© 2016 IJSRSET | Volume 2 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Differences in Water Quality In Relation To Human Activities along River Shimiche Ecosystem, Western Kenya

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ABSTRACT

A vast majority of inland water bodies are rapidly undergoing degradation or drying up mainly due to human influences and climate change. These water bodies and especially those that supply domestic water to human populations should be given more attention for management and conservation. The main objective of this study was to determine the differences in water quality in relation to economic land use practices along River Shimiche in Western Kenya. The River's ecosystem drains three land use types; forested environment in the upper course, sugarcane plantations and urban settlement in the middle and small-scale mixed farming activities in the lower course. Sampling was done at nine sampling stations once a month from January 2014 to August 2014. The sampling stations were selected to represent the main land uses along the course of the river determined by direct surveys and observations. Water temperature, pH, electrical conductivity and total dissolved solids were measured *in-situ* in triplicate, using appropriate meters. Water samples were also collected randomly in triplicate at each station and taken to the laboratory for determination of total suspended solids and enumeration of *Escherichia coli*, a coliform bacterium. Statistical analyses were done using Statistical Analysis System (SAS) version 9.1. Mean, variance and standard error were used to assess the spread of the data. The means of the parameters and one-way analysis of variance (ANOVA) were calculated to compare the mean values of observations based on land use. Where ANOVA showed significant differences, the means were separated through difference of the least square analysis. Pearson correlation co-efficient explored the relationships between physico-chemical parameters and *E. coli* concentrations. The means of all the physico-chemical variables at the three land uses were significantly different ($p<0.05$); indicating that land use variation impacts on physico-chemical conditions in the river's ecosystem. Mixed agriculture and urban settlements areas recorded the highest concentration of the *E. coli*. Changes in riparian land uses in the watershed therefore impact on the river physico-chemical conditions which consequently affect concentrations of *E. coli*, a biological indicator of water quality. There is need for the establishment of effective management schemes by different stakeholders for sustainable utilization of land along the course of River Shimiche and other similar small rivers.

Keywords: *Escherichia coli*, Water Quality, River Ecosystem, Anthropogenic Activities

I. INTRODUCTION

Water bodies around the world are faced with problems of pollution (Maier *et al*., 2001). The current pollution are occasioned by industrial, domestic and agricultural activities experienced in the watershed and along the riparian zones (Dynessius and Wilson, 1994). However, there is scarcity of information on anthropogenic activities advanced on major water bodies such as streams.

Streams are water bodies that give rise to larger water resources such as rivers, lakes and other wetlands. They are invaluable in providing sources of water for agricultural activities including irrigation of crops, livestock farming, fishing, economic activities such as sand harvesting, as well as water for domestic and industrial uses. Due to rising populations along riparian areas, streams and rivers face considerable pressure which reduces the water quality and quantity. In Kenya, the Nzoia, Yala, Sio, Nyando, Sondu-Miriu and Kuja are the major rivers draining into Lake Victoria (Enanga *et al*., 2010). These rivers are of economic importance to the riparian populations and the Lake Victoria basin as a whole, as well as providing habitat for aquatic flora and fauna (Townsend *et al.,* 1997). However, there is scarce information on the water quality and quantity on most of the tributaries streams in East Africa (Andrea *et al*., 2009) such as River Shimiche which discharges its waters into River Nzoia. Therefore, continued degradation of River Shimicheand and suchlike rivers are a threat to the survival of flora and fauna therein in River Nzoia and Lake Victoria at large.

In a preparatory measure to mitigate on the current pressure and the resulting consequences on aquatic water bodies and life forms, the present study endeavoured to establish the differences in water quality in relation to economic land use practices along River Shimiche. Information generated by this study is valuable to stakeholders including the water management authorities in devising ways of sustainable utilization of the River Shimiche, other rivers and aquatic ecosystems as a whole.

II. METHODS AND MATERIAL

A. Study Area

The study was carried out along a 46 km stretch of River Shimiche, a tributary of River Nzoia in western Kenya, which eventually discharges into Lake Victoria (Fig. 1, Table 1). Nine sampling stations were selected on the course of the river to cover the river's upstream course near the source with forest, the middle course with urban settlements and sugarcane plantations, and the downstream course with small-scale mixed farming just before the confluence of Shimiche with the larger River Nzoia.

The sampling stations were selected to represent the different land uses and were coded 1a, 1b and 1c in the upper course of the river; 2a, 2b and 2c in the middle course and 3a, 3b and 3c in the lower course. Station 1a was in the upper stream near the source of the river, station 1b and 1c were 50 m and 100 m below the source of the river respectively. Station 2a was 50 m before the bridge on the Mumias-Bungoma road while station 2b was at the bridge. Station 2c was at 50 m after the bridge while Station 3a was 100 m before the confluence of River Shimiche with River Nzoia. Station 3b and 3c were 50 m before and at the confluence of Shimiche with River Nzoia, respectively.

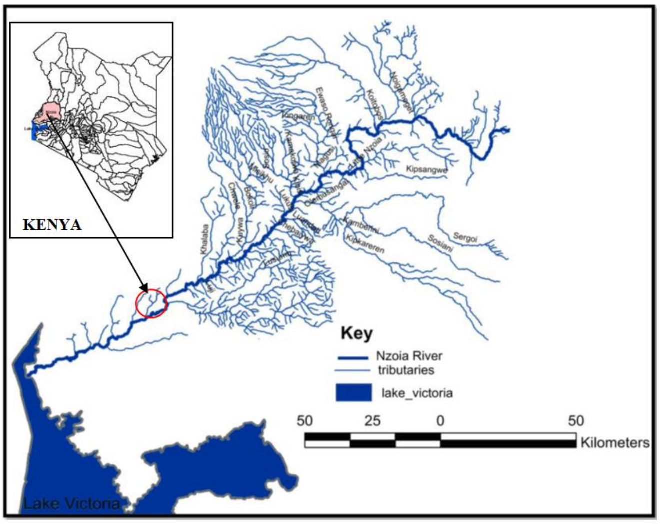

Figure. 1. Location of River Shimiche (circled) on River Nzoia in western Kenya.

Table 1. Geographical position of the 9 sampling stations on River Shimiche (1a – 3c).

Station code	Name	Position		Altitude (m a.s.l.)	Land use
		Latitude	Longitude		
1a	Upper stream	0°35´50´´N	34°38´46´´E	1300	Forest
1b	Upper stream	0°35´46´´N	34°38´46´´E	1298	Forest
1c	Upper stream	0°35´40´´N	34°38´46´´E	1298	Forest
2a	Middle stream	0°21´35´´N	34°28´46´´E	1298	Urban, sugarcane
2b	Middle stream	0°21´49´´N	34°28´46´´E	1280	Urban, sugarcane
2c	Shibale Bridge	0°21´26´´N	34°28´60´´E	1272	Urban, sugarcane
3a	Lower stream	0°21´11´´N	34°28´46´´E	1272	Mixed farming
3b	Lower stream	0°21´31´´N	34°28´64´´E	1270	Mixed farming
3c	Confluence with R. Nzoia	0°21´09´´N	34°28´46´´E	1270	Mixed farming

The environmental characteristics and human activities at each sampling station were considered and recorded, including type of vegetation and land use, river water use and other human activities, urban centers and other conditions that may influence water quality and quantity. The anthropogenic activities were determined directly by observation. Photographs were taken at each station as a record of the dominant economic land use. The study was conducted using purposive and experimental sampling design. Three land use practices were identified along the course of the river, i.e. from the source in the upper course; along the river before the bridge (Mumias-Bungoma road), and the confluence of River Shimiche with River Nzoia. The source of the river is dominated by forests; which give way to sugarcane plantations towards the Mumias-Bungoma road in the middle course. These are followed downstream by the urban Shibale residential estates of Mumias and settlements, two petrol stations (Magharibi and Total Petrol Stations) and a Nursing Home. The lower course of the river is characterized by mainly small-scale mixed farms with vegetable and maize cultivation, and grazing of livestock. There are also non-agricultural activities including sand harvesting and fishing.

B. Water Sampling

Water sampling was done once a month, on the first day of each month from January 2014 to August 2014. At each sampling station, water temperature, pH, total dissolved solids (TDS), electrical conductivity were measured *in-situ* using H12211 PH/ORP meter, and turbidity using a portable turbidity meter TN-100 Eutech instruments. Water samples were collected in triplicate just below the water surface using 1 Litre sampling bottles previously washed in dilute hydrochloric acid and thoroughly rinsed with distilled water. The bottles with samples were labelled and stored at 4 °C in a cooler box, transferred to a refrigerator in the laboratory and analyzed within 24 hours after collection, for total suspended solids (TSS) and concentration of *E. coli*.

TSS was analysed as outlined in APHA (1998). 100ml of the water sample was filtered through a pre-weighed GF/C filter paper of pore size 0.45µm. The filter paper and its contents was dried in an oven at 105 °C for 1 hour, and cooled in a desiccator for 1 hour. The filter paper and its contents were weighed again and TSS determined using the formula:

$$\mathrm{TSS(mgL^{-}1)} = \frac{(\text{Weight of filter paper + sediments}) - (\text{Weight of filter paper}) \times 10^6}{\text{volume of water sample filtered}}$$

Concentrations of *E. coli* were determined using membrane filtration method. 10 ml of water sample was passed through a membrane filter (pore size 0.45µm). The filter paper with residue was placed on an absorbent pad in a petri-dish saturated with MUG (4-MethylUmbelliferyl-D-Glucoronide) which produced a flurogenic product when hydrolyzed by the glucorinadase. The petri-dish and pad were incubated upside-down at 44.5 °C for 24 hours. After incubation, the colonies that had grown were identified and counted using a colony counter under a dissecting microscope (Leica Zoom Model 2000, Leica Microsystems Wetzar, Germany).

C. Data Analysis

All the statistical analyses were done using Statistical Analysis System (SAS), version 9.1. For every physico-chemical parameter at different stations, descriptive statistics including the mean, range, standard deviation and standard error were calculated at 95% confidence interval.

One-way analysis of variance (ANOVA) was calculated to test for any significant differences between the means of physico-chemical parameters at different stations on the basis of land use practices. Significant differences revealed in the means were separated using t-test in the differences of the least square difference (LSD) analysis.

Pearson correlation coefficient was performed to explore the relationships between different physico-chemical parameters and concentration of *E. coli*. Correlation analysis was used to determine the relationship between the various physico-chemical parameters and anthropogenic activities at different sampling stations.

III. RESULTS AND DISCUSSION

1. Physico-Chemical Parameters

Mean values of the physico-chemical parameters measured at the 9 sampling stations across the eight months and summarized for each land use are given in Table 2. All the six physico-chemical parameters and concentration of *E. coli* showed significant differences between the three land uses.

Generally, all the parameters measured showed increasing trends from the upstream forested areas to the middle stream with urban settlements and sugarcane plantations to the lower section with small-scale mixed farming. Lower temperatures with a mean of 21.08 °C were recorded upstream, they increased to 23.81 °C in the middle stream and to 24.71 °C in the lower stream. Values of pH followed a trend similar to that for temperature. A low pH of 6.44 occurred in the upstream and increased to 7.81 in the lower stream.

TDS, conductivity, turbidity and TSS (Fig. 2) were lower in the upstream, increased in the middle stream, and increased even further in the lower stream. Land use had significant impact on TSS (df=2; F=243.55); p=0.000). LSD analysis showed further that the means of Total suspended solids (TSS) within the three land uses were significantly different (p=0.000<0.05)

Table 2. Mean (±S.E) values for physico-chemical parameters and concentration of *E. coli* in the different land use areas along River Shimiche.

Physico-chemical parameter	N	Forest	Urban settlements and sugarcane plantations	Small-scale mixed farming	F-values *p*-values
Temperature (°C)	72	21.08±0.11	23.81±0.13	24.71±0.17	F = 185.581 P = 0.000
pH	72	6.44±0.02	7.46±0.1	7.81±0.01	F = 1850.695 P = 0.000
TDS (ppm)	72	25.92±0.64	42.42±0.43	48.81±0.65	F = 406.447 P = 0.000
Conductivity ($\mu S\ cm^{-1}$)	72	46.23±1.21	59.05±0.75	67.12±1.26	F = 92.7 P = 0.000
TSS ($mg\ l^{-1}$)	72	161.5±6.01	384.20±8.53	415.14±11.26	F = 243.55 P = 0.000
Turbidity (NTU)	72	187.54±5.18	266.33±2.5	366.37±2.95	F = 577.519 P = 0.000
E. coli concentration/100 ml	72	12.97±0.34	118.51±1.16	178.97±1.05	F = 8172.148, P = 0.000

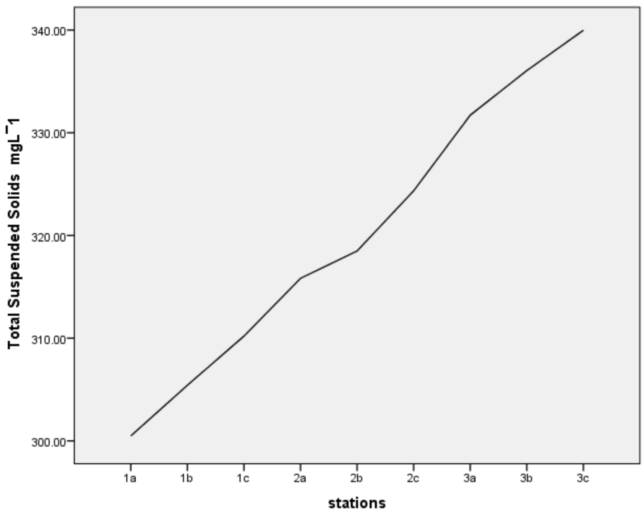

Figure 2. Trends in mean TSS in the sampling stations along River Shimiche.

Both TSS and turbidity indicate the amount of solids suspended in the water, whether mineral such as soil particles or organic such as algae. However, the TSS test measures an actual weight of material per volume of water, while turbidity measures the amount of light scattered from a sample (more suspended particles cause greater scattering). This difference becomes important when trying to calculate total quantities of material within or entering a stream. Such calculations are possible with TSS values but not with turbidity readings. High concentrations of particulate matter can cause increased sedimentation and siltation in a stream, which in turn can ruin important habitat areas for fish and other aquatic life. Suspended particles also provide attachment places for other pollutants, such as metals and bacteria. High values of suspended solids or turbidity readings thus can be useful indicators of other potential pollutants in a watershed.

The high TSS within the urban settlements/sugarcane plantations and mixed farming areas can be expected partly due to high amounts of water and run offs with suspended matter flowing into the river from the highly populated Mumias municipality and agricultural farms especially during rainstorms. This observation concurs with Ahearn *et al.*, (2005) who points out that large storms are needed to increase TSS in a water system.

Agricultural activities extending down to riverbanks within the small-scale mixed farming land use area, and destruction of riparian vegetation allow for accelerated deposition of materials into the water channel, raising TSS levels. These findings agree with Raburu and Okeyo (2010) who report that removal of riparian vegetation cover increases turbidity, and that TSS tend to be high in similar areas on River Nyando, Kenya. Shivoga *et al*. (2005) also observed that high levels of TSS occurred due to increased human population density and inappropriate agricultural practices leading to increased deposition of sediments in River Njoro, Kenya.

Landuse is probably the greatest factor influencing changes in TSS or turbidity in streams as shown by the results of this study. As the River Shimiche watershed develops downstream, perturbations (urbanization, human settlement agricultural activities and construction sites), increase, vegetation cover decreases and the amount and rate of runoff increases especially during heavy rains. These processes increase soil erosion, particulate matter, dissolved ions and nutrients, which in turn elevate the levels of TDS, conductivity, TSS and turbidity as the river flows downstream. Onyando *et al*. (2013) made similar observations and recorded an increase in levels of the nutrients nitrate-nitrogen and phosphate-phosphorus as the river flows downstream in River Isiukhu, also a tributary of River Nzoia, with similar watersheds.

High levels of particulate matter can cause increased sedimentation and siltation in a stream or river, which in turn can destroy important habitat areas for fish and other aquatic life. Suspended particles also provide attachment places for other pollutants, such as bacteria and heavy metals. Thus, high suspended solids or turbidity readings can be used as indicators of other potential pollutants in a watershed.

2. Relationships between physico-chemical parameters

Spearman rank order correlation between physicochemical parameters showed several significant positive and negative correlations (Table 3). Conductivity and TDS were strongly positively correlated with water pH (r=0.77 respectively). These three parameters depend on the concentration of ions in water. An increase in the concentration of hydroxyl ions in water (that raises the pH) increases conductivity. This explains the positive correlation between conductivity and pH. The hydroxyl ions and other ions that can conduct an electric current are formed from the dissolution of solids in water. This could explain the strong positive correlation between TDS and pH ($r=0.75$; $p<0.05$).

Increase in water temperature as the river flows downstream was probably because of warming of the land with reduction in vegetation cover and increased human activities results in warming of the water that may lead to decreased solubility of oxygen consequently lowering the amount of dissolved oxygen (DO). High temperature may also increase the rate of oxygen consuming processes such as respiration and bacterial metabolic activities leading to a decline in DO concentrations. Although DO was not measured in this study Shehata and Badr (2010) established that in River Nile, temperature was negatively correlated with DO.

3. Relationship between physico-chemical parameters and concentration of *E. coli*

The relationship between physico-chemical parameters and concentration of *E. coli* with respect to land use practices along River Shimiche is given in Tables 3 and 4. Significant correlations were observed between the concentration of *E. coli* and most of the environmental parameters, in the different land use areas, thereby supporting the observation that *E. coli* are good indicators of water quality status of River Shimiche. Overall, the concentration of *E. coli* reflected the least polluted water along the river to be the upstream station in the forest land use with relatively clean waters of low temperature, TDS, conductivity and turbidity, and low concentration of *E. coli* (Figs. 3 and 4). The middle stream stations had moderate levels of the measured environmental parameters as well as *E. coli*, while the downstream had high values of these parameters also indicating lower water quality.

Table 3: Results of Spearman's Rank Correlation between Concentration of *E. coli* and physico-chemical parameters in River Shimiche.

Area	Parameter	Statistics	Temp.	pH	TDS	Conduct.	TSS	Turbid.
Forest	*E. coli*	r	-0.333	0.256	-0.538	-0.307	0.063	-0.06
		s	0.005	0.03	0.00	0.009	0.598	0.619
Urban Sugarcane	*E. coli*	r	-0.118	-0.066	-0.082	-0.067	0.031	-0.081
		s	0.324	0.582	0.493	0.576	0.796	0.498
Mixed farming	*E. coli*	r	-0.491	0.197	-0.046	0.431	-0.298	-0369
		s	0.000	0.097	0.7	0.000	0.06	0.001

r = spearman rank correlation; s = probability value. s is the significance of the correlation (probability values) if $s < 0.05$ the correlation is significant.

Table 4. Correlations Statistics between concentration of *E. coli* and temperature along the land use gradient of River Shimiche ecosystem.

Area of Research			Temperature °C	Coliform No/100ml
Forest	Temperature °C	Pearson Correlation	1	.344**
		Sig. (2-Tailed)		.003
		N	72	72
	Coliform No/100ml	Pearson Correlation	.344**	1
		Sig. (2-Tailed)	.003	
		N	72	72
Urban Settlement	Temperature °C	Pearson Correlation	1	.551**
		Sig. (2-Tailed)		.000
		N	72	72
	Coliform No/100ml	Pearson Correlation	.551**	1
		Sig. (2-Tailed)	.000	
		N	72	72
Mixed Agricultural areas	Temperature °C	Pearson Correlation	1	.008
		Sig. (2-Tailed)		.949
		N	72	72
	Coliform No/100ml	Pearson Correlation	.008	1
		Sig. (2-Tailed)	.949	
		N	72	72

** Correlation is significant at the 0.01 level (2-Tailed).

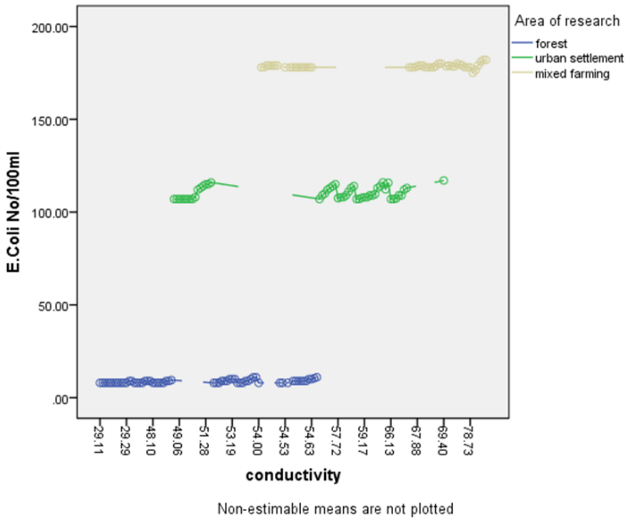

Figure 3. Values of concentration of *E. coli* against conductivity with respect to land use gradient along River Shimiche.

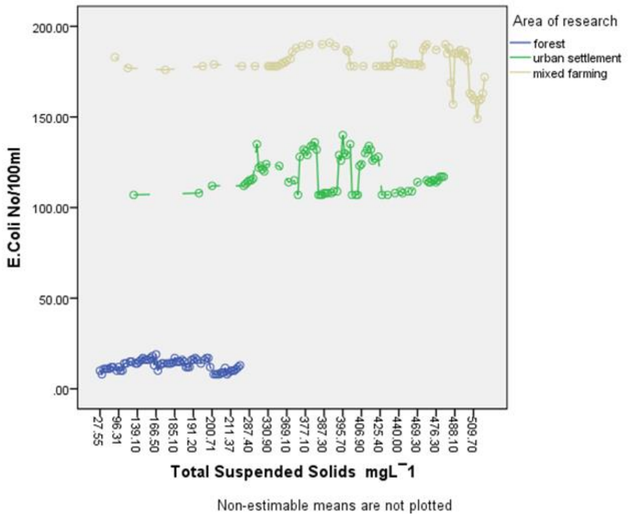

Figure 4. Values of concentration of *E. coli* against total suspended solids with respect to land use gradient along River Shimiche.

4. River water quality in relation to economic land use practices

Water quality is, basically, the physical, chemical and biological characteristics of water. Most frequently, it is used by reference to a set of standards against which compliance can be assessed, and as a measure of the condition of water relative to the requirements of one or more biotic species and/or human need or purpose. The most common standards used to assess water quality relate to drinking water and safety of ecosystems. Environmental water quality relates to water bodies such as streams, rivers, lakes and oceans.

Forest watersheds often yield high-quality water because of erosion protection provided by forest vegetation, the forest floor, and forest soils. However, forests are subject to human and natural disturbances that can cause major changes in water quality (Brookes, 1992). Shifts in the prevailing riparian vegetation for example, can change the physico-chemical and biological nature of streams and rivers (Townsend *et al.*, 1997).

Rivers drain water that fall in upland areas and as a consequence many landscape factors such as channel slope, vegetation on the banks and conditions of riparian zone can affect the water quality of the river. The water quality of many rivers and streams around the world has been lowered and polluted primarily by the three major sources of pollution (industry, agriculture and domestic) which are normally concentrated in the riparian areas. In addition to freshwater, rivers provide transportation routes and convenient place to discharge wastes. Agricultural activities, for example have tended to be concentrated near rivers, because river flood plains are exceptionally fertile from nutrients that are deposited in the adjacent soil when the river overflows (Tabacchi *et al.*, 1998). Furthermore, the characteristics of surface soil control water movement and retention and secondarily control the main water supply for riparian plants and animal communities. Therefore, analysis of land use and land cover and water quality should be conducted during storm seasons because the landscape has large influence on the watercourse. Streams surrounded by agricultural activities are greatly disturbed by human activities. This tends to modify the hydrology of lotic systems through a combination of alterations such as irrigation impoundments, which makes most of the large rivers of the world to be influenced greatly by human activities (Dynessius and Wilson, 1994).

Many human factors including wastewater effluents and non-point pollution greatly influence rivers. Eutrophication occurs in large rivers because the large rivers integrate various substances from large land areas. Many major cities are located on large rivers making their watershed a home of large human populations. The increase in human activities results in increase dissolved ions concentrations and suspended materials in water. This makes rivers to be more susceptible to high turbidity than small streams in the basin as also observed by Shivoga *et al.,* (2005) in the watershed of River Njoro, Kenya, where the water resources were degraded due to high population growth and change in land use upsetting environmental stability. According to Shivoga *et al.* (2005), a decrease of about 20% of forested areas occurred between 1986 and 2003 with forests and large-scale farms being converted to small-scale mixed farms and human settlements affecting negatively on the ecological integrity and hydrologic processes in the river.

Land use had significant effects on riparian soil properties in the watershed of River Njoro such that phosphorus of the surface and sub-surface soils in riparian buffers generally increased with more intensive land use in the adjacent areas (Enanga *et al*., 2010). The commercial agriculture buffers had significantly more phosphorus in their soils than the buffer soils in the reference condition, peri-urban and recent settlements land use types. The mid-stream portion of the river with industrial, human settlement and agricultural land uses accounted for the highest cover and lower phosphorus loss from the sub-watershed (Shivoga *et al.,* 2005). Nutrient levels decreased significantly downstream indicating natural purification as the river flows through an area of large-scale farming with dense riparian vegetation. Small-scale farms and bare lands contributed over 55% nutrients load into the river. Increased erosion, nutrient and sediment loadings, human and animal pollution, along with damage to the integrity of the riparian corridor and changes in the hydrologic regime of the river have been observed in many rivers systems.

Toxic substances and high population of certain micro-organisms can present a health hazard in water even for non-drinking purposes such as irrigation, swimming and fishing. Such conditions may also affect wildlife which uses the water for drinking or as a habitat as reported by Maier *et al*. (2001) for Murray-Darling River systems in Australia. Andrea *et al.,* (2009) reported that in order to achieve the water quality objective by European Water Framework Directive, there is need to combine limitation of pollution sources and quality standards in the receiving natural water bodies. Proper management of the catchments of the rivers and streams can be achieved through such approaches. The shading effect of riparian vegetation for example, is stimulated by reduction of the light intensity reaching the stream, which directly affects the algal growth and influences water temperature through a heat balance model. Therefore, restriction of riparian buffers is an example of watercourse management practices that can be used to control water quality of streams.

Enanga *et al*. (2010) stated that several spatial and temporal patterns observed in stream water chemistry in most catchments are controlled by land use history and hydrology, which also control the storage and transportation of constituents. Concentration of nitrogen, alkalinity and TDS are more sensitive to agricultural land use during summer and underlying geology during autumn (Maier *et al*., 2001). Similarly, Raburu *et al*. (2010) reports that in River Nyando which drains an area of vast and varied land use activities ranging from forested upper reaches to the urban-industrial middle and low reaches results in high amounts of nutrients and suspended solids occurring in the river. Raburu *et al*., (2010) attributed this to high effluent loads, both domestic and industrial, entering the river and high inputs of phosphorus and nitrogenous fertilizers used in agricultural farms in the catchment.

The physico-chemical quality of water bodies and its relationship with land use in Costilla La Mancha, Spain, revealed that agricultural fertilizer runoff and urban wastewater discharge are major contributors to river contamination (Tabacchi *et al.,* 1998). Use of mixture of new techniques and social organization gives a balanced attention to improving resource management and farmers livelihoods. However, Osbourne and Wiley (1998) found that urban land use influenced concentrations of soluble reactive phosphorus in an East Illinois watershed while agriculture was only a secondary predictor of Nitrogen and phosphorus. Osbourne and Wiley, (1998) noted that medium nitrate concentrations correlated with agricultural practices during high flow spring periods and correlated with urban land cover during low-flow in summer and autumn.

5. Some aspects of water quality

Water quality encompasses the physical, chemical, and biological character of water. Common parameters used to assess water quality include pH, dissolved solids, suspended sediment, turbidity, dissolved oxygen, water temperature, and key nutrients. Some of the parameters that are basic to life in aquatic ecosystems and which when impaired can cause impacts to the flora and or fauna in a given water body are discussed below.

6. Biodegradable Organic Substances (BOS)

Human and animal wastes as well as effluents from industrial processing plants or animal products contain a mixture of complex organic substances such as carbohydrates, proteins and fats as their major pollution load (Danida, 1998). These substances are readily biodegradable and when introduced into the environments are decomposed quickly through the action of natural microbial populations. Some of the organic matter is oxidized to carbon dioxide and water while the rest is assimilated and used for the synthesis of new microbial cells. In due course, these organisms die and become food for other decomposers. Eventually, virtually all the organic carbon is oxidized (Lamb, 1985).

When a biodegradable organic waste is discharged into an aquatic ecosystem such as a stream, estuary or lake, oxygen dissolved in the water is consumed due to the respiration of microorganisms that oxidize the organic matter (Danida, 1998). The more biodegradable a waste is, the more rapid the rate of its oxidation and the corresponding consumption of oxygen. Because of this relationship and its significance to water quality (dissolved oxygen levels in the water), the organic content of waste waters is usually measured in terms of the amount of oxygen consumed during its oxidation, termed the Biochemical Oxygen Demand (BOD).

High numbers of species of organisms are supported in an aquatic ecosystem when the dissolved oxygen (DO) concentration is high. Oxygen depletion due to organic waste discharge has the effect of increasing the numbers of decomposer organisms at the expense of others. When oxygen demand of a waste is so high as to eliminate all or most of the dissolved oxygen from a stretch of a water body, organic matter degradation occurs through the activities of anaerobic organisms, which do not require oxygen (Meertens *et al*., 1995). The water then become devoid of aerobic organisms, and anaerobic decomposition becomes prominent and results in the formation of a variety of foul smelling volatile organic acids and gases such as hydrogen sulphide, methane and mercaptans (certain organic sulphur compounds). The stench from these can be quite unpleasant and is frequently the main cause of complaints from residents in the vicinity.

Chemical Oxygen Demand (COD) is the measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. It does not differentiate between biologically available and inert organic matter. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements usually take five days (BOD_5).

7. Soil pH

pH is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration (UNESCO, WHO &UNEP, 1996). In waters with high algal concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis, whereas, pH drops during the night when the algae respire and produce carbon dioxide. According to Salequzzaman *et al.* (2008), pH changes can tip the ecological balance of the aquatic system and excessive acidity can result in the release of hydrogen sulphide. The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to aquatic organisms is affected. According to Mosley *et al.* (2004), water with a pH >8.5 indicates that the water is alkaline. Most metals become more water soluble and more toxic with increase in acidity. Toxicity of cyanides and sulphides also increase with a decrease in pH (increase in acidity), while the content of toxic forms of ammonia to the non-toxic form also depend on pH dynamics.

The concentration of carbon (iv) oxide; can be augmented into a water body from a variety of sources such as respiratory activities by aquatic organisms, release from bacteria in the water and atmospheric carbon (iv) oxide. The dissolved carbon (iv) oxide forms a weak carbonic acid which then lowers the pH of the water. According to USEPA (2006), the pH levels of drinking water should range between 6.5 and 8.5 and that waters to be used for domestic water supply should have pH values between 5.0 and 9.0. Extreme pH values greater than 9.5 or less than 4.5 are unsuitable for most aquatic organisms, for example, high pH levels (9-14) can harm fish by distorting the cellular membranes and eventually killing the fish. At very low pH levels below 5, the larval stages of aquatic insects may die. The values of pH recorded in River Shimiche in the present study ranged between 6.44 and 7.81, which are within the values suitable for aquatic organisms.

8. Total Solids (TS) and Total Dissolved Solids (TSS)

The term "Total solids" refers to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total solids (also referred to as total residue) are the term used for material left in a container after evaporation and drying of a water sample. Total Solids includes both total suspended solids, the portion of total solids retained by a filter (0.45 µm pore size) and total dissolved solids, the portion that passes through a filter (APHA, 1998).

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually 0.45-µm pore size) and is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because when the concentrations are very high, the growth of many aquatic lives can be limited, and death can occur. Similar to TSS, high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature.

TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect. The main factors influencing levels of TDS include geology and soil in the watershed, urban runoff, agricultural and fertilizer runoff, wastewater and septic system effluents, soil erosion, and decaying plants and animals as discussed below.

Some rock and soil release ions very easily when water flows over them; for example, if acidic water flows over rocks containing calcite ($CaCO_3$), such as calcareous shales, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve into the water. Therefore, TDS will increase. However, some rocks, such as quartz-rich granite, are very resistant to dissolution, and do not dissolve easily when water flows over them. TDS of waters draining areas where the geology only consists of granite or other resistant rocks will be low (unless other factors are involved).

During storm events, pollutants such as salts from streets, fertilizers from lawns, and other material can be washed into streams and rivers. Because of the large amount of pavement in urban areas, natural settling areas have been removed, and dissolved solids are carried through storm drains to creeks and rivers. Fertilizers can dissolve in storm water and be carried to surface water during storms, and contribute to TDS.

Wastewater from houses contains both suspended and dissolved solids that are released down the drains. Most of the suspended solids are removed from the water at the wastewater treatment plants before being discharged into streams, but wastewater treatment plants only remove some of the TDS. Important components of the TDS load from these wastewater treatment plants include phosphorus, nitrogen, and organic matter. Therefore, the effluents from wastewater treatment plants contribute dissolved solids to streams.

Soil erosion occurs due to disturbance of land surfaces from activities such as farm cultivation, building and road construction, forest fires, logging, and mining. The eroded soil particles may contain soluble components that can dissolve and be carried by storm water to surface water. This will increase the TDS of the water body. When plants and animals decompose or decay, dissolved organic matter is released and can contribute to the TDS concentration in the receiving water body.

9. Tot`al Suspended Solids (TSS)

Total suspended solids (TSS) are solids in water that can be trapped by a filter of pore size 0.45µm. TSS includes a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life. High TSS, for example, can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down, the reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling and submerged plants, the plants will stop producing oxygen and will die. As the plants decompose, bacteria will use up even more oxygen from the water, and the resulting low dissolved oxygen can lead to fish kills and death of other aquatic organisms. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warm water can hold less DO), and can harm aquatic life in many other ways (Mitchell and Stapp, 2008), as already observed with temperature.

Decrease in water clarity caused by TSS can affect the ability of fish to see and find food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks, which are normally used as habitats by aquatic organisms (Mitchell and Stapp, 2008).

High TSS in a water body often associated with high concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. In the water, the pollutants may be released from the sediment or travel farther downstream (USEPA, 2006). Furthermore, high TSS can cause problems in water for industrial use, because the solids in it can clog or scour pipes and machinery.

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, there are spatial variations in physico-chemical parameters from upstream to downstream in River Shimiche watershed, corresponding with changes in riparian land uses. Within the watershed, forest and sugarcane plantations, land uses showed lower values of all the physico-chemical conditions (temperature, pH, TDS, electrical conductivity, turbidity and TSS) measured, while peri-urban and mixed agricultural land use zones had high values of these physico-chemical parameters.

Low concentrations of *E. coli* upstream indicate that the upper part of River Shimiche traversing through the forest is less polluted but the sections of the river downstream are increasingly contaminated and show the risk of being heavily polluted if remedial actions are not taken to mitigate the current trends. Rainfall and its associated storm water runoff increase the transportation of many pollutants into the river including faecal material from a variety of animals (humans, pets, livestock, and wildlife), that may be washed into the river leading to microbial contamination of the river water.

This study recommends that River Shimiche ecosystem needs further investigation with regard to impacts of rainfall and runoff on concentrations of *E. coli* in the river water. Detailed examinations are also needed to determine influences of land use and other human activities on the ecological water quality status. All the stakeholders need to embrace environment friendly industrial, agricultural practices and production technologies to ensure pollution prevention measures to minimize the volume and pollution loading in the runoff and wastewaters before discharges into River Shimiche.

V. ACKNOWLEDGEMENTS

Mumias Sugar Company (MSC) facilitated the collection of samples and data in the field and experimental analysis of this study. The authors would like to thank Jackson Cheruiyot and Phitalis Were Masakhwe of (Masinde Muliro University of Science and Technology) for their initial advice and encouragement, and technical assistance by Peter Nyongesa, Mulati Omukoba and Steven Ogalo.

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