay, silt, sand from inorganic materials and organic matter cause turbidity in rivers (Serajuddin et al., 2019).

Nitrates and phosphate pollution in river water is a major cause of eutrophication that lead to oxygen loss, that result to death of aquatic plants and animals (Haas et al., 2017; Goyette et al., 2018). Furthermore, Sajedi-Hosseini et al. (2018) reported that, compounds of N in water can transform into nitrites and when taken in drinking water, increase the risk of some human diseases such as gastric cancer, diabetes, spontaneous abortion and thyroid diseases. According to Sebastianiá et al. (2019), water turbidity induced by suspended solids scatter light instead of allowing it to go down the water column thereby reduced penetration of light, temperature distribution and visual acuity, negatively to aquatic life. The maximum allowable amounts for nitrates, phosphorus and turbidity in drinking water as set by World Health Organization (2011) is 45mg/l, 5mg/l and 5 Nephelometric Turbidity Units (NTU), respectively.

Rupingazi river watershed which is part of the Upper River Tana catchment, Kenya, has experienced a shift in land use practices notably an increase in size of agricultural and built-up land area at the expense of land under vegetation and water-bodies (Langat et al., 2021). Constant cultivation of the steep valleys of river has resulted to high soil erosion and consequent input of nitrates and phosphorus rich particles in the river (Mburu et al., 2016).

MATERIALS AND METHODS

Study Area

The study was carried out along the 24 km reach of the River Rupingazi watershed that lies within the administrative boundaries of Embu West Sub-County, Kenya. The river cuts across two constituencies of the sub-county namely Manyatta and Runyenjes. The study area lies within S0.2851^{o} and E36.6465^{o} at elevation of 1,493M above the sea level with land mass of about 288ha. The area is inhabited by 240 farmers each with an average of 1.2ha of farm (Figure 1).

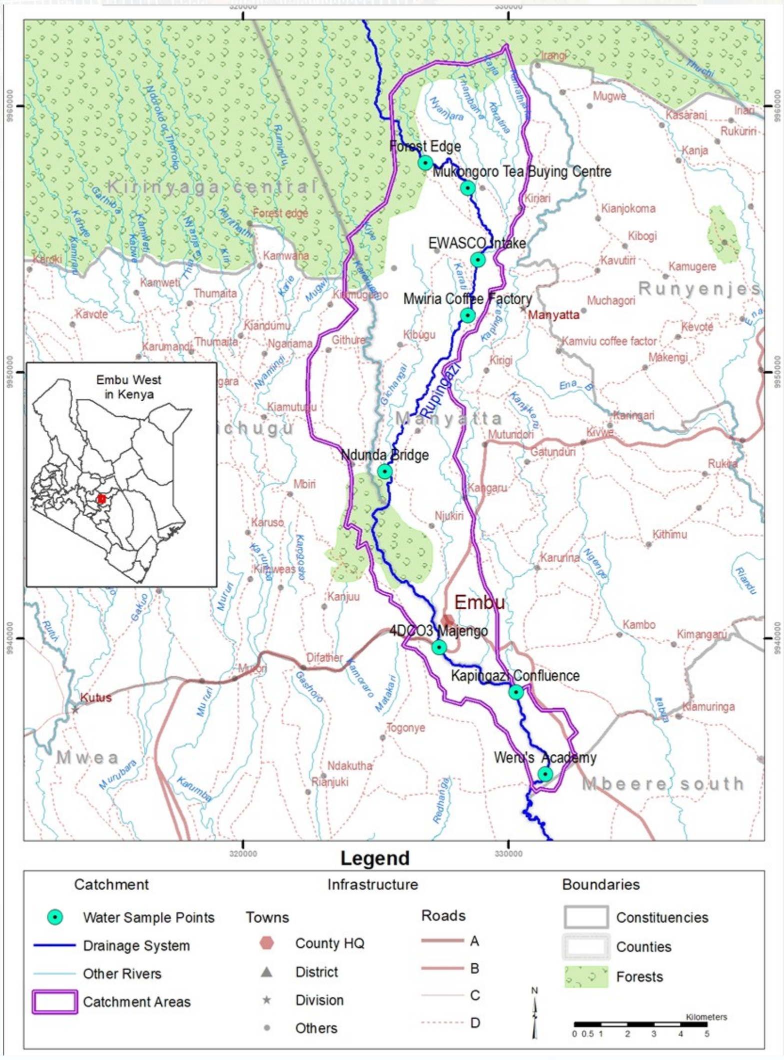

Figure 1: Map of Study Area- Rupingazi watershed in Embu West Sub County, Kenya
(Source: Modified Google Map, 2023

An ecological survey approach was used to establish the effect of different farming practices in the study area on the levels of turbidity, nitrates, and phosphorus. Observation of land use practices was undertaken through a transect walk leading to division of study reach into 7 zones namely; Main Tea zone, Tea zone, Tea/Coffee zone, Coffee zone, Mixed Farming zone, Town zone, and Livestock zone. Stratified random sampling was used for selection of farmers who participated in the study. From each between zone, adjacent to the river, water samples were collected for testing between March and July, 2018.

Sampling Procedure and Sample Size

From a total population of 240 farmers, a sample size of 150 farmers was selected by using Krejcie & Morgan (1970) guidelines. The 150 farmers were proportionately assigned to each zone using a stratified random sampling technique. Selected farmers were interviewed on factors regarding farming practices. The river water samples were collected randomly at depth of 30 cm fortnightly at the upper point (entry point) and lowest point (exit point) of each zone. In each of the 8 sampling points, 12 water samples were collected resulting to a total of 96 water samples. Collected samples were stored in sterile 500ml plastic bottles and preserved in cooler boxes to minimize chemical biological activities (APHA, 2005). Samples were analyzed at the Water Resource Authority Regional Laboratories in Embu for turbidity, nitrates, and phosphorus using direct and calorimetric methods. Contribution of farming practices to the levels of measured parameters were obtained from the difference in observed levels between the entry and exit point of a zone. Data on catchment and river characteristics such as slope and area were collected and recorded in data sheets.

Statistical Data Analysis

Data from farmers' questionnaire responses on farming practices was analyzed using the Statistical Package for Social Scientists ver. 20.0 (SPSS). To determine the significance in variation of the levels of turbidity, nitrogen, and phosphorus across different zones, one-way Analysis of Variance (ANOVA) at $P< 0.05$ was undertaken. The relationship between the turbidity, nitrogen, and phosphorus levels and the farming practices was shown using bar graphs, tables, and descriptive statistics.

RESULTS AND DISCUSSION

Quantification of Spatial Farming Practices Across the Zone

In terms of type of crops grown, perennial crops growing was the main farming practice in the Main Tea, Tea, Tea/Coffee, and Coffee zones (Table 1). This is consistent with findings of Waarts et al. (2012) who reported that tea and coffee have been the primary crops in Kenya's Upper Tana catchment since the 1970s. Surprisingly farmers in the Tea zone also cultivated vegetables like kales and tomatoes and root crops like sweet potatoes along the riparian areas. In the Mixed Farming, Town, and Livestock zones, growing of non-perennial crops like maize and beans predominated as a farming practice. In both the Main Tea and Tea zones, 85% of the farms lacked constructed physical soil and water conservation structures (S&WC). These results agree with those of (MoEW&NR, 2014) who reported that farmers in these zones typically do not practice soil conservation measures but use tea plants to serve as a land cover. Town and Livestock zones scored 60% and 50% of their farms without physical S&WC respectively due to the former zone being fairly flat slope with gradient of (0%-12%) and having no major size of land under farming practice while in the later zone mostly under free range livestock rearing. The Mixed Farming zones displayed a heterogeneous blend of farms, some with physical S&WC and others without. A distinct pattern of constructed physical S&WC structures was evident in Coffee growing zone (Table 1). This can be attributed to the colonial agronomical policy of building physical S&WC that advocated construction of bench terraces on any ground under coffee plantation (Angima et al., 2003).

In the Main Tea and Tea zone, it was noted that farmers applied relatively high rates of NPK fertilizer of between 176 and 200 kg per acre (Table 1). Similarly, Cui et al. (2020) reported that farmers in other tea zones apply NPK fertilizer at high rates, to maximize tea production. Good amount of this fertilizer leaches into the subterranean systems and eventually into rivers during wet seasons. In addition, farmers in Tea/Coffee, Coffee, Mixed Farming, and Livestock zones practiced application of planting and topdress fertilizer at 26-50kgs per acrea as report by the Ministry of Agriculture (2010).

Table 1: Description of Main Farming Practice in each Zone

Zone/ Farming Practice	Main Type of Crop (Perennial/Non-perennial)	% of Land with Soil & Water Conservation Structures	Fertilizer Application	Land Gradient
Main Tea	Perennial, mainly tea bushes	<5%	Mainly top dress at very high rates (176-200Kgs/acre)	Steep- (13%-34%)
Tea	Perennial, mainly tea bushes, riparian area farmed with vegetables i.e. kales	<5%	Mainly top dress at very high rates (176-200Kgs/acre)	Steep- (13%-34%)
Tea/ Coffee	Perennial- Mixture of tea & coffee almost in equal proportion	50%- Land under coffee crop with bench terraces but poorly maintained	Mainly top dress at normal rates (26-50Kgs/acre)	Steep- (13%-34%)
Coffee	Perennial- Mainly coffee bushes	90% under bench terraces but poorly maintained	Mainly top dress at normal rates (26-50Kgs/acre)	Steepest- (35%-55%)
Mixed Farming	Non-perennial- maize & beans	<5% under fanya juu terraces	Both planting & top dress at normal rates (26-50Kgs/acre)	Flat(0%-12%)
Town	Non-perennial- maize & beans	<5%	Both planting & top dress at low rates (<26Kgs/acre)	Flat(0%-12%)
Livestock	Non-perennial- maize & beans	<5%	Both planting & top dress at low rates (<26Kgs/acre)	Flat(0%-12%)

Spatial Variation of Turbidity Levels among the Study Sites

A one-way ANOVA performed at $\alpha = 0.05$ probability level revealed that there were no statistically significant differences in water turbidity among the seven zones, $F(6, 77) = 2.061$, $p = 0.067 > 0.05$ (Table 2). Results in a recent study on effects of human activities on water quality of River Rupingazi by Bonareri (2017) reported no statistically significant mean difference of spatial variation of turbidity levels in the rivers within a season but significant differences occur between the dry and wet seasons.

Table 2: Analysis of Variances (ANOVA) of Data on Spatial Variation of Levels of Turbidity

					ANOVA	
Parameter	Zones/ Strata	N	Mean	Std. Deviation	F	Sig.
Turbidity (NTU)	Coffee	12	50.78	93.09	2.06	0.07
	Livestock	12	41.98	52.71		
	Main Tea	12	1.41	4.24		
	Mixed Farming	12	-7.03	49.08		
	Tea	12	39.31	77.12		
	Tea/ Coffee	12	6.73	16.85		
	Town	12	21.19	21.42		
	Total	84	22.06	56.24		

Spatial Variation of Nitrates Levels at Study Sites

A one-way ANOVA at α<0.05 probability level (Table 3) indicated that there were no significant differences in mean nitrates levels between the seven zones where $F(6, 77) = 1.270$, $p = 0.281 > 0.05$. Related studies by Samuel (2021), indicates that within a season, there was no significant variation of nitrates levels along the river but significant differences happen across dry and wet season. According to Wensheng et al. (1998), the levels of nitrates in many natural waters are very low, below the detection limits of conventional colorimetric analysis, hence probably the low levels of the ion noted in this study. Even though there was no significant variation of nitrates levels along the river, recent studies by Wijesiri et al. (2018) indicated a direct relationship between change in natural lands into different land use characteristics including built environments and the increase of levels of nitrates pollution in river waters. Thus, this prompted the study to a further analysis of the contribution of each farming practice to the levels of nitrates obtained in the River Rupingazi.

Table 3: Analysis of Variances (ANOVA) of Data on Spatial Variation of Levels of Nitrates

Parameter	Zones/ Strata	N	Mean	Std. Deviation	ANOVA	
					F	Sig.
Nitrates (mg/l)	Coffee	12	1.28	1.82	1.27	0.28
	Livestock	12	-1.35	8.01		
	Main Tea	12	0.89	1.07		
	Mixed Farming	12	1.24	2.78		
	Tea	12	1.46	2.55		
	Tea/ Coffee	12	-2.08	2.55		
	Town	12	1.92	8.27		
	Total	84	0.48	4.79		

Spatial Variation of Phosphorus Levels Across the study sites

A one-way ANOVA to determine if there was any significant mean difference of the phosphorus levels across the zones at α<0.05 probability level reveal that there were no significant differences in mean phosphorous between the seven zones, $F(6, 77) = 1.501$, $p = 0.189 > 0.05$ (Table 4). Similar results were obtained in a recent study by Samuel (2021) that there was no spatial variability of levels of phosphorus in River Rupingazi in a given season. However, during the wet season, phosphorus levels rise and can cause pollution and eutrophication of rivers. Results agree with those of Githumbi et al. (2021) who reported rise of phosphorus levels in the river due to sediment suspension following a storm event in river sections close to farmlands that apply phosphorus nutrients.

Table 4: Analysis of Variances (ANOVA) of Data on Spatial Variation of Levels of Phosphorus

Parameter	Zones/ Strata	N	Mean	Std. Deviation	ANOVA	
					F	Sig.
Phosphorus (mg/l)	Coffee	12	-0.10	0.36	1.50	0.19
	Livestock	12	-0.24	0.88		
	Main Tea	12	0.00	0.27		
	Mixed Farming	12	0.37	0.57		
	Tea	12	0.16	0.45		
	Tea/ Coffee	12	-0.04	0.65		
	Town	12	0.29	0.85		
	Total	84	0.06	0.63		

Contribution of Farming Practices on Levels of Turbidity, Nitrates, and Phosphorus Along River Rupingazi

Highest levels of turbidity were experienced in the Coffee, Livestock, and Tea zones with readings of 50.783 NTU, 41.983 NTU, and 39.308 NTU, respectively (Figure 2). However, it is only in Main Tea and Mixed Farming zones that the turbidity levels were below WHO Guidelines on maximum allowable amount of turbidity for drinking water of 5NTU (WHO, 2011). The rest of the other five zones had turbidity levels way above the WHO limits therefore not suitable for drinking.

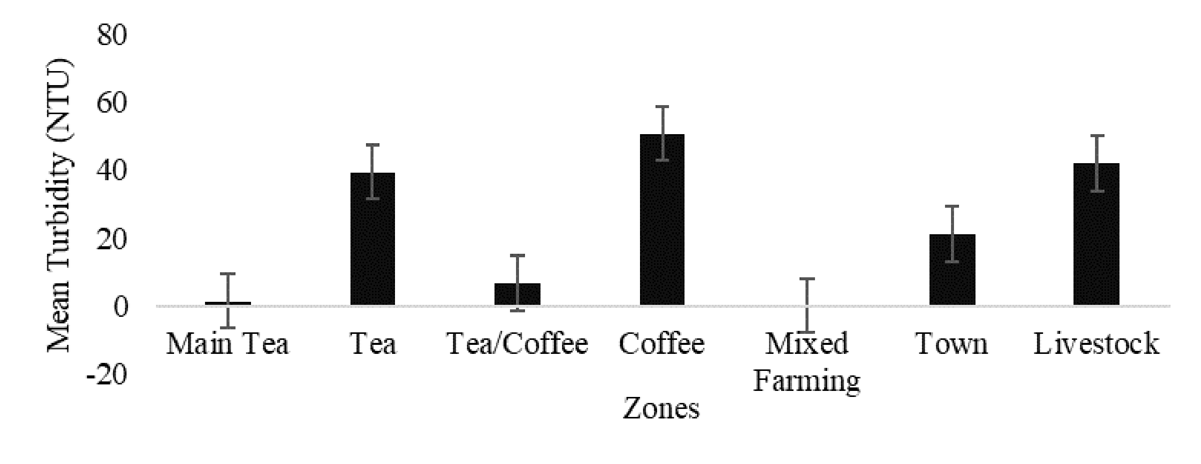

Figure 2: Mean Turbidity Levels per Zone

During the present study, some farmers in Tea zone practiced farming of vegetables such as tomatoes and kales along riverine strip. This practice loosened the soil and making it susceptible to erosion. However, the presence of tea cover crop and bench terraces tended to minimize sediments flow into the river during rains. Absence of soil conservation structures and perennial crop in the Livestock zones contributed to the high turbidity levels in the river. These findings are consistent with those by Dieu et al. (2020), who reported that terracing, mulching and use of cover crop in Rwanda lessen the intensity of rill erosion caused by surface runoff. Another studies along Mau Mau Stream (a tributary of Nairobi River, Kenya) found a strong correlation between horticultural farming along the banks and stream turbidity (Wilson et al., 2021). Low turbidity in the Main Tea and Tea/Coffee zones is attributed to the presence of cover crops as well soil and water-conservation structures that enhance water infiltration and slows the rate of runoff overland flows into the river.

The seven zones indicated varying levels of nutrients and turbidity at the adjacent sections of the river. The mean nitrate contribution into water for Town, Tea, and Mixed Farming zones was 1.917mg/l, 1.458mg/l, and 1.242mg/l, respectively (Figure 3), while those of phosphorus were 0.285 mg/ l, 0.155 mg/l, and 0.368 mg/l, respectively (Figure 4). However, all values were below the WHO permissible limits for drinking water which is 45mg/l and 5mg/l, respectively (World Health Organization, 2011).

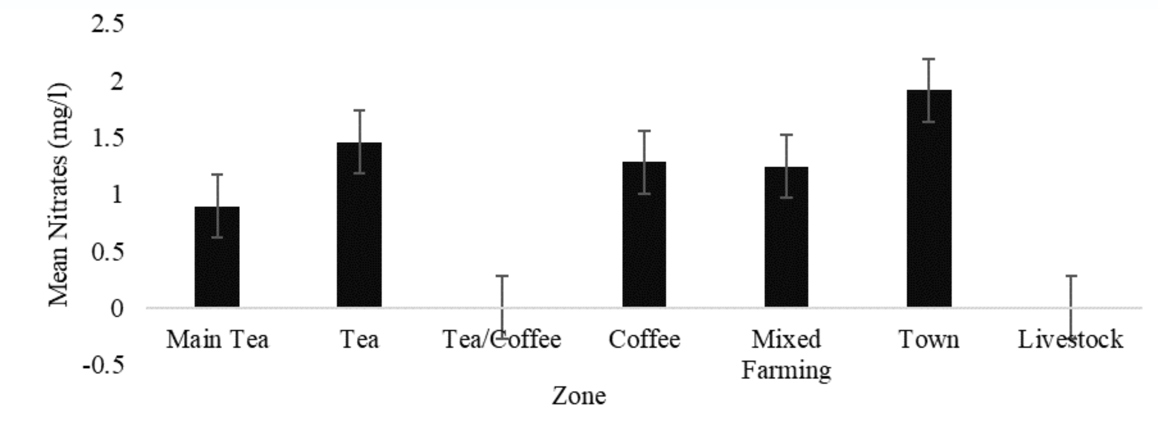

Figure 3: Mean Nitrates Levels per Zone

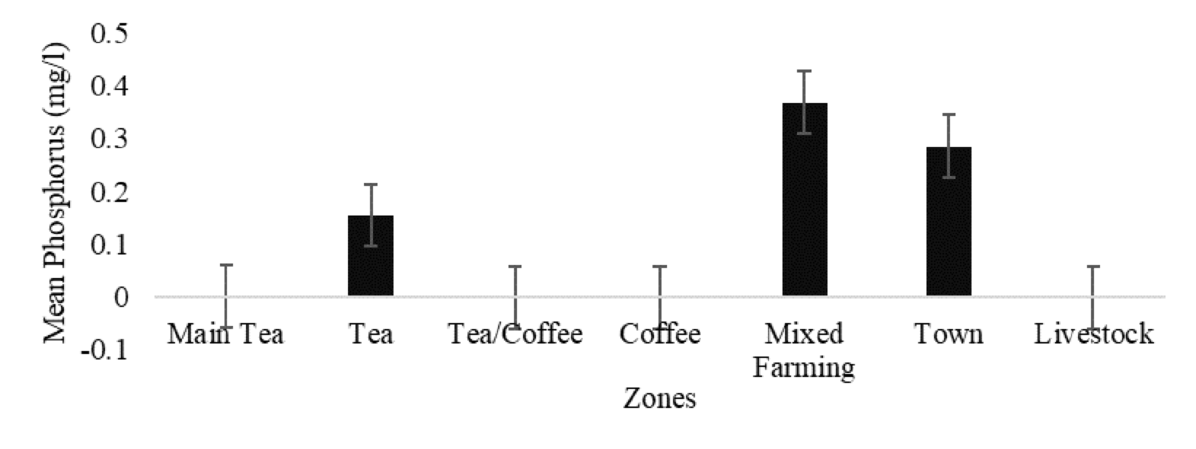

Figure 4: Mean Phosphorus Levels per Zone

The average nitrate and phosphorus levels reading in the river in the section between Main Tea zone and Coffee zone was 0.908 mg/l and 0.005 mg/l respectively, which was lower as compared to that of the section between the Mixed Farming zone and Livestock zone at 1.053 mg/l and 0.140 mg/l, respectively. The main general difference in the kind of farming practice between these two sections is that in the former section, farmers practiced planting of perennial permanent crops i.e. tea and coffee while in the later section, non-perennial crops such as maize, beans, tomatoes and sweet potatoes were planted. Crews et al. (2018) indicate that establishment of perennial crops in a river basin has rapid positive response to water quality by discouraging continuous mechanical soil disturbance during cultivation that render the soil loose and exposed to erosion. Therefore, low average mean nitrates and phosphorus reading between the Main Tea zone and Coffee zone was prompted by the surface coverage of tea and coffee permanent perennial crop.

Permanent perennial cover crops such tea have shown to reduce nitrates leaching and phosphorus loss from agroecosystems (Thapa et al., 2018). Comparatively, the farming practice of planting permanent perennial cover crop of tea played a major part in the low levels of mean nitrates and phosphorus of 0.892 mg/l and 0.000 mg/l respectively registered in the Main Tea zone as compared to the other seven zones. However, this function of the permanent tea cover crop in Tea zone was curtailed by the riparian horticultural crop cultivation in this zone as evidenced by registering the second highest mean nitrates levels of 1.458mg/l and third highest mean phosphorus levels of 0.155 mg/l.

According to Karuku, (2018) coffee farms in Embu County have well-constructed bench terraces for soil and water conservation due to the steep gradient valleys in the region. Ndiritu et al. (2022), observed that the main soil and water conservation measure practiced by over 80% of coffee farmers in Kenya is bench terraces. These bench terraces averagely measure 5m-10m in length (Angima et al., 2003). Bench terraces on steep slopes have proved to be effective in soil conservation structures that impede movements of nutrient rich soil particles flow into rivers (Singh, 2021). In the present study, Coffee zone with steep slopes of 35%- 55% had over 90% of land with constructed bench terraces (Table 1), and mean nitrate concentration of 1.283mg/l in adjacent river water (Figure 3). However, this zone recorded the least amount of phosphorus levels in water at -0.100mg/l (Figure 4). Most of the bench terraces both in the Coffee and Tea/Coffee zone were poorly maintained (Table 1), resulting to their ineffectiveness in controlling soil erosion. Mcharo and Maghenda (2021), explained the relatively high cost of maintenance is the reason low maintenance of terraces in most of the coffee farms.

Although the Tea/Coffee zone had similar slope characteristics with those of the Coffee zone, the river water adjacent to the former recorded lower amount of nitrates and phosphates (0.000mg/l and 0.040mg/l, respectively (Table 1). This is attributed to the synergistic effect of the combination the bench terraces and cover crop of tea bushes. According to Rutebuka et al. (2021), a combination of cover crop with physical soil and water conservation structures such as bench terraces exhibit superior control of soil erosion hence reduction of nitrates and phosphorus into water bodies. Cover crops on their own can be effective in reducing soil loss by up to 75% when planted in fallow land (Daryanto et al., 2018).

CONCLUSION

This study established that there were no statistical significant variations of the means of turbidity, nitrate, and phosphorus levels in River Rupingazi water across the seven zones- Main Tea, Tea, Tea/Coffee, Coffee, Mixed Farming, Town and Livestock zones. A review of the land use revealed four main farming practices across the seven zones including planting of permanent perennial crops, planting of permanent cover crops, planting of non-perennial crops, and construction of physical soil and water conservation structures. The study concluded that there was a direct relationship between these four farming practices and the mean turbidity, nitrate, and phosphorus levels recorded in the river. Planting of permanent perennial crops such as coffee and tea contributed to reduction of turbidity, nitrates, and phosphorus levels in the river. On the other hand, planting of non-perennial i.e. kales, tomatoes, and sweet potatoes as root crops increased the mean turbidity, nitrates, and phosphorus levels in the river. Perennial permanent crop required less if not at all continuous cultivation thus discourage physical disturbance of the soil, that otherwise would have become lose and subject to soil erosion as observed in the case of planting non-perennial crops.

Therefore, to discourage continuous land disturbance and protect it from direct splash and sheet erosion from rains, riverine farmers should be encouraged to practice farming of perennial permanent crops. Promoting planting of high value agro-forestry trees like macadamia and mangoes can benefit the farmer both economically from the tree product while at the same time maintain and improve soil fertility from reduced nutrients loss into the river through controlled soil erosion. On farm construction and proper maintenance of physical soil and water conservation structures such bench terraces reduces the mean turbidity, nitrate, and phosphorus levels in the river.

Physical soil and water conservation structures can be an effective method of reducing pollution of rivers in areas with high slopes. Further, a combination of physical soil and water conservation structures with permanent perennial crops especially those that are cover crops give superior reduction of turbidity, nitrates, and phosphorus levels in the river than when the former land use pattern is practiced exclusively. Farmers in a river basin should be encouraged to plant riparian buffer crops composed mainly of cover crops to trap all the nutrient loaded silt flowing from the upper sloppy regions of their farm.

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