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IS THE SOSIANI RIVER HEALTHY? INVESTIGATING THE RELATIONSHIP BETWEEN WATER QUALITY INDICATORS AND MACROINVERTEBRATE ASSEMBLAGES IN THE SOSIANI RIVER

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ABSTRACT

The health of rivers is of great concern to governments and communities worldwide due to their important ecological functions. Numerous studies have established that water quality indicators have a positive effect on river health. However, only a few studies have examined equatorial rivers, and, to date, there has been no study on the Sosiani River in Kenya. As such, this study explored the health of the Sosiani River by considering how its aquatic macroinvertebrate assemblages were affected by various water quality parameters. The research considered whether there was a relationship between water quality indicators and macroinvertebrate assemblages in the Sosiani River. This knowledge is of paramount importance to the communities and decision makers of the Sosiani catchment, and Kenya as a whole, since there is need to understand the relationship between the water quality indicators and the health of the river in order to allocate resources for its rehabilitation and maintenance. This study examined 10 sites, nine being "test" sites and one a "reference" site. The study established a significant relationship between water quality parameters and macroinvertebrate assemblages. The sites with natural riparian zone vegetation conditions were found to have more Ephemeroptera, Plecoptera, and Trichoptera macroinvertebrates when compared to those without or with exotic vegetation. In terms of absolute numbers of surface aquatic macroinvertebrates, sites characterised by dense stream bank vegetation had more macroinvertebrates than those characterised by forest with eroded, bare stream banks. From the study, it was therefore concluded that Sosiani River is healthier at head waters where there was natural forests compared to downstream where there was plantations, intensive farming and urban area. The study recommends that more detailed studies classify macroinvertebrates to gunus level and include microinvertebrates, since this may give a more accurate assessment of the river's health. The study further recommends that identification keys for East African macroinvertebrates be developed.

Keywords: River health, Macroinvertebrates, Water quality indicators, Sosiani river.

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Contribution/ Originality

This study contributes in the existing literature by establishing the relationship between the condition of riparian zone vegetation and indicators of river health in the equatorial region. Much of the literature in this field is based on studies from outside of the equatorial region.

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1. INTRODUCTION

The health of river systems has become a global concern, some of the reasons for which are as follows: the extinction of some aquatic species as a result of deteriorating water quality (Growns *et al*., 2013; Xu and Liu, 2014); reduced ecological benefits from both aquatic and riparian communities (Leigh *et al*., 2013) an invasion of exotic aquatic species (Madin, 2012; Sheldon *et al*., 2012) and less attention given to the conservation of aquatic ecosystems due to a lack of knowledge on howriver health relates to aquatic communities (Zhao *et al*., 2013) especially in equatorial regions.

River health has been widely studied (Giller *et al*., 2004; Hough, 2014) as complex components of aquatic ecosystems (Jonsson *et al*., 2002; Giller *et al*., 2004). However, there are scant studies that have particularly focused on equatorial rivers. These few studies tend to concentrate on the relationship between land use and the health of rivers (Masese *et al*., 2009) and, more specifically, on the effect of non-point pollution on macroinvertebrate assemblages (Kibichii *et al*., 2007; Kasangaki *et al*., 2008). There is no much information on how water quality condition affect the health of equatorial rivers.

In Kenya, the health or rivers had been deteriorating in terms of supporting its aquatic ecosystems. Over the same period, the Kenyan government continued to allocate resources to the water development sector without devoting much attention to resource protection (Government of Kenya, 2007). This has resulted in rivers (among other fresh water resources) deteriorating in both water quality and quantity (GOK, 2007). The deterioration of the river system is mostly due to human-induced forces upon the aquatic ecosystem (Narangarvuu *et al*., 2014). Recognizing the considerable human footprint on its watersheds, the government of Kenya developed a policy document in 1999, titled National Water Resources Management and Development (NWRMD), to address issues relating to the conservation of its water resources. This document sets out a comprehensive framework for managing Kenya's water resources, which includes the involvement of communities and other stakeholders so that the long-term sustainability of water development projects is assured (GOK, 2007). It was through this legal framework that some sections of the riparian zone vegetation along the Sosiani River in Kenya had been rehabilitated so as to improve its health. This study investigated the health of the Sosiani River using water quality indicators. This was accomplished by investigating the relationship between water quality indicators and macroinvertebrate assemblages in the Sosiani River. The knowledge of this relationship is of particular importance to the educational community since much of the literature in this area is based on studies from outside of the equatorial region. The policy makers and water resource managers could also benefit from this study by gaining knowledge on the relationship that exists between riparian zone vegetation and the health of rivers. This knowledge will facilitate the allocation of resources commensurate with the environmental services provided by healthy rivers.

The term "health" is normally used to present the biological functionality of living organisms, but in the current research, it has been extended to describe the response of river ecosystems towards human disturbances that make them less efficient in supporting life (Rapport *et al*., 1998). In terms of its ecosystem, a healthy river is one that is similar to non-impacted rivers or streams of the same type (Schofield and Davies, 1996; Rapport *et al*., 1998). In other words, the health of rivers should consider the importance that human beings attach to them through the services they provide (Boulton, 1999). Among the diverse impacts that can affect river health are loss of riparian vegetation, effluent discharge, flow controls, excessive water extraction (Poff *et al*., 1997; Richter *et al*., 1997; Puckridge *et al*., 1998; Hart and Finelli, 1999) sediment loading, nutrient loading, and pesticides (Schofield and Davies, 1996). Unsurprisingly, it is often difficult to find natural, non-impacted rivers or fully healthy rivers in many parts of the world (Jungwirth *et al*., 2002).

The diverse range of taxa grouped under the general term "macroinvertebrates" have consequently varied responses to changes in water quality. Some macroinvertebrate groups, such as *Odonata* and some *Tricoptera*, are generally intolerant to pollution, while others, such as *Diptera Chironomidae* and *Oligochaeta Tubificidae*, are not sensitive to pollution, which allows them to inhabit different water quality environments (Canobbio *et al*., 2009). A high concentration of organic matter and nutrients strongly influences the ecological health of streams since they act as substrates for micro-organisms when released to stream water. As the organic matter and nutrients decompose, dissolved oxygen in the water is used up at a greater rate than it can be replenished through other processes, causing oxygen deficiency (Greenway, 2006) which has severe consequences for the stream biota. Large quantities of organic matter may also reduce the light available to photosynthetic organisms and, on settling out, alter the characteristics of the river bed, rendering it an unsuitable habitat for many invertebrates. Apart from runoff, the changes in river flow have an impact on the concentration of nutrients in rivers (Lake, 2003). However, Boyle and Fraleigh (2003) point out that there are several variables other than physical parameters that determine the development and survival of macroinvertebrates. For example, many taxa decrease in number with the presence of pollutant effluent in a stream or any other water body. This indicates that river health should not be determined by water quality indicators alone but together with habitat composition indicators. In the Sosiani catchment, it was not easy to find sites that can be classified as being a reference condition, except for minor pockets found on private land parcels. The upper catchment has forests exotic trees, the middle parts has many canalized river channels and the lower catchment, has large- and small-scale farmers and flower farmers

2. METHODS

2.1. Study Area

The Sosiani catchment lies on the equator at latitude 00˚ 18' 00" N, 00˚ 37' 00" N and longitude 35˚ 00' 00" E, 35˚ 35' 00" E. The Sosiani River contributes about 30% of the volume of water entering the Nzoia River (Water-Resource-Management-Authority-(WRMA), 2014) which then together drain into Africa's largest fresh water lake, Lake Victoria. Temperature in the catchment range from 11 ˚C to 16 ˚C, while rainfall ranges between 1200mm and 1800mm.

The Sosiani River catchment is highly modified by human activities. One of the major human disturbances for the aquatic ecosystems in this catchment is agriculture, which occurs in both small and large scale. The middle parts of the catchment is characterised by having Eldoret Municipal Town. These land use characteristics have an effect of increasing runoff and leaching of the nutrients. Leaching and coliforms from manure, which are discharged through runoff, affect stream health (Fellows *et al*., 2006). Crops grown in the Sosiani sub-catchment, such as maize, beans, wheat, horticultural crops and flowers, all utilize manure and chemicals, such as fertilizers, pesticides and herbicides (WRMA, 2013). Some parts of the Sosiani River riparian zones have been stripped of vegetation (WRMA, 2013) in favour of horticultural crops, reducing the ability to buffer the stream.

2.2. Sampling Sites

Ten sites were identified in the Sosiani River basin that encompass a range of land use and were spatially separated to cover as much of the catchment as possible (Figure 5). Of these 10 sites, one (SR1) was a "control" or "reference" site as it had near natural vegetation conditions than the others, and the other nine (SR2–SR10) were considered "test" or "study" sites, since they all had some degree of land degradation. The sampling of these 10 sites was carried out between January and February 2014. January was still relatively wet, as the river flows were subsiding from the December 2013 rain, while February was drier.

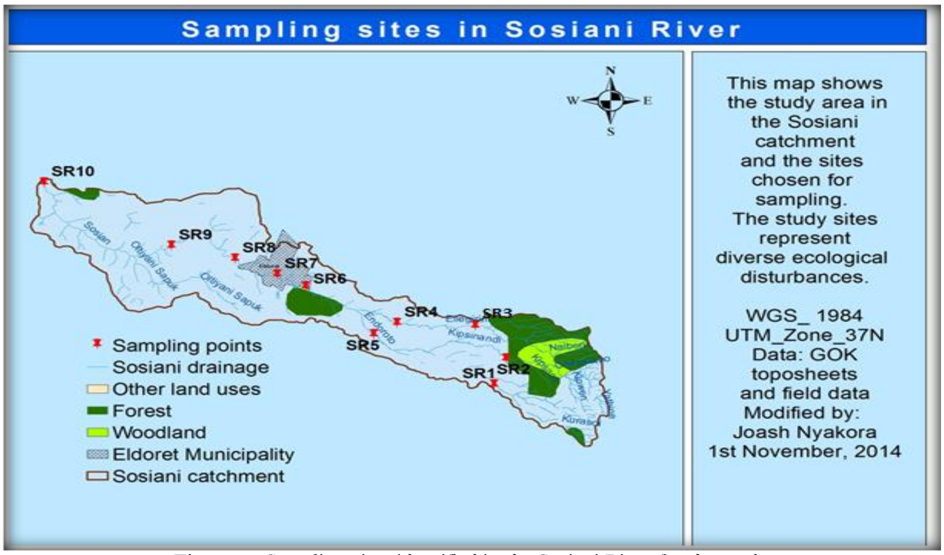

Figure-1. Sampling sites identified in the Sosiani River for the study.
Source: Field data

2.3. Land Use Classification

To further characterise the 10 sites, each one was assigned to the land use type most prominent near the sampling zone. The Kenyan Land Use and Management Classification developed by the Japanese International Corporation Agency (JICA) during their preparation of the Water Master Plan Kenya 2030 (GOK, 2013) was applied to give five classes of land use dependent on the dominant activities and their potential impact on river health. Land use with minimal human intervention to the environment within a radius of 50 m was allocated a score of 5, while the one most impacted was allocated with a 1 (Table 3). The five classes of land are detailed below.

2.3.1. Forest

Land used primarily for conservation purposes or land uses. Minimal impact is experienced, since the focus is on maintaining the essentially natural ecosystems present.

2.3.2. Municipality

Land within the municipality but rehabilitated through planting indigenous riparian vegetation and no channelization. However, there may be limited change from native vegetation due to recreational functions.

2.3.3. Plantation

Land used mainly for primary production, based on rain-fed land farming systems. Plantations practice monoculture and are mechanised, which leads to leaving a small riparian vegetation zone along the rivers.

2.3.4. Grazing

Land used by pastoralists for animal grazing. Native vegetation has been extensively destroyed, leading to observable erosion gullies. Animals drink water directly from the river, which impacts the quality of the water.

2.3.5. Intensive Farming

Land used for mixed farming by peasant farmers. Land parcels are too small for families, which often leads to the clearance of riparian zones for food production. Fertilizers are intensively used to increase production but soil erosion structures are absent and thus the majority of it ends up in the river during rainy periods.

Table-1. Sites' classification according to land use.

Site	Land use
SR1	Grazing
SR2	Forest
SR3	Forest
SR4	Plantation
SR5	Plantation
SR6	Municipality
SR7	Municipality
SR8	Municipality
SR9	Intensive farming
SR10	Intensive farming

Source: Field data

2.3.6. Field Sampling of Water Quality Parameters

To sample water in both the laboratory and field analyses, standard methods were applied for glassware preparation. The container for sampling water for conductivity, total solids, turbidity, pH, and total alkalinity tests were washed with a brush and phosphate-free detergent and rinsed in cold water three times in the laboratory, and rinsed three times with distilled water in the field. The containers and glassware for sampling nitrates, nitrites and phosphates were first equally washed with a brush and phosphate-free detergent in the laboratory, rinsed three times with cold water, rinsed again with 10% hydrochloric acid and finally rinsed three times with deionized water in the field. The samples were kept in a portable cooler with cold packs and transported to the water resources laboratory, where they were stored in the refrigerator until analyzed.

2.3.7. Field Measurements

Field measurements of conductivity, dissolved oxygen (DO), total dissolved solids acidity/alkalinity (pH), temperature, salinity and total suspended solids were undertaken using a DO Cyber scan PD 300 meter for DO, a Turbid meter Hach 2100P for turbidity and a Cyber Scan 650 for pH. Each field parameter was measured three times and the average was recorded as the measurement value. To ensure measurements were accurate, a sampling point was used within 10 m upstream of the macroinvertebrate sampling point where there was a good mixing of water either in the run or fall. In all cases, close distance to the river bank was avoided, especially where there was stagnant water. Where a stream was deep enough, the depth of the water sampling was at 20 cm, while shallow sections of the stream water samples were taken at the surface. Water velocity at each site was measured by dividing the stream channel cross section into numerous vertical subsections. In each subsection, the area was obtained by measuring the width and depth of the subsection, and the water velocity was determined using an OTT current meter.

2.3.8. Laboratory Methods

In the laboratory, velocity readings were converted into discharge by multiplying the subsection area by the measured velocity. The total discharge was then computed by summing the discharge of each subsection. Analysis of these samples for nitrates, nitrites, phosphorous and sediment was carried out at the Water Resources Management Authority (WRMA) laboratory in Kenya using the standard method (APHA, 1998) which requires phosphates to be carried out by Gas Chromatography GC-ECD/NFD. Nitrates were analyzed using a visible spectrophotometer (Pharmacia Biotech – model Nova spec II) while nitrites were analyzed using a Shimadzu 1700 UV-visible Spectrophotometer.

2.3.9. Macroinvertebrate Sampling

Three samples, representing riffle, pool and run, were taken from each site, making a total of 60 samples. The aquatic surface macroinvertebrates were sampled using a standardized 250μm mesh dip net. The sampling distance was about 10 m, which included different velocities of water and various habitats. The time taken for each sampling was 60 seconds so as to ensure a representative sample. In the field, collected samples were washed through a 1 mm sieve to remove the soils for easy picking of the specimens. The sorting was undertaken according to the AusRivAs protocols for live picking of specimens and then preserved in a 70% methanol solution, in labeled plastic screw-top jars, for export to Griffith University's environmental laboratories (Australia). This was in accordance with AusRivAS protocol (Australian Government, 2001) which allows either field or laboratory picking of specimens. To avoid the errors identified by Metzeling *et al.* (2003) whereby inexperienced researchers ignore small and cryptic taxa, the research assistants, who were WRMA staff members, were inducted in-house before engaging in the fieldwork. The sorting out of the macroinvertebrates was carried out in Griffith University environmental laboratory by the researcher. Macroinvertebrates were identified according to Australian Government (2001) procedure. This method was preferred as it reduced the weight of samples to be exported.

In the laboratory at Griffith University, Australia, samples were displayed on a sorting tray and sorted under a dissecting microscope, and further preserved in bottles containing 70% methylated spirit. Identification to family level was done under a stereo dissecting microscope using standard published keys (Cooperative Research Centre for Freshwater Ecology Identification guides, Australia) (Gooderham and Tsyrlin, 2002) and in-house taxonomic identification keys (Watts, 1998) and guides (Dean, 2011) and the abundance of each taxon was recorded. As there are no specific keys for the macroinvertebrates of Eastern African Rivers, the family level keys available in Australia were used; where these identification keys were insufficient, experts were consulted. Identification to order and family level was adequate for such a general study (Chessman, 2003; Marchal, 2005) since this level of identification differs only slightly from species and genus level assessments, and is sufficient to distinguish different levels of impacts (O'Leary *et al.*, 2004; Heino and Soininen, 2007). Furthermore, family level identification of macroinvertebrates for river health studies has been employed elsewhere (Bunn *et al.*, 2010).

4. ANALYSIS

To explore the general patterns along the gradient of land use disturbance and whether macroinvertebrate indicators could explain any of the environmental disturbance variations, the average conditions for two sampling dates were used. Averaging the variables removes pseudoreplication (Beketov *et al.*, 2009) for those parameters recorded both in January and February (macroinvertebrate assemblages and physical parameters) and provides for a better overall assessment of river health. Furthermore, averaging across a number of sampling times to understand background river health has been employed in other studies (Bunn *et al.*, 2010).

After the general patterns were explored using averaged variables, each month was then analyzed separately to explore if the same patterns existed in wetter (January) and drier (February) months. The sampling for the month of January was carried out on 11 January, which was two weeks after the last rains. The sampling for the month of February was carried out on 7 February, which was about seven weeks since it had last rained.

The emerging patterns for environmental drivers were explored using statistics procedures in both SPSS v22 and PRIMER v6 (Clarke and Gorley, 2006). This was accomplished through reducing the dimensions of these drivers by using Principal Component Analysis (PCA). PCA identifies two directions (PC1 and PC2) along which the data have the largest spread and explain the most variation in the original data (Ringnér, 2008) and the distribution of the samples is then displayed in either two or three dimensions. The two dimensions used ensured that the PC1 axis maximizes the variance of the points projected orthogonally onto it, while the PC2 axis was constrained to be orthogonal to PC1 and chosen as the direction in which the variance of points projected perpendicularly onto it is maximized (Clarke and Gorley, 2006). However, before the environmental raw data were used to calculate difference measures, it was square-root transformed and then standardized using the following range standardization: $X = \frac{Xi - Min.}{Range}$, Where X is standardized value; *xi* is the original value; *Min.* is the minimum sample value for the parameter; and *Range* is the difference between the maximum and minimum parameter values in the sample. The standardized data were used to generate a distance matrix, which generated a cluster analysis. This was found to be a better method of transforming the data before the application of Euclidean distance similarity, since it down-weighted the importance of highly variable parameters such that the similarity is also accounted for by the less-variable parameters (Clarke and Gorley, 2006). The Euclidean distance matrix was also used to undertake a "randomization" test whereby a one-way Analysis of Similarity (ANOSIM) was used to test for variations between the sampling sites in terms of environmental variables and measured riparian zone condition.

Since the flow conditions may influence patterns of macroinvertebrate assemblages, the same macroinvertebrate indicators used in averaged data were then explored separately for January (the wetter month) and February (the drier month).

4.1. Emerging Patterns in Environmental Drivers

To characterise the water quality of the aquatic environment, the following 12 parameters were used: dissolved oxygen (DO), pH, total phosphates (TP), total suspended solids (TSS), Temperature (Temp), conductivity (Cond), nitrates, nitrites, sediment load, and water quantity (Q). These are represented in Table 2.

During the study months of January and February 2014, the pH values in the samples were found to be relatively constant and sat within the neutral range (mean = 7.419±0.187) (Table 2). The month of February had a lower discharge compared to January (Table 5). TP was found to fluctuate between 0.03 mg/L (SR3) and 0.22 mg/L (SR8) in January and between 0.021mg/L (SR3) and 0.558 mg/L (SR2) for the month of February (Table 5); however, the mean phosphate for the river was 0.115±0.013 mg/L (Table 6). It is worth nothing that in the month of January, SR2 and SR3 had the same value for TP (0.03 mg/L) and these sites are both found in forested land, but one in indigenous (SR3) and the other (SR2) in exotic. Conductivity, TDS and salinity had the highest SE of ±4.48, ±16.66 and ±4.1 respectively across the sites and months (Table 2), which may be a good range to cause aquatic ecosystem variation (Kilonzo *et al.*, 2014). The river stretch had minimal nitrates in the month of January (< 0.02mg/L) compared to the month of February (ranging between 0.1 and 4.3 mg/L) (Table 2). In contrast to nitrates, nitrites had higher values in the month of January (ranging between 0.719 and 1.847 mg/L) compared to the month of February (< 0.4mg/L) (Table 2). The sites found immediately after the Eldoret municipality (SR8, SR9 and SR10) had the highest concentrations of nitrates especially in February (1.4, 4.3 and 3 mg/L respectively), while sites located before the town had low values. TSS showed a mixed pattern for both January and February; however, the values ranged between 3±2.3 mg/L and 20±2.3 mg/L (Table 2). Like other parameters, sediment loading varied greatly in January, from 0.27 tonnes/day at SR1 to 3.77 tonnes/day at SR6, and in February from 0.043 tonnes/day at SR1 to 2.692 tonnes/day at SR10. Generally, higher concentrations were found in the month of January when discharge was high, compared to drier February samples.

Table-2. Mean summary of water quality parameters of the 10 sites tested in the Sosiani River for the months of January and February 2014.

Site	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10
Dissolved oxygen (mg/L)	8.05±0.35	8.33±0.18	8.33±0.06	7.61±0.09	8.38±0.4	7.93±0.56	7.24±0.56	6.68±0.62	5.62±0	7.5±0
Temperature (0 c)	15.3±1.2	15.8±1.3	15.15±0.55	17.15±0.35	17.05±0.85	19.75±0.75	19.65±0.75	21.25±0.35	19.6±0	18.3±0
pH	7.32±0.07	7.38±0.04	7.37±0.19	7.43±0.17	7.5±0.08	7.63±0.14	7.53±0.06	7.27±0.14	7.09±0	7.65±0
Conductivity (µs/cm)	39.2±6.95	28.61±5	24.01±4.53	30.38±7.5	39.52±8.5	38.22±6.18	46.29±4.98	69.44±14.64	83.02±0	79.4±0
Total Dissolved Solids (mg/L)	27.3±2.47	20.4±2.3	17.24±0.61	21.31±2.45	27.21±3.1	29.08±3.24	36.22±3.44	56.17±14.5	63.64±0	63.25±0
Salinity	39.64±6.33	30.1±4	26.9±3	30.97±4.97	38.83±6.5	38.27±4.96	45.22±4.55	65±13.19	76.12±0	72.94±0
Nitrates (mg/L)	0.21±0.19	0.1±0.1	0.05±0.05	0.05±0.05	0.26±0.24	0.15±0.15	0.15±0.15	0.7±0.7	4.3±0	3±0
Nitrites (mg/L)	0.44±0.44	0.44±0.42	0.37±0.36	0.37±0.35	0.63±0.6	0.58±0.56	0.57±0.49	1.014±0.83	0.37±0	0.13±0
Total Phosphates (mg/L)	0.03±0.01	0.29±0.26	0.02±0	0.04±0	0.03±0.01	0.05±0.01	0.04±0	0.15±0.07	0.499±0	0.24±0
Total Suspended Solids(mg/L)	12±8	4.5±0.5	6.5±3.5	5±2	10±5	12.5±2.5	4±1	12.5±2.5	7±0	15±0
Discharge (m3/second)	0.29±0.17	0.56±0.27	0.77±0.27	0.69±0.35	1.1±0.38	1.81±1.09	1.7±0.83		1.91±0	2.08±0
Sediment (tonnes/day)	0.42±0.38	0.21±0.08	0.51±0.39	0.24±0.03	1.07±0.78	2.19±1.58	0.51±0.14		1.15±0	2.69±0

Source: Field data

Principal components PC1 and PC2 explained 73.44% of the total variance. The percentage of total variance is used as an index to determine how well the total factor solutions account for what the variables (in this case, pH, Nitrates, TP, TSS, and sediment) together represent. PC1 was characterized by high positive loadings (factor-variate correlations) on TSS (0.897) and sediments (0.865), which explained 39.52% of the total variation and can be termed as an axis representing "turbidity". Nitrates (0.899) and TP (0.863) contributed to the second principal component PC2, which explained 35.97% of the total variance. PC2 could generally be termed as a "nutrient" factor (Figure 7; Table 4).

Table-3. Contribution of various physical parameters in the two principal components of the PCA obtained from the averaged data from the Sosiani River for the months of January and February 2014. Each physical parameter is provided with the resultant communality value.

	Principal Components (PC)		
	1	2	Communalities – extraction
DO	-0.852	0.395	0.918
Temperature	0.744	0.23	0.855
pH	-0.254	0.835	0.819
Conductivity	0.983	0.009	0.973
TDS	0.985	0.039	0.975
Salinity	0.983	0.007	0.973
Nitrates	0.852	-0.243	0.985
Nitrites	0.072	0.126	0.932
TP	0.686	-0.523	0.83
TSS	0.425	0.709	0.696
Discharge	0.769	0.278	0.94
Sediment	0.537	0.682	0.932

Source: Field data

Table-4. Summary statistics explaining the total variance (PCA method) for the 10 sites in the Sosiani River, using averaged physical parameters as measured in the months of January and February 2014. The first three components accounted for 90% dissimilarity.

Total Variance Explained						
	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.511	54.256	54.256	6.511	54.256	54.256
2	2.302	19.185	73.441	2.302	19.185	73.441
3	2.014	16.78	90.221	2.014	16.78	90.221
4	0.637	5.309	95.53			
5	0.265	2.208	97.738			
6	0.16	1.331	99.069			
7	0.069	0.573	99.642			
8	0.041	0.342	99.984			
9	0.002	0.016	100			

Source: Field data

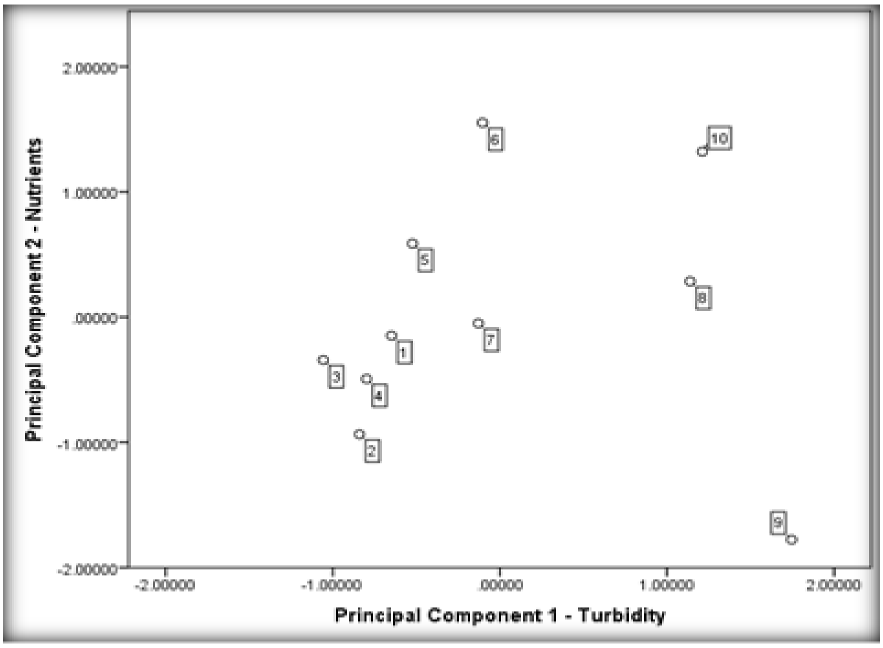

Figure-2. Two-dimensional PCA ordination of the environmental variables in the 10 sites in the Sosiani River as measured in the months of January and February 2014. The numbers in the plot represent the sampling sites.
Source: Field data

When a site's riparian zone condition was explored to see how it affected the environmental variables, the PCA plots in Figure 2 were produced. SR10 and SR8 tended to cluster together but were more controlled by sediment and turbidity parameters, while the rest were controlled mostly by DO and nitrites. The contribution of PCA1 and PCA2 accounted for 74% of the total clustering (PCA1 = 55.9%, PCA2 = 18%). BEST analysis on physical parameters was performed to establish the Spearman Rank Correlation between the sites. Within-sample analysis produced Euclidean distance for each, indicating a sample statistic (Rho) of 0.997 (p = 0.001). The best result was found to lie between 0.985 and 0.997.

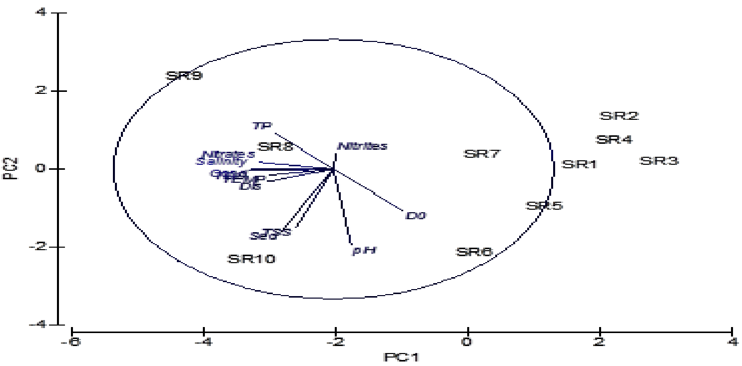

Figure-3. PCA for environmental variables. A short arrow means that this particular variable was not well represented in the first two dimensions and that the correlation with the other variable was low.
Source: Field data

4.2. General Spatial Patterns of Macroinvertebrate Assemblages

To explore macroinvertebrate patterns between sites the species abundance for different sites (Table 5) was averaged between the months of January and February. On average, there were 297±2 individuals represented in 11 orders that belonged to 27 families.

Table-5. The occurrence of macroinvertebrate species at the 10 Sosiani River sites in January and February 2014.

Site	SR1		SR2		SR3		SR4		SR5		SR6		SR7		SR8		SR9	SR10	Total
	J	F	J	F	J	F	J	F	J	F	J	F	J	F	J	F	F	F	
Baetidae	21	12	7	7	9	4	4	2	6	4	12	4	29	9	3	20	14	5	172
Leptophebiidae	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hydrobiosidae	21	2	2	1	1	1	1	0	4	7	2	2	20	7	1	20	10	2	104
Chironomidae	1	2	20	2	0	0	1	4	0	2	0	0	0	6	7	11	1	3	60
Dytiscidae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	2	5
Epiprotophora	0	0	0	2	2	2	2	2	0	0	0	1	0	0	0	0	0	0	11
Gyrinidae	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	4
Mesoveliidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Gripopterygidae	0	2	1	0	3	0	0	0	0	0	0	1	4	6	1	0	1	0	19
Psephenidae	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Thaumaleidae	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6
Oligochaete	0	0	0	0	0	0	0	0	0	0	0	0	1	18	4	27	3	0	53
Gerridae	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	3
Hydrophilidae	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3
Decapoda	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Simuliidae	1	0	0	0	3	4	0	0	1	0	0	0	0	0	0	1	9	0	19
Zygoptera	0	1	0	1	0	0	0	2	0	0	2	3	0	5	1	1	6	2	24
Pleidae	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	1	6
Caenidae	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4
Notonectidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	3
Sundathelphusidae	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Hydraenidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Nepidae	0	0	0	0	0	0	0	0	0	0		1	0	0	0	0	0	0	1
Haliplidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4
Glossosomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	12
Veliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Elmidae	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	3
Total	47	23	33	15	22	11	8	10	13	16	19	12	62	52	24	98	45	18	528

Source: Field data

Table-6. Macroinvertebrate metrics calculated from two months averaged data to discriminate the 10 Sosiani River sites in terms of their absolute numbers, abundance, richness, diversity and evenness.

Sample	Richness (S)	Abandance (N)	Margalef Richness (d)	Shannon Diversity (H)	Simpson Diversity (λ)	Pielou evenness
SR1	11	35	2.813	1.463	0.684	0.6103
SR2	10	24	2.832	1.558	0.7255	0.6768
SR3	7	17	2.14	1.664	0.8133	0.8549
SR4	5	9	1.82	1.461	0.8403	0.9078
SR5	8	15	2.618	1.568	0.7765	0.7541
SR6	8	16	2.554	1.52	0.7297	0.7309
SR7	10	57	2.226	1.791	0.8037	0.7779
SR8	14	61	3.162	2.039	0.85	0.7726
SR9	8	45	1.839	1.722	0.8081	0.8283
SR10	9	18	2.768	2.029	0.8954	0.9235

Source: Field data

While overall family richness ranged from 5 families at SR4 to 14 families at SR8, the Margalef's species richness ranged between 1.82 and 3.16, with SR4 having the lowest and SR8 the highest (Table 6). The Shannon diversity index indicated the same pattern, with a range between 1.46 (SR4) and 2.03 (SR8). However, the Simpson diversity index showed a different pattern, with the lowest index (0.684) occurring at SR1 and the highest (0.895) at SR10. This may have been caused by evenness, as indicated by the lowest Pielou evenness of 0.61 at SR1 and highest value of 0.92 at SR10 (Table 6), which is the same pattern as that of Simpson diversity since the diversity is made up of both richness and evenness components. Nonetheless, the statistics in Table 9 clearly indicate that SR8 had the highest values of all metrics except Pielou evenness (0.77) and Simpson diversity (0.85), for both of which SR10 had the highest values.

The similarity dendrogram for the 10 sites in relation to the surface aquatic macroinvertebrates indicated four clusters at 50% similarity. The first cluster was composed of SR4, SR6 and SR10; the second cluster included SR1, SR2, SR7, SR8 and SR9; and the third and fourth clusters included SR3, which was in a more natural condition (Figure 9). The MDS plot for the sites in macroinvertebrate similarity using Euclidean distance in 2D normalised data similarly produced four clusters at 50% (stress = 0.15) (Figure 10).

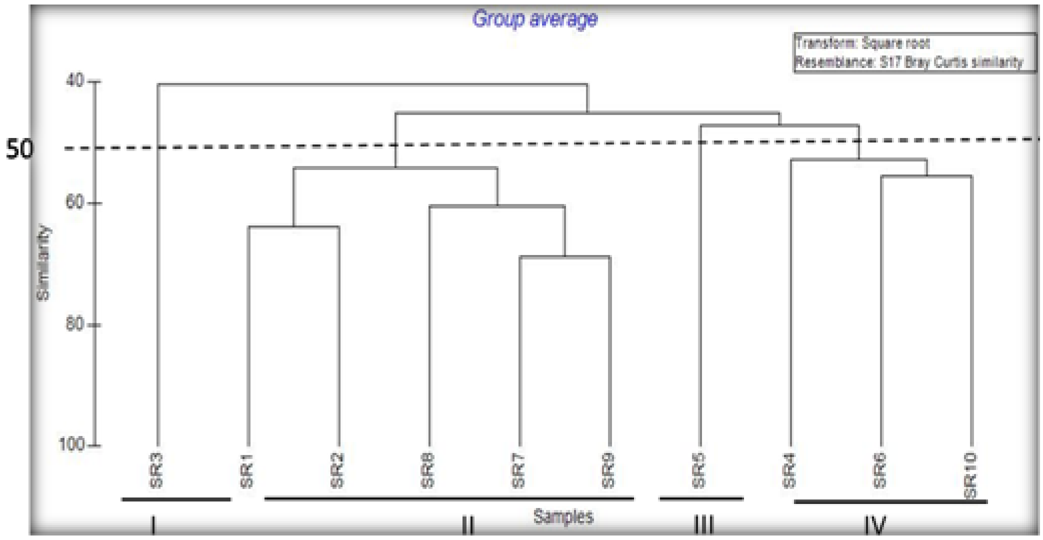

Figure-4. Dendrogram of the 10 Sosiani River sites based on complete linkage hierarchical cluster analysis from Bray-Curtis similarities on square-root-transformed abundances. The four clusters of sites are separated at 50% similarity threshold. Group I was the control site, Group II were mostly having more riparian vegetation Group III was a plantation field with fairly intact riparian vegetation on one bank, and Group IV had no riparian zone vegetation.

Source: Field data

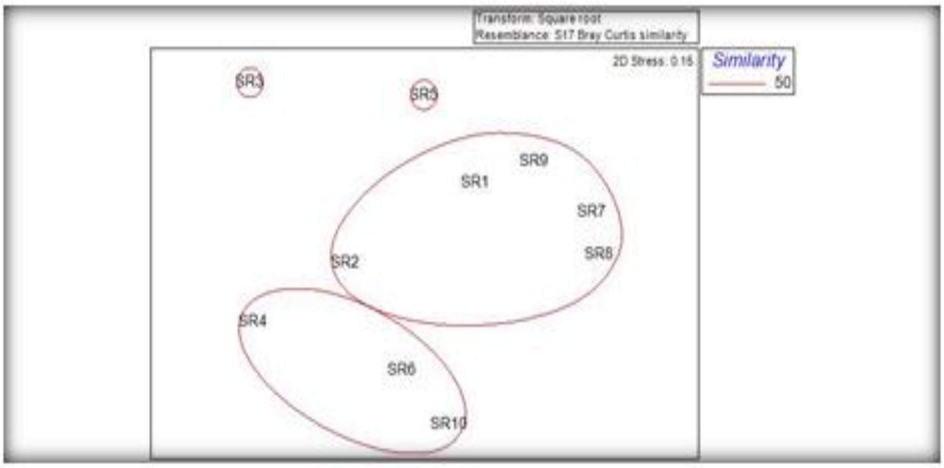

Figure-5. The 10 Sosiani River sites macroinvertebrates' MDS. With the averaged abundances, the sites group into two major clusters, leaving aside SR3 and SR5. SR3 was the "reference" site and SR5 was a grazing site but had natural intact riparian vegetation on one bank that extended for more than 100 m.

Source: Field data

When the sites were grouped according to their local land use, there were significant differences in macroinvertebrate composition among them (ANOSIM, R = -0.075, p = 0.0016). Pairwise, the ANOSIM test suggested a significant difference in composition between urban land use and forestry (R = 0.294, p = 0.07) and between urban and plantation land use (R = 0.317, p = 0.07). The rest of the land-use pairs suggested no difference (p > 0.07). The spatial MDS for the macroinvertebrates factored by environmental variables produced Figure 6, whereby there were three major clusters that were mixed in terms of their water quality parameters.

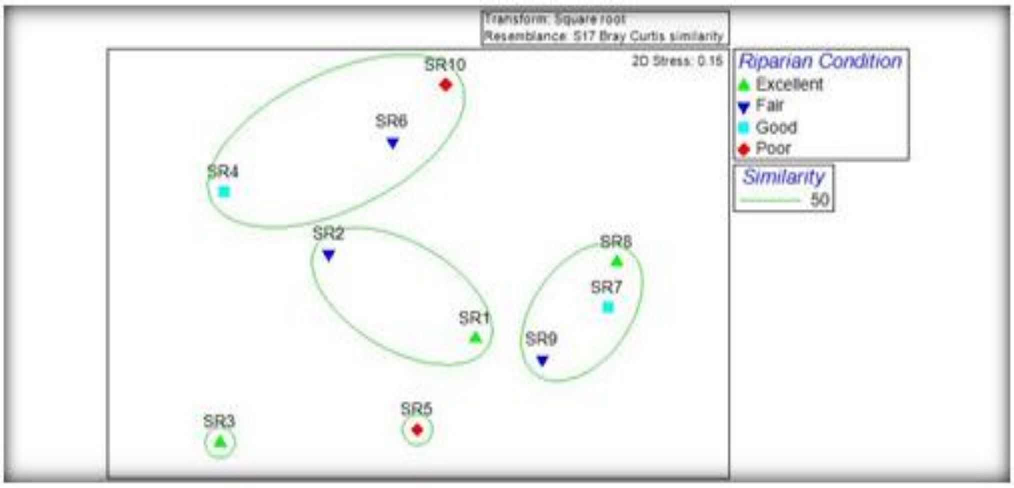

Figure-6. Two-dimensional MDS configuration with superimposed clusters from complete linkage from Bray-Curtis similarities on square-root-transformed abundances. Three major clusters separate at 50% (stress = 0.15); however, SR3 and SR5 are left out as distinct from the three clusters.
Source: Field data

Four macroinvertebrate family groups contributed to 97% of the dissimilarity between macroinvertebrate compositions for the four water quality condition classification groups (SIMPER). These contributions were *Baetidae* 50.36%, *Hydrobiosidae* 19.56%, *Chironomidae* 13.54% and *Sundathelphusidae* 13.56%. Individual permutations indicated *Biosidae* and *Chironomidae* to be the major determinants of similarities between sites to different land use. *Baetidae* and *Hydrobiosidae* groups were abundant in all sites. *Epiprotophora*, *Chironomidae*, *Gripopterygidae* and *Simuliidae* were most abundant in forest landscapes, while *Chironomidae* were abundant in plantation farming landscapes, which, at the time of sampling, were laying fallow after wheat and maize harvesting. *Oligochaeta* and *Zygoptera* were more abundant in intensive farming landscapes with horticultural crops, and *Oligochaeta* and *Zygoptera* were abundant in municipal landscapes that had fairly vegetated riparian but poorly maintained sewage and storm water systems, while *Baetidae* and *Hydrobiosidae* were indifferent to these gradients in catchment land use.

The ecosystem health of the Sosiani River was explored using a number of frequently used macroinvertebrate river health indices (SIGNAL and percentage EPT scores). For the spatial data, the SIGNAL and percentage EPT scores obtained are outlined in Table 6. The percentage EPT taxa accounted for between 31.44% (SR4) and 82.6% (SR1) of the total families across the sites (Table 14). The SIGNAL scores calculated for individual sites varied between 3.9 (SR4) and 5.9 (SR5).

Table-7. Results from EPT and SIGNAL score metrics of the 10 sampling sites in Sosiani River during the study period calculated from averaged macroinvertebrate data.

Sample	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9	SR10
% EPT	82.6	35.4	50.4	31.44	65.48	63.42	64	34.95	51.82	33.28
SIGNAL score	5.8	4	5.1	3.9	5.9	4.7	5.3	4.5	5.2	4.2

Source: Field data

To test the validity of using the SIGNAL score, which was developed in Australian local rivers, to make assumptions about the health of sites in the Sosiani River, the percentage EPT families from all sites were compared with a calculated SIGNAL score. A linear regression model indicated that sites with high percentage

EPT had also tended to have higher SIGNAL scores (R2 = 772), which was significantly high (paired samples t-test, p = 0.001) (Figure 17).

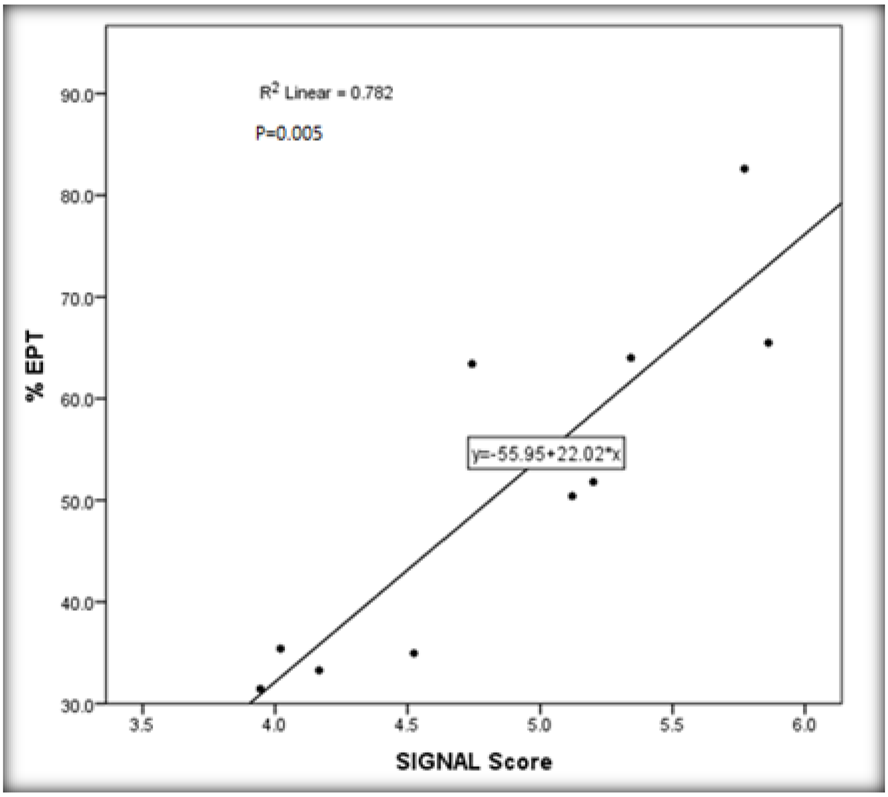

Figure-7. Regression plot using the averaged data for January and February 2014 to validate the application of SIGNAL scores and % EPT for the 10 sites at the Sosiani River.
Source: Field data

Of the EPT taxa, the *Ephemeroptera* dominated the family richness across all sites, while *Plecoptera* were only abundant at a few sites (SR3 and SR7), and the richness of *Trichoptera* families was variable (Table 15). It is also worth noting that SR4, SR5 and SR10 had no *Plecoptera* in all the samples taken.

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Table-8. Summary of the EPT family compositions in the 10 Sosiani River sites in January and February 2014.

Site	Ephemeroptera (%)	Plecoptera (%)	Tricoptera (%)
SR1	61.4	3.0	35.6
SR2	87.2	2.1	10.6
SR3	70.6	20.6	8.8
SR4	92.3	0.0	7.7
SR5	52.6	0.0	47.4
SR6	76.1	4.3	19.6
SR7	40.8	15.1	44.1
SR8	53.1	0.8	46.1
SR9	50.0	3.3	46.7
SR10	77.8	0.0	22.2
Total	57.1	6.2	36.7

Source: Field data

Figure 18 indicates that improved riparian zone condition increased the SIGNAL and percentage EPT scores for the sites. However, increases in TP reduced the SIGNAL scores. Unexpectedly, as the land use changed from intensive farming to forest, the percent EPT per sample appeared to reduce. Further, the study established that "excellent" and "good" sites had more totals of *Ephemeroptera*, *Plecoptera* and *Tricoptera* (Figure 19). However, in all riparian

The study established that in both January and February, there were more EPT macroinvertebrates in zones with natural vegetation along the Sosiani River compared to zones without natural vegetation (Figure 19), which indicated that there was no temporal difference between sites in the two months. Furthermore, both months had generally low *Plecoptera* numbers compared to *Ephemeroptera* and *Tricoptera* (Figure 20). This observed trend was similar to the one obtained in the averaged data sets.

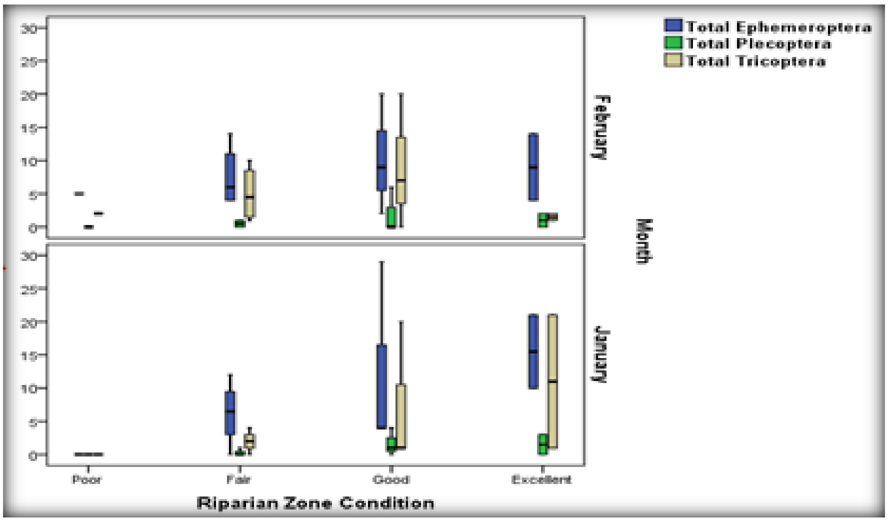

Figure-8. Temporal comparison of Total *Ephemeroptera*, *Plecoptera* and *Tricoptera* as per different riparian zone conditions in the 10 Sosiani River sites. The Y-axis represents the abundance of each EPT per category.
Source: Field data

5. DISCUSSION

5.1. Emerging Patterns in Environmental Drivers

The fact that SR1 and SR3 were areas under government forest protection accounted for the high scores they obtained in the natural vegetation criterion. Meanwhile, SR8 is protected by a landowner for personal reasons, which indicates that different stakeholders may contribute to the health of a river (Jungwirth *et al.*, 2002) although their individual goals may differ. The sites undergoing riparian rehabilitation could not score highly since the vegetation was still low and young, not intact, and their root system had not developed enough to stabilize the banks. This is consistent with Maguire *et al.* (2011) and Nyakora and Ngaira (2014) who warn that riparian zone rehabilitation is a long-term process and its outcome may only be seen after several years. The long time required for this rehabilitation may have contributed to the weak relationship found between land use conditions and environmental variables in this study. However, where riparian zones have been rehabilitated, there may be an influence on the health of a river since local material and nutrient inputs originating from that particular site, may not reach the river (Sheldon *et al.*, 2012). Nevertheless, sites with indigenous vegetation intact scored higher values.

The land use of a location determines the materials likely to reach the river system. For example, SR3, which was the "reference site", was classified as being in "excellent" condition due to its riparian zone vegetation condition and the surrounding land use, which was indigenous forest. The dense, indigenous, continuous vegetation likely prevented foreign materials from reaching the river system, thus giving it less nutrients and sediment as indicated in the results obtained during the study. This was consistent with the findings of Walsh *et al.* (2005) that urban streams are usually degraded due to the absence of the filtering mechanism provided by riparian zone vegetation. In particular, changes in land use have been shown to have significant impacts on stream ecosystem health (Allan, 2004; Sheldon *et al.*, 2012). By contrast, municipal land use increases pollutant delivery into rivers, especially untreated waste water from either sewage or runoff. The newly planted vegetation at SR6 and SR7 had the capacity of preventing solid waste from reaching the river but liquid waste could still be passing through as the trees' roots might have not developed enough to take up more nutrients. Similarly, the sites with overly narrow, broken up un-continuous or grazed adjacent land tended to rate as "poor" in terms of riparian zone vegetation condition. In the Sosiani River, the wider the area surrounding the site with natural forest cover, the better the site, which was consistent with the findings of Tong and Chen (2002). Combining the surrounding land use with riparian zone vegetation thus provided a useful metric for classifying the health of a river in terms of material movement and in-stream processes.

The environmental variables measured from the Sosiani River did not significantly vary between the 10 sites, except for conductivity, TDS, TSS and salinity. Although variation between sites was minor, the data suggested better water quality could be expected in the headwater sites (SR1, SR2, SR3) as compared to the downstream sites (SR7, SR8, SR9, SR10). Studies at the Walnut Gulch watershed in Tombstone, Arizona, USA, found that most of the suspended sediments at the outlet of the watershed originated from the shrub-dominated sub-watersheds (Ritchie *et al.*, 2009). This might have been the reason for the low macroinvertebrate assemblages found in SR9, which was dominated by shrubs used for grazing. Furthermore, SR9 had the highest sediments, nitrates, TP, and low DO, all likely to discourage the establishment of macroinvertebrates. The poorer water quality measured at SR9 may have resulted from a lack of riparian vegetation to intercept pollution from grazing fields. Although researchers have not found the actual impact of agriculture and urbanization on aquatic biota (Wasson *et al.*, 2010) there is evidence that riparian vegetation absorbs nutrients from sub-surface soil as it flows down from agricultural farms to river systems (Gregory *et al.*, 1991; Sponseller *et al.*, 2001) thus protecting the stream from eutrophication processes. Preventing materials from the adjacent land from reaching the stream could be achieved by allowing both storm and waste water to pass through the well-maintained riparian zone before entering the main stream.

The high TSS and sediment, which accounted for 39.5% variance in PCA component 1 on water quality data, may be attributed to surrounding anthropogenic activities, such as the discharge of poorly treated sewage at SR7 and SR8, as well as the washing of clothes and cars, and the watering of animals in the river, which was common within the municipality. Nitrites and nitrates, which accounted for most of the variation along PCA component 2, may have originated from the raw sewage discharged into the river within the municipality as well as the horticultural farming undertaken along the small patches of river stretch where fertilizers and pesticides are highly used. Furthermore, environmental variables provided a useful metric (Kilonzo *et al.*, 2014) since the first two PCA components were able to explain 73.4% of the total variance. The 10 sites' PCA ordination of the environmental variables grouped SR1 SR2 SR3 SR4 and SR5 together with SR7 from the rest of the sites. This separation was an indication of those less impacted by anthropogenic activities and these are the sites determined by less TSS and sediment. SR7, which was within the municipality, may have been grouped together with the upstream sites due to its rehabilitated riparian zone that filters solid wastes. Nevertheless, when the riparian zone condition data were correlated with the measured water quality data for all sites, BEST analysissuggested a significant difference in terms of environmental drivers, which may have been influenced by land use and the resulting riparian zone vegetation, as advocated by Abal *et al.* (2005); Bernhardt and Palmer (2007) and Gundersen *et al.* (2010).

In this study, the trend in environmental parameters was, as expected, such that the sites that were within and downstream of the municipal town had higher values than forested upstream sites, suggesting a pollution gradient from both solid and liquid wastes as one moves from the forest into the municipality. This led to high values of nitrates, phosphates, and total dissolved solids while DO reduced tremendously. While it is difficult to disentangle the downstream change in land use from natural downstream changes in streams, the sites directly before the municipal land use with intact vegetation had lower values of nutrients, similar to upstream sites (SR1, SR2, and SR5), suggesting that the patterns more likely reflected local vegetation conditions than position in catchment. Riparian vegetation intercepts pollutants from runoff before they reach the river system. The higher values of nitrates and nitrites at SR3 may have been caused by the upstream logging taking place about 3 km upstream of the site. The finding provided evidence that the upstream sites of the Sosiani River, where the riparian zone is dominated by indigenous vegetation, had high DO, average nitrates and nitrites, while TDS, TSS and sediment loading were low. However, the low temperatures experienced in this catchment throughout the year might be influencing the rate of aquatic metabolism, thus prohibiting high usage of oxygen as evidenced by its high concentrations.

Such spatial variations in water quality have been experienced in other parts of the world both in tropical and non-tropical areas [e.g. Cooper Creek, Australia (Sheldon and Fellows, 2010) Bwindi River, Uganda (Kasangaki *et al.*, 2008) Mississippi River, USA (Angradi and Jicha, 2010) Bushmans River, Lesotho (Grab, 2014)]. The geology of the Sosiani catchment comprises humic nitisols, which are rich in nutrients and both deep and fertile, thus leading to high nitrogen and nitrites even in a well-conserved and forested catchment. This is supported by Sheldon and Fellows (2010) who argue that spatial pattern in water quality may be driven by catchment characteristics, such as the geology, as well as land use of the area.

5.2. Emerging General Spatial and Temporal Patterns of Macroinvertebrate Community

In contrast to other studies done in equatorial rivers in Kenya (e.g. Kipkaren River (Aura *et al.*, 2010) and Mara River (Kilonzo *et al.*, 2014)) which largely focused on the large-scale land-use effects on macroinvertebrate assemblages, this study concentrated on the effects of riparian zone vegetation, including the surrounding land use categories, within 100 m of the river course. This study's results suggest that the undisturbed forest streams and rehabilitated disturbed streams support a diverse and rich macroinvertebrate community. The number of taxa obtained (27) and orders represented (11) was comparable with other studies done at Kipkaren River system (Aura *et al.*, 2010) which is adjacent to Sosiani River in which the number of orders found were 13 with 28 families. Sites in the study area that had higher family richness corresponded with those sites that had dense riparian vegetation at the water's edge. Those sites with forested land use, but no vegetation at the water's edge (SR3), had fewer macroinvertebrate families present. This pattern reflects the need for many aquatic insects for vegetated riparian zones for adult dispersal and breeding (Price *et al.*, 2003) as well as those macroinvertebrate adults seek refuge in riparian vegetation to avoid predation (Arimoro *et al.*, 2012). Further, SR3, which was the site with the densest forest, may have lacked enough sunlight to facilitate the growth of photosynthetic microfilms, which most macroinvertebrates feed on Barbosa *et al.* (2001).

This result differs from studies carried out in temperate climate regions that suggest higher taxonomic representation. For example, in Oulankajoki River, Finland, 53 macroinvertebrate taxa were found (Heino *et al.*, 2009). Interestingly, in the current study, the total abundance of macroinvertebrates was significantly lower in the "reference" sites compared with some test sites (SR1, SR2, SR7, SR8 and SR9), which might be due to (Huston, 2014) Intermediate Disturbance Hypothesis (IDH), which states that "local species diversity is maximized when ecological disturbance is neither too rare nor too frequent". This finding indicated that sites experiencing intermediate levels of disturbance (in this case, canopy cover), i.e. SR7 and SR8, led to a maximized number of species there since competitive and opportunistic species coexisted (Bohn *et al.*, 2014).

The macroinvertebrate assemblage composition in sites sampled in the Sosiani River reflected the degree of nutrient and sediment pollution. The macroinvertebrate assemblages in the forested headwater sites SR1, SR2 and SR3 were dominated by pollution-sensitive EPT taxa (45% of total abundance) while the rest of the sites were dominated by pollution-tolerant *Chironomidae* and *Oligochaeta* (50% of total abundance). The findings are similar to those of Aura *et al.* (2010) who established that headwaters stations at Kipkaren River were dominated by taxa associated with unpolluted waters. Their findings further revealed that stations far from headwaters and more subjected to pollution were dominated by *Hemiptera*, *Odonata*, *Chironomidae* and *Oligochaeta*, which are tolerant to pollution.

The results obtained from the Sosiani River indicated an increase in the abundance of those species tolerant to pollution, as the Sosiani River flows from the headwaters through the Eldoret municipality to the lower parts to join the main trunk (Kipkaren River). SR7 and SR8, which were within municipality but at the middle part of the river system, had high numbers of opportunistic species (Barbosa *et al.*, 2001) that are tolerant to pollutants, such as *Oligochaeta* and *Chironomidae*. Klerk and Wepener (2013) observed that since stream pollution, especially that emanating from municipal liquid waste, causes a change in an aquatic ecosystem, it encourages structures that favour opportunistic species. Tolerant species such as some *Chironomidae* can survive where oxygen concentration is low (Weigel *et al.*, 2002; Griffith *et al.*, 2005) and usually flourish when there is no competition (Klerk and Wepener, 2013). SR7 is situated at the town centre and receives both solid and liquid waste from the nearby 'referral' hospital (Kibichii *et al.*, 2007). However, it had fair riparian zone vegetation planted by the National Environment Management Authority (NEMA) as a means of preventing further pollution from the town streets, which accounts for the presence of other intolerant macroinvertebrates. SR8 receives nutrients and organic pollutants from the poorly treated municipal sewage, which discharges its effluent 50 m above the sampling site, thus accounting for the great numbers of *Oligochaeta*. The results obtained indicate that the greatest macroinvertebrate abundance was in SR8, which may be due to the "excellent" condition of its riparian zone. Thus, the richness index is a good indicator of river health (Aura *et al.*, 2010; Klerk and Wepener, 2013) and responded well in assessing the health of the Sosiani River.

In this study, the surrounding land use type was found to have a significant effect on the macroinvertebrates in the Sosiani River. River systems with good riparian conditions may reduce the negative effect of land use since riparian vegetation alters micro-climates, converts nutrients transported from hill slopes, supplies food, provides shelter to organisms, and serves as migratory routes and forest connectors between habitats (Gregory *et al.*, 1991; Kominoski *et al.*, 2011).

As evidenced in the previous chapter, this study found that the environmental variables most highly associated with macroinvertebrate assemblage composition were nitrates, TDS, discharge, TSS and sediments. The results obtained in this study confirm that water quality environmental variables were more highly associated with differences in macroinvertebrate structure than surrounding land cover variables. This may reflect the fact that river flow determines substrate properties in-stream, affects transportation of external nutrients, and affects the amount of TSS in the river (Pan *et al.*, 2013). The low correlation with land use likely reflects the narrow extent of the riparian zone vegetation maintained on the river banks. Studies done by Aura *et al.* (2010) at Kipkaren River, which lies next to the Sosiani River, established that water quality variables were negatively correlated with pollution-tolerant macroinvertebrates, and sections of river basins habited by humans showed reduced macroinvertebrate richness. At the same time, sites that received polluted runoff and sewage had been rehabilitated by the government, thus making the sites more habitable for surface macroinvertebrates.

6. CONCLUSION

The different land use conditions that exist along the Sosiani River have led to variations in river health status across the system. The study established a significant relationship between water quality indicators and macroinvertebrate assemblages in the Sosiani River. The variations found in land use conditions suggested that pollution reaching the river and stream system influences water quality variables, which in turn affects the macroinvertebrate assemblages in the Sosiani River. Metrics used to measure the water quality indicated a better water quality, with minimal nitrates, sediments, TSS, TP and high DO, at the headwaters, with these variables reversing downstream. The macroinvertebrate assemblages in SR1, SR2 and SR3 were dominated by pollution-sensitive EPT while the rest of the sites were dominated by pollution-tolerant *Chironomidae* and *Oligochaeta*. The better water quality may have contributed to the pollution-intolerant species of macroinvertebrates being more abundant at the headwaters compared to the downstream, which has poor water quality. However, since water quality is a result of complex interrelated factors, some sites did not indicate the expected result.

The study established a weak relationship between land use conditions and water quality indicators. This weak relationship was found to be influenced by the direct discharge of poorly treated sewage to the Sosiani River within the municipality, which led to unexpectedly high TSS, TP, nitrates and nitrites and low DO. This effect was more prominent at SR8, which had an intact riparian vegetation but poor water quality. However, the metric had a high response at SR9 and SR10, which had poor water quality with at the same time no riparian vegetation. The metric also responded as expected at sites located at headwaters, whereby those with natural forest conditions had good water quality due to the vegetation intercepting pollutant materials as they moved downslope via the runoff to the stream.

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