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Original Research Article

Effect of Anthropogenic Activities on Physico-chemical Parameters and Benthic Macroinvertebrates of Mara River Tributaries, Kenya

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Abstract

The impact of anthropogenic activities within Bomet and Mulot towns on water quality of Amala and Nyangores tributaries of Mara River, Kenya was assessed using a combination of solid waste, physico-chemical parameters and benthic macroinvertebrates. Site characteristics and on-going anthropogenic activities were observed and recorded, while solid waste was visually identified and categorized. Physico-chemical parameters were determined *in situ* while benthic macroinvertebrates were analyzed on sediment samples and classified using appropriate keys. Results indicated that all sites were disturbed by anthropogenic activities, except one that was relatively protected at the upper catchment spring draining into Nyangores tributary. Most (96.1%) solid waste encountered was recyclable, while polythene bags were dominant (48.9%). Significantly more solid waste was recorded along Amala than Nyangores tributary. Dissolved oxygen, conductivity, total suspended solids and total phosphorus levels varied significantly between sites, along Amala as well as Nyangores tributaries. Eight benthic macroinvertebrate taxa comprising 628 individuals were encountered in both tributaries, with Nyangores recording a significantly higher diversity than Amala tributary, as also confirmed by Shannon-Weiner diversity index. Dipterans were the most dominant taxa, contributing 81.9% and 70.9% of the total benthic macroinvertebrates encountered along Amala and Nyangores tributaries, respectively, while pollution sensitive taxa in the orders, Ephemeroptera and Plecoptera combined, accounted for less than 0.88% of the total benthic macroinvertebrate taxa in the two tributaries. These findings are indicative of perturbed systems whose severity seem to be driven by anthropogenic activities within and along the Mara River tributaries.

Keywords: Anthropogenic activities, benthic macroinvertebrates, disturbed sites, indicator species, solid waste, water quality

INTRODUCTION

Rivers are open dynamic ecosystems whose physical, chemical and biotic characteristics are greatly influenced by anthropogenic activities taking place within their drainage basins (Mokaya et al., 2004). A number of rivers and streams flow through urbanized areas across the world and are profoundly impacted by changes associated with urbanization (Bernhardt and Palmer, 2007). Such urban flowing rivers, often occurring at low lying points of the landscape are particularly sensitive and prone to pollution from urban development and other anthropogenic activities which result in increased pollutant load through surface runoff (Bernhardt and Palmer, 2007). Continuous economic growth, urbanization and high population growth rate are some of the contributors to the rapid increase in volume and variety of both industrial and household waste generated in many mushrooming urban centers, especially in developing countries (Fakayode, 2005). The total amount of domestic waste generated globally in the year 2006 for instance was about 2.02 billion ones, representing a 7% annual increase in comparison to 1.89 billion ones recorded previously in the year 2003 (Global Waste Management Market Report, 2007). As at 2009, between 3.4-4 billion ones of municipal and industrial waste was reportedly produced annually, of which non-hazardous industrial waste accounted for 1.2 billion ones (Chalmin and Gaillochet, 2009). However, the major share of this waste (1.7-1.9 billion ones, or 46 per cent of the total waste generated) was municipal solid waste originating from urban settlements (UNEP, 2010).

Owing to lack of sufficient infrastructure, especially in most developing countries, to handle such waste, the bulk of the waste generated is often left in the open and eventually finds its way into aquatic systems (UN-Habitat, 2008). It is estimated that between one third to one-half of solid waste generated in most towns in low and middle-income countries is left uncollected due to lack of capacity (Xiao et al., 2006), and usually ends up as illegal dumps on streets and open spaces, thus polluting nearby water bodies (UNEP, 2002; UN-Habitat, 2008). The inadequate capacity to collect domestic waste in most developing countries has however been blamed on insufficient funding, high population growth rate and rapid urbanization without a corresponding expansion of critical infrastructure and sanitation facilities (Ikiara et al*.,* 2004). While in the past, the environment was thought to have an infinite capacity to naturally degrade wastes without any ill effects, more recently however, the effect of poor waste disposal has rendered many aquatic systems less suitable for primary and in some cases secondary usage (Fakayode, 2005). Excessive loading of domestic waste into rivers can alter the physical, chemical and biological characteristics of the aquatic system beyond their natural self purification capacity. Higher levels of turbidity, nutrients, suspended and dissolved solids as well as coliform bacteria in rivers are all indicative of compromised systems attributed to increased pollutant load, resulting largely from anthropogenic activities (Adams and Papa, 2000). Such changes in water quality can alter the community structure of benthic macroinvertebrates and other aquatic biota therein (Boyle and Fraleigh, 2003).

Though physico-chemical water quality parameters provide snapshots of the condition of a river at a given point in time, they may not effectively provide an integral measure of the overall health of the river and can, at times, inadequately identify impaired waters (USEPA, 2005). An integrative approach incorporating biological measures like the benthic macroinvertebrate community structure alongside other physico-chemical water quality parameters, can thus provide a more comprehensive assessment of the health of a river over time (Bonada et al., 2006). Benthic macroinvertebrate assemblages and distribution frequently change in response to pollution stress in predictable ways, thus their importance as biological criteria for evaluation of anthropogenic influences of aquatic systems (Boyle and Fraleigh, 2003). The Shannon-Weinner diversity index and evenness index are also important in determining the species composition between various habitats and thus give a reflection of the health of aquatic systems (Shannon-Weaver, 1963).

Virtually all urban centres in Kenya are faced with solid waste management problems, Mulot and Bomet towns are no exception as they have also experienced rapid population growth characterized by poor urban planning, mushrooming informal settlements, limited amenities and poor sanitation (KNBS, 2007). Amala and Nyangores tributaries form the main drainage systems for many small towns and urban centers along their course including Mulot and Bomet towns, respectively. Though the towns do not have major industries as yet, they nevertheless lack the capacity and resources to handle the current quantities of solid waste produced by inhabitants, thus encourage haphazard disposal of the waste in open spaces and poorly situated dumpsites along the river banks and in river channels. Sewage treatment plants are also inexistent in the two towns (Mati et al., 2008), implying that the two tributaries may also be serving as conduits of waste water and raw sewage, thus exposing the basin's inhabitants who depend on the river water for domestic use to risk of water borne diseases. The ecological and economic importance of the Mara River to the inhabitants of the basin and to the economy of Kenya and Tanzania through tourism hinged on the world famous wildebeest migration spectacle necessitates its protection and conservation. The increasing levels of anthropogenic perturbation of the Mara River especially at the upper catchment tributaries flowing through urbanized areas (Mati et al., 2008) underscored the need for this study. This paper presents the findings of investigation on the effects of anthropogenic activities on water quality and benthic macroinvertebrate species diversity and composition along the Amala and Nyangores tributaries in the upper Mara River, Kenya.

MATERIALS AND METHODS

Study area

The Mara River basin covers a surface area of 13,504km^2 and is located between longitudes 33°88' E and 35°90'E and latitudes 0°28' S and 1°97' S at altitudes of between 2,932m at its source in the Mau Forest escarpment to 1,134m at the entry point into Lake Victoria (Mati et al., 2005; Mutie et al., 2006). The perennial tributaries i.e. Amala and Nyangores originate from the Mau escarpment, and form the larger Mara River at the confluence in the mid Mara River basin before flowing further down and discharging into Lake Victoria at Musoma bay in Tanzania (Mutie et al., 2006). These tributaries serve as the main sources of water for the inhabitants of Mulot and Bomet towns as well as many other urban centres and human settlements through which they flow. However, the tributaries also double up as unofficial waste conduits contributing to water quality degradation.

Sampling design

This was a cross-sectional study, carried out in August 2011 along Amala and Nyangores tributaries on the upper Mara River catchment. Sampling sites were selected based on their characteristics and location along the two tributaries. Four sites each were chosen along Amala and Nyangores tributaries; three within the towns (Bomet town-along Nyangores tributary and Mulot town-along Amala tributary), to capture the contributions from the two urban centres (Mulot and Bomet) to water quality degradation, while a fourth site for each tributary was located at a spring on the upper catchment that discharged its water into each respective tributary, for comparison purposes.

Sample collection and analysis

The site characteristics of each of the eight study areas were observed and on-going anthropogenic activities at the time of sampling noted. At each site, solid wastes deposited along a 100m stretch of the river and within 30m of the river banks were analyzed at their points of disposal, and characterization done by either visualization or hand sorting based on their characteristics. Visualization was carried out for waste that was nearly homogeneous, such as mill tailings, agricultural chaff, sawdust, liquid waste among others, since hand sorting was not possible to characterize such waste. The waste was grouped into different categories based on their physical characteristics and recorded in a solid waste frequency and composition recording sheet. Physico-chemical parameters namely dissolved oxygen, conductivity, turbidity and salinity, were measured *in situ,* in replicates of three, at intervals of 10 metres downstream using a YSI 556 MPS Handheld Multi Parameter Instrument (YSI Incorporation, Yellow Spring, USA). Total suspended and total dissolved solids were analyzed on water samples (also collected from same sites as physico-chemical parameters) following methods outlined in APHA (1998) by filtering 50 mls of the sample through a pre-weighed standard glass-fiber filter into a dry and pre-weighed evaporating dish. The residue retained on the filter paper was dried to a constant weight while the filtrate in the evaporating dish was evaporated in an oven at 103 to 105°C for 1 hour. These were cooled in a desiccator and weighed. The cycle of weighing was repeated until a constant weight was obtained, after which TSS and TDS was calculated and presented in milligrams per litre.

Sediment samples for benthic macroinverterbrate determination were collected, in replicates of three from each study site, using a D-frame dip net of 0.3m width by 0.3m height attached to a long pole and with a cone shaped bag for capturing the organisms. Sampling was done from downstream end of the river to upstream. A total of 3 jabs were made at each sampling point, with a single jab consisting of a forceful thrust of the sampler into the sediment for a linear distance of 0.5m. The sediment samples collected were transferred into plastic buckets, sieved using a series of Tyler sieves with mesh sizes of between 1.00 mm and 250mm. The organisms retained in the mesh were segregated in a white tray and transferred into plastic bottles where they were preserved using 90% ethanol pending laboratory analysis. Counting and identification was done using a dissecting microscope at a suitable magnification (10 - 500x). Identification was done to genus or species level using manuals of Needham and Needham (1962) and Egborge (1995). The Shannon-Weiner (H') Diversity index (1949) and Shannon evenness index were worked out to determine the benthic macroinvertebrate species diversity and community structure.

Statistical analysis

Descriptive statistics presented as means and their standard deviations were used to summarize the data characteristics. One-way Analysis of Variance (ANOVA) and Duncan Multiple Range Test (DMRT) were used to test for significant differences in physico-chemical parameters, solid waste, and benthic macroinvertebrates among study sites and to locate site(s) of significant difference, respectively. Regression analysis was used to describe relationships between the variables. Students't-test was used to establish possible differences among variables between Amala and Nyangores tributaries. The Shannon-Weiner Diversity (H') and evenness indices (1949) were used to evaluate

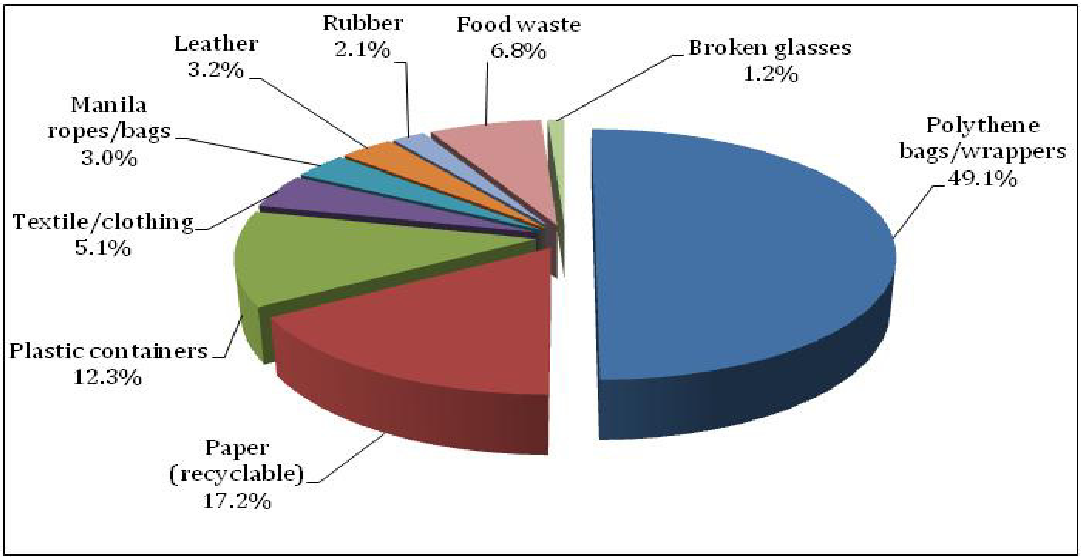

Figure 1. Percentage composition of solid waste encountered along Nyangores tributary

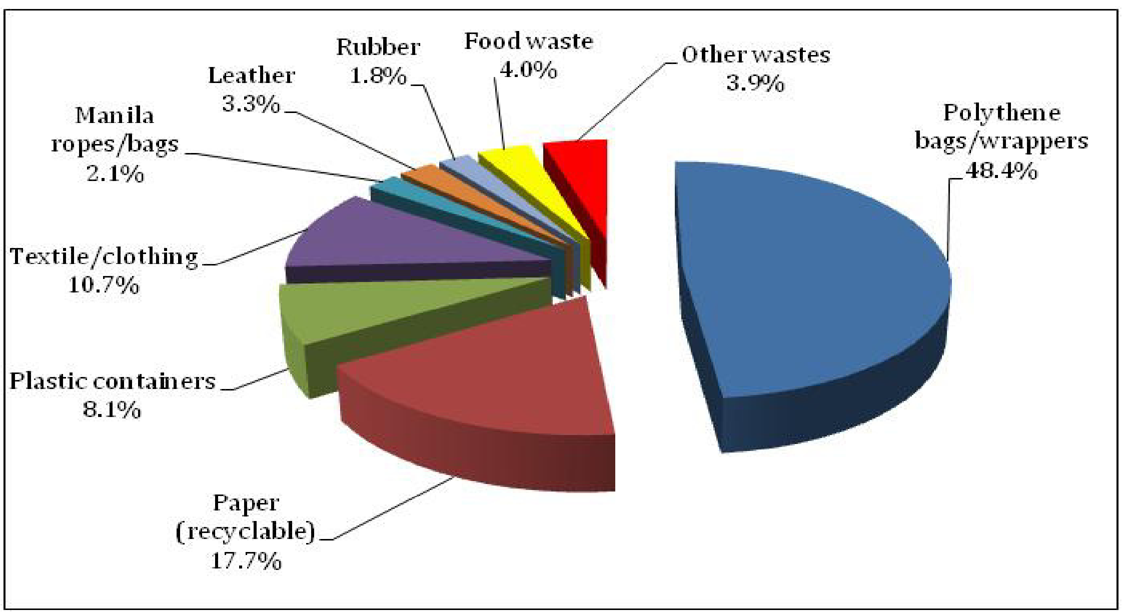

Figure 2. Percentage composition of solid waste encountered along Amala tributary

the abundance and evenness of benthic macro-invertebrates amongst the tributaries. All statistical procedures were performed using SAS V9 statistical software and $P<0.05$ level was considered statistically significant.

RESULTS

Anthropogenic activities

Observations made at sampling points showed that all sites located within the urbanized areas (Bomet and Mulot towns) were impacted, though to varying degrees. Anthropogenic activities such as bathing, washing clothing, water collection using donkeys for domestic purposes, swimming among others were evident in all the sites studied except one site located at the upper catchment spring draining into Nyangores tributary, which was relatively protected.

Solid waste

Grocery polythene bags were the most dominant 499 (48.9%) and commonly encountered solid waste along

Table 1. Physico-chemical characteristics along Nyangores and Amala tributaries

Parameter	Tributary	Physico-chemical parameters (Mean±SD) at different sites along Amala and Nyangores tributaries				
		Upper catchment spring	Upper part of town	Middle part of town	Lower part of town	Overall mean
pH	Amala	7.42±0.77^{A}	7.52±0.06^{A}	7.54±0.03^{A}	7.75±0.04^{A}	7.56
	Nyangores	6.64±0.05^{C}	7.63±0.08^{B}	7.77±0.09^{B}	8.13±0.15^{A}	7.54
DO (Mg/l)	Amala	6.00±0.80^{B}	8.23±0.13^{A}	8.12±0.23^{A}	7.76±0.05^{A}	7.53
	Nyangores	6.25±0.22^{C}	8.13±0.18^{A}	7.59±0.14^{B}	7.72±0.04^{B}	7.42
Turbidity (NTU)	Amala	101.4±18.2^{B}	131.9±1.54^{A}	115.9±1.50^{AB}	128.6±0.25^{A}	119.44
	Nyangores	111.1±42.6^{A}	121.6±2.76^{A}	136.7±6.5^{A}	127.9±1.21^{A}	124.12
Conductivity	Amala	309.0±19.1^{A}	57.0±2.0^{B}	53.3±1.15^{B}	59.7±0.58^{B}	119.75
(µS/cm)	Nyangores	74.5±2.5^{A}	51.0±1.73^{B}	58.0±7.55^{B}	52.0±2.0^{B}	58.87
TSS (Mg/l)	Amala	21.0±5.3^{C}	28.7±2.5^{B}	33.7±4.2^{AB}	37.0±2.0^{A}	30.08
	Nyangores	8.3±1.5^{C}	27.7±1.5^{B}	36.2±3.8^{A}	36.0±2.0^{A}	27.04
TDS (Mg/l)	Amala	175.3±62.6	215.7±3.5	226.0±5.6	241.3±17.8	214.58
	Nyangores	181.3±19.8	155.7±9.0	171.0±8.2	148.0±21.0	164.0

*Means with different superscripts in the same row are significantly different at P<0.05. (Data analyzed by Duncan's Multiple Range Test)

the banks of Amala and Nyangores tributaries. Other solid wastes encountered included office paper 176 (17.3%), plastic bottles 98 (9.6%), textile/torn clothing 87 (8.5%), food waste 50 (4.9%), leather 29 (2.8%) and manila bags/ropes 27 (2.6%). In addition, pieces of broken glasses, tins/cans, sponges, rotting wooden pieces, gunny bags and ceramics were also encountered though in relatively smaller quantities. Figure 1 and Figure 2 show the percentage composition of solid waste types encountered along Nyangores and Amala tributaries, respectively.

Statistical analysis showed that significantly more solid waste was encountered along Amala tributary (636, 62.4%) compared to Nyangores tributary (384, 37.6%) (Student's t-test, P = 0.031). In addition, significant variation were observed in solid waste types encountered at different sites along Nyangores tributary (one-way ANOVA, $F_{(3,63)}$=5.15, P<0.003) as well as Amala tributary (one-way ANOVA, $F_{(3,63)}$ =7.23, P<0.0003). Highest proportions (44.5%) of solid waste were recorded at the upper part of Mulot town along Amala tributary that was characterized by elevated anthropogenic activities. Most of the waste encountered along the banks of the two Mara River tributaries was recyclable (96.1%) as opposed to non-recyclable (3.9%).

Physico-chemical Water Quality Parameters

The mean and standard deviations of various physico-chemical parameters for Amala and Nyangores tributaries are given in Table 1. Dissolved oxygen (DO) levels ranged between 6.0mg/l and 8.23mg/l along Amala tributary and between 6.25mg/l and 8.13mg/l along Nyangores tributary. There were significant differences in DO levels between sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ =14.6, P<0.001), and also along Nyangores tributary (one-way ANOVA, $F_{(3,11)}$ =77.74, P<0.0001). Duncan Multiple Range Test (DMRT) further established significant differences between specific sites along the two tributaries. There were however no significant differences in DO levels between Amala and Nyangores tributaries (Student's t-test, P>0.05).

Conductivity levels ranged between 53.30µS/cm and 309.0µS/cm along Amala tributary and between 51.0µS/cm and 74.5µS/cm along Nyangores tributary. Like DO, conductivity levels also varied significantly between sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ =1500.8, P<0.0001), as well as Nyangores tributary (one-way ANOVA, $F_{(3,11)}$=17.14, P<0.001). Duncan Multiple Range Test further showed that conductivity levels were significantly higher at the upper catchment springs of both tributaries compared to the other sites located within the urbanized area (Table 1).

pH levels at different sites along Amala and Nyangores tributaries were close to neutrality ranging between 7.42 and 7.75 along Amala triburtary and between 6.64 and 8.13 along Nyangores tributary. There were significant diff-

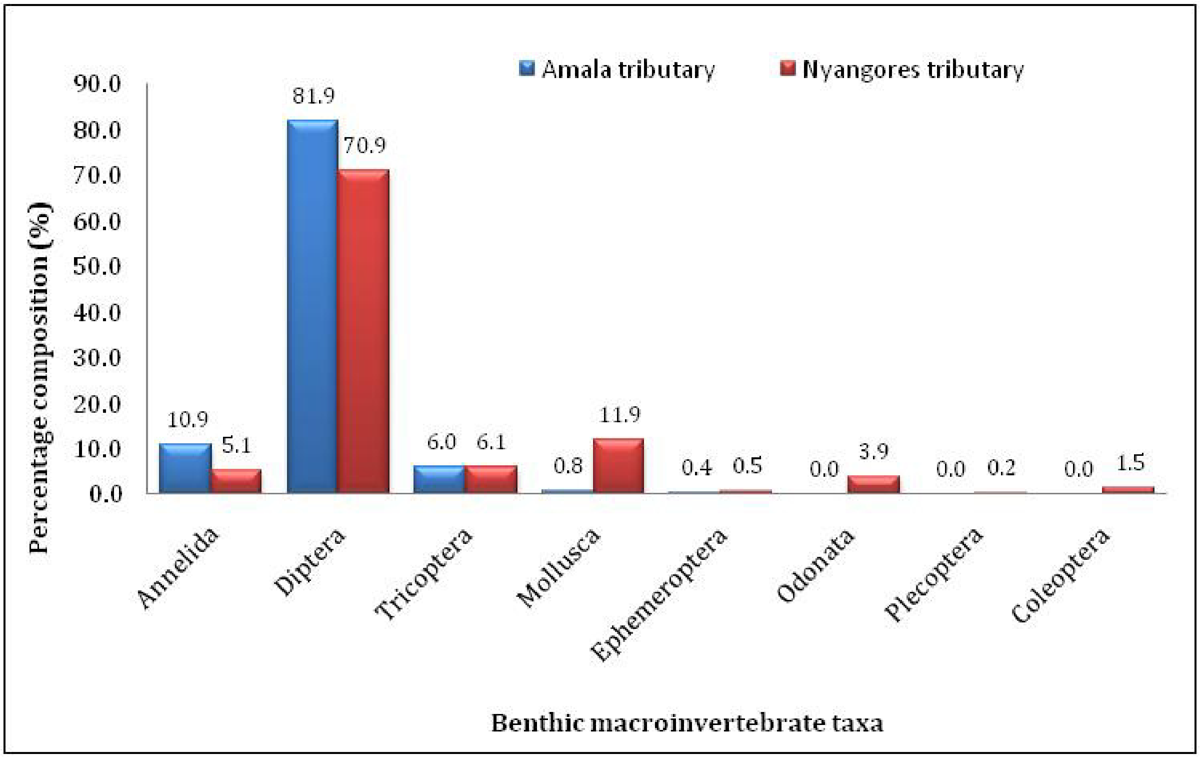

Figure 3. Percentage composition of benthic macroinvertebrate taxa along Amala and Nyangores tributaries

erences in pH levels between sites along Nyangores tributary (one-way ANOVA, $F_{(3,11)}$ = 142.15, P<0.0001) but not Amala tributary. In addition, DMRT further established that pH levels were significantly higher at the more disturbed exit point from Bomet town and significantly lower at the less disturbed upper catchment spring draining into Nyangores tributary (Table 1). Mean turbidity was higher (av. 124.12 NTU) along Nyangores than Amala tributary (av. 119.44 NTU), exceeding the allowable turbidity limits of between 5-10 NTU (WHO, 2004), though the difference between the two tributaries was not statistically significant (Student's t-test, P = 0.289). However, turbidity levels varied significantly between sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ = 5.16, P = 0.028), with highest levels recorded at the highly disturbed sites located within the urbanized section (Mulot town) (Table 1),

The mean TSS and TDS levels were relatively higher along Amala tributary compared to Nyangores tributary though the differences were not statistically significant (Student's t-test, P>0.05). Considering each tributary separately, TSS levels varied significantly between sites along Amala tributary (one-way ANOVA, $F_{(3,11)}$ = 8.04, P<0.01), and also along Nyangores tributaries (one-way ANOVA, $F_{(3,11)}$ = 126, P<0.001) (Table 1) with more disturbed sites recording higher values compared to less disturbed sites.

Benthic Macroinvertebrate Species Diversity and Abundance

Eight benthic macroinvertebrate taxa comprising of 678 individuals were encountered along the two tributaries combined. There were significant differences in benthic macroinvertebrate species diversity and abundance between Nyangores and Amala tributaries (Student's t-test, P = 0.02), with a higher species diversity recorded along Nyangores than Amala tributary. Benthic macroinvertebrates of the order Diptera were the most dominant of all benthic macroinvertebrate taxa, contributing 81.9% and 70.9% of the total macroinvertebrates along Amala and Nyangores tributaries, respectively, (Figure 1). However, family Chironomidae -pollution tolerant taxa accounted for over 99% of the dipteran density along both tributaries. In addition, Oligochaetes (also pollution indicator species), in the phylum Annelida were encountered in all sampled sites along Amala tributary and in three sites along Nyangores tributary. On the contrary, indicators of clean water in the orders Ephemeroptera and Plecoptera combined, accounted for only 0.88% of the total benthic macroinvertebrate taxa recorded in the entire study, while the Odonata, Plecoptera and Coleoptera taxa were absent from all sampled sites along Amala tributary (Figure 3)

There were significant variations among benthic macroinvertebrates recorded along Nyangores tributary

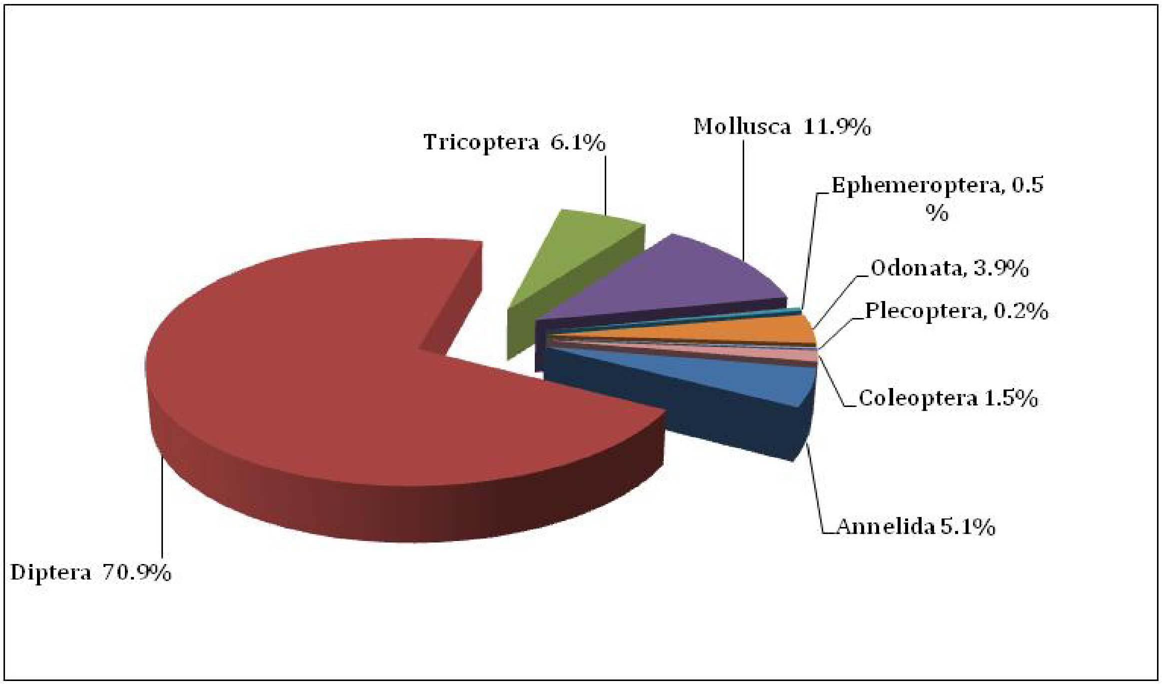

Figure 4. Figure 4. Percentage composition of benthic macroinvertebrate taxa diversity along Nyangores tributary

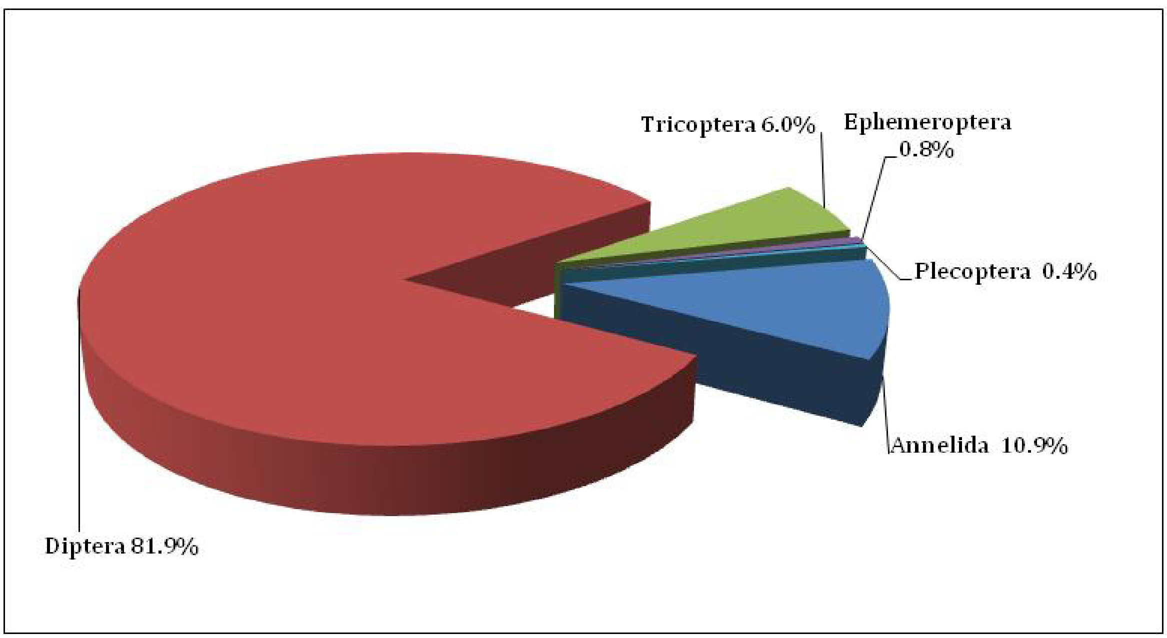

Figure 5. Percentage composition of benthic macroinvertebrate taxa diversity along Amala tributary

(one-way ANOVA, $F_{(7,31)}$ =8.58, P<0.0001), and also along Amala tributary (one-way ANOVA, $F_{(7,31)}$ =9.04, P<0.0001). Further analysis established that Dipteran abundance differed significantly between sites along Amala tributary (one-way ANOVA, $F_{(3,\ 11)}$ = 4.66, P = 0.036) but not along Nyangores tributary. The composition of benthic macroinvertebrate taxa encountered along Nyangores and Amala tributaries are shown in Figure 4 and Figure 5, respectively.

Regression analyses on pooled data of benthic macroinvertebrates revealed that only total dissolved solids (TDS) was predictive of benthic macroinvertebrate in the Mara River (R^2= 0.6170, n=8, P=0.02), while all the other parameters were not.

Table 2. Diversity of benthic macroinvertebrate along Amala and Nyangores tributaries

Parameters	Amala tributary	Nyangores tributary
No of individuals	265	413
Taxa richness (d)	6	13
Shannon-Weiner Diversity Index (H')	0.64	1.12
Shannon Evenness Index (E)	0.3563	0.4351

Benthic Macroinvertebrate Diversity Indices

Macroinvertebrate diversity indices yielded a slightly higher (1.12) Shannon-Weiner diversity index (H^I) along Nyangores tributary than Amala tributary (0.64) (Table 2). Likewise, the Shannon Evenness Index was also relatively higher (0.4351) along Nyangores tributary than Amala tributary (0.3563) (Table 2), but still fell far below the ideal metric value of 1 which is indicative of similar proportions of all species in the system.

DISCUSSION

Mara River tributaries serve as critical water sources for various uses as was exemplified by anthropogenic activities such as bathing, washing clothing, water collection using donkeys for domestic purposes, swimming among other activities that were on-going at the time of sampling. Observations made at sampling points showed that all sites located within the urbanized areas (Bomet and Mulot towns) were impacted, though to varying degrees. Anthropogenic activities contribute to water quality degradation, exposing the users to risk of water borne diseases. The fact that the quality of water at a relatively protected spring located at the upper catchment and flowing into Nyangores tributary remained relatively good in comparison to all other sites sampled was a further indication of the increased anthropogenic role in water quality degradation along the Mara River tributaries. It was established that the most common solid waste disposal method among residents of Bomet and Mulot towns was open dumping, owing to a general lack of clearly demarcated waste disposal sites in both towns. Dumping of garbage along the river banks and in storm drains as was evident at the upper part of Mulot town along Amala tributary may have facilitated their transportation and subsequent deposition in the Mara River tributaries, resulting in water quality degradation. Earlier studies by Inanc et al*.,* (1998) and Martin et al., (1998) both attributed surface water contamination within urbanized areas to solid and liquid waste resulting from anthropogenic activities and deposited either along the banks, in storm drains or directly into the river channel.

Like was the case in the current study, Krhoda, (2002) in a study of pollutant sources into Motoine/Ngong River in Kenya identified uncontrolled disposal of solid waste and excreta from informal settlements along the river continuum, inappropriately sited disposal pits, blockages and/or breakages of sewer lines at major junctions, increased human activities and urban surface runoff as among the sources of pollution into the Motoine/Ngong River. Highest proportions (44.5%) of solid waste were recorded at the upper part of Mulot town along Amala tributary that was characterized by elevated anthropogenic activities. This could have contributed to the high turbidity and suspended solid levels recorded at more disturbed points compared to the low levels of the same at the relatively well protected points as was the case at the upper catchment spring draining into Nyangores tributary. Consistent with the current findings, Bernstein, (2004) also reported that sections of the river flowing through urbanized areas and informal settlements were highly prone to pollution owing to their proximity to numerous pollutant sources such as waste water discharge points, solid waste disposal sites, raw sewage spills, urban runoffs, among others.

The type of solid waste encountered along the banks of the two Mara River tributaries was typical of the ongoing activities in the immediate vicinity. For instance, the upper catchment spring draining into Amala tributary and characterized by elevated anthropogenic activities among them washing and bathing had detergent/soap wrappers, tattered clothing and confectionary wrappers, as the most dominant waste types. Likewise, soft drink and mineral water plastic bottles, grocery polythene bags, detergents and confectionary wrappers were dominant at the middle part of Bomet town, along Nyangores tributary, where motor vehicle washing, bathing and water collection activities were dominant. This could be a strong indicator that most of the waste was likely to have been deposited at the site by the locals and not transported from elsewhere as was also observed by Munala and Mirongo (2011).

Most (96.1%) of the waste encountered along the banks of the two Mara River tributaries was recyclable, a clear indication that the residents of the upper Mara River basin and more so those residing along the banks of Nyangores and Amala tributaries have not embraced the waste management practices of reduction, reuse and recycling, that have been reported to be effective in reducing large quantities of waste. These findings were consistent with those of Ikiara et al. (2004) and Peters (2009) carried out in Nairobi, Kenya and Accra, Ghana, respectively, in which recyclable waste, mainly polythene bags and plastic bottles, were also reported as the most dominant of all the waste generated within the two cities, a clear indication that the problem of littering is definitely not only limited to Bomet and Mulot towns, but many other cities and towns as well. Based on the current study findings, it is apparent that both instream anthropogenic activities and those carried out along the river banks, more so within highly populated areas and urbanized sections have a significant influence on the water quality. The fact that a high population growth will always trigger an equally high demand for produced goods, whose consumption results in increased waste generation, it is important that basin inhabitants are educated through public awareness campaigns of the importance of embracing the waste minimization approaches of reduce, reuse and recycle. Kaseva and Mbuligwe (2000) acknowledged that solid waste recycling is indeed an appropriate and simple approach towards solid waste management and is highly desirable from the environmental, economic and social perspectives.

Physico-chemical Water Quality Parameters

Sewage discharges, urban surface runoff, silt deposition resulting from river bank erosion and driven mainly by livestock activities especially at watering points, poor land use practices among other anthropogenic activities contribute to water quality degradation thus alter the physico-chemical water quality parameters in the river. There were significant differences in DO levels between sites along Amala tributary and also along Nyangores tributary with lower oxygen levels recorded at the upper catchment springs compared to downstream. Contrary to expectations, the relatively lower dissolved oxygen levels recorded at the upper catchment springs draining into the two tributaries compared to the more disturbed sites located within the urbanized section, was probably due to increased biodegradation of organic waste resulting from human and livestock activities especially at the upper catchment spring draining into Amala tributary. Majule (2010) also reported that human, wildlife and livestock activities had significant impacts on water quality of the Mara River through organic matter deposition into the channel, thus probably resulting in the low dissolved oxygen levels observed.

Conductivity levels were significantly higher at the upper catchment springs of both tributaries compared to the other sites located within the urbanized area with the spring draining into Amala tributary recording about 6 times higher than that recorded at the sampling point located at the exit point from Mulot town along the same tributary. The significantly high conductivity levels recorded at the upper catchment spring draining into Amala tributary could have been influenced by the bedrock composition through which the sub-surface water flows before recharging the spring and not necessarily from anthropogenic activities. Studies show that clay soils have materials that tend to ionize when washed and therefore surface waters in regions composed mainly of clay soil can exhibit high conductivity levels (Jordao et al., 2007). This study did not however investigate the soil composition of the area. pH values were close to neutrality for both tributaries but varied significantly between sites along Nyangores tributary. The pH level however fell within the WHO (1993) maximum allowable range of 6.5-8.5 for a drinking water source.

Turbidity levels varied significantly between sites along Amala tributary with highest levels recorded at the highly disturbed sites located within the urbanized section (Mulot town) probably contributed by high input of organic and inorganic substances in water contributed by sediments originating from agricultural activities, livestock activities, urban surface runoff among others sources. Continued accumulation of dissolved and suspended solid in aquatic systems reduces water transparency, effectively impacting on primary productivity, thus affecting benthic macroinvertebrates (Emere and Narisu, 2007). It can also clog gills of aquatic fauna (Edokpayi and Nkwoji, 2007) and destroy critical habitats by settling at the bottom of the water body, forming a blanket over critical spawning and breeding ground, thus interfere with the life cycle of aquatic organisms including benthic macroinvertebrates.

The mean TSS and TDS levels were relatively higher along Amala tributary compared to Nyangores tributary though the differences were not statistically significant. However, considering each tributary separately, significant variations were observed in TSS between sites along Amala and Nyangores tributaries with more disturbed sites recording higher values compared to less disturbed sites. This was a clear indication of the role of anthropogenic activities on water quality degradation. The current findings were consistent with earlier studies carried out in different river basins including those by Jaji et al. (2007) along Ogun River in South West Nigeria, Jordao et al. (2007) in the Turvo Limpo River in Minas Gerais State, Brazil and Surindra et al. (2010) in the Hindon River in India, in which increased turbidity, TSS and TDS levels were observed in the three rivers, along sections flowing through agricultural and urbanized areas.

Benthic Macroinvertebrate Species Diversity and Abundance

Eight benthic macroinvertebrate taxa comprising of 678 individuals were encountered along the two tributaries combined. The 8 taxa recorded were however relatively low compared to those that have been reported in almost similar tropical streams in parts of Africa (Ogbeibu, 2001; Adakole and Annune, 2003). The low species diversity and the dominance by few species could have been due to poor water quality resulting from changes in physico-chemical parameters as well as nutrient levels contributed by increased waste load into the river channel.

Pollution tolerant taxa in the family Chironomidae accounted for over 99% of the dipteran density along both tributaries, while Oligochaetes (also pollution indicator species), in the phylum Annelida were encountered across all sampled sites along Amala tributary and in three of the four sites along Nyangores tributary. On the contrary, indicators of clean water in the orders Ephemeroptera and Plecoptera combined, accounted for only 0.88% of the total benthic macroinvertebrate taxa recorded in the entire study–a possible indication of the impact of increased anthropogenic activities within the basin on water quality of the two tributaries. The dominance of pollution tolerant taxa (Chironomidae and Oligochaetes) over the sensitive and non tolerant taxa could be a pointer to poor water quality at certain points along the two tributaries. The variation is also an indication of the existence of small-scale, localized variability in water quality probably arising from site specific anthropogenic activities along the river continuum.

Consistent with the current study findings, Cortes et al. (2002) observed a clumped distribution among benthic macroinvertebrates which they attributed to small scale variability in a variety of water quality parameters, while Chatzinikolaou et al. (2006) established that pollution and excessive nutrient enrichment from anthropogenic sources can affect benthic macroinvertebrates' trophic relationships as well as their habitats and thus change their community structure and composition. According to Adakole and Annune (2003) changes in physico-chemical parameters can disrupt the life and reproductive cycles of aquatic fauna, impact on food chain and migration patterns or worse still impose physiological stress on even the tolerant macroinvertebrates. Bonada et al. (2006) also reported that continuous exposure of benthic macroinvertebrate to pollution, changes their species composition in response to the magnitude, duration and frequency of the pollutants and level of human disturbance. Like was the case in the current study, the prominence of Chironomidae larvae and Oligochaetes (both pollution indicator species), in many tropical assemblages has also been acknowledged by other researchers like Ogbeibu and Oribhabor (2002) and Osemwegie and Olomukoro (2004) in other aquatic systems.

Contrary to expectations, *Chironomous* spp., (a pollution tolerant species), showed its peak at the upper catchment spring (AS), draining into Amala tributary - a site thought to contain clean water as exemplified by the large number of locals who depended on it as their main source of water for domestic use. The high human activities at this point could have contributed to deterioration of its waters especially because the spring was not protected and wastewater could therefore flow back easily and contaminate the water. In addition, naturally occurring organic detritus matter from decaying leaves and other plant material could have increased organic matter thus influencing the occurrence of certain macroinvertebrates and not others. The prominence of *Chironomus* spp. has been acknowledged by Emere and Narisu (2007) arguing that they dominate benthic macroinvertebrate communities because they hardly show any habitat restriction, and are likely to replace other invertebrate taxa in streams perturbed by human activity. Studies also show that *Chironomus* spp. are common inhabitants of sewage polluted waters that are often rich in nutrients and poor in oxygen (Chackraborty and Das, 2006).

In the current study, benthic macroinvertebrates were not uniformly distributed along the river continuum neither did they exhibit consistent increase or decrease downstream of both tributaries, but instead, varied significantly between sites along both tributaries. This was expected since highly disturbed areas are often favourable to pollution tolerant taxa over the sensitive taxa. These findings were consistent with those of Kibichi et al. (2007) carried out along the River Njoro watershed of Lake Nakuru drainage basin which also reported that benthic macroinvertebrate diversity and abundance, from the upper reaches to lower reaches were highly dependent on anthropogenic activities along the river continuum. Other studies have shown that human activities can alter the community structure of benthic macroinvertebrates as well as influence the abundance of specific taxa (Ogbeibu and Oribhabor, 2002).

Regression analyses on pooled data of benthic macroinvertebrates revealed that only total dissolved solids (TDS) was predictive of benthic macroinvertebrate in the Mara River, while all the other physical chemical parameters did not. The benthic macroinvertebrates could have acquired adaptive mechanisms to enable them survive various environmental conditions. Mandaville (2002) observed that benthic macroinvertebrates are a diverse group that display variations in their tolerance to contaminants, ranging from tolerant to sensitive taxa, and therefore some are able to survive in waters with wide ranging levels of physico-chemical parameters. The lack of a clear relationship between benthic macroinvertebrates and all physico-chemical parameters except TDS along the Mara River tributaries could have been as a result of their physiological adaptations to unfavourable environmental conditions as was also reported by Tyokumbor et al. (2002) in which weak relationships between Diptera, Odonata and Mollusca to water temperature were reported. This implies that most benthic macroinvertebrates have the ability to survive, adapt, migrate or die under favourable or unfavourable environmental conditions as was also observed by Tyokumbur et al. (2002).

The most striking feature though about this study was the overall low diversity of benthic macroinvertebrates along the two tributaries. Considering that Shannon – Weiner diversity index values which normally range between 0.0 – 5.0 and decreases with increasing stress of the aquatic ecosystem (Magurran, 2004) the values recorded in the current study of 1.12 and 0.64 along Nyangores and Amala tributaries, respectively, were still far below the normal range. Likewise, the Shannon Evenness Index which decreases with increasing stress to the ecosystem (Magurran, 2004), was also relatively higher (0.4351) along Nyangores tributary than Amala tributary (0.3563) (Table 2), but still fell far below the ideal metric value of 1 which is indicative of similar proportions of all species in the system. This implies that the species composition was very dissimilar a fact that was indeed exhibited by the dominance and abundance of pollution tolerant taxa (chironomids and oligochaetes) over other taxa including the sensitive taxa (Ephemeroptera and Plecotera).

In conclusion, it is evident that the Mara River tributaries are highly impacted by increased anthropogenic activities especially within urban areas which are contributing to waste discharge into the tributaries, subsequently degrading the water quality. A change in physico-chemical water quality parameters driven mainly by anthropogenic activities also impact negatively on benthic macroinvertebrates and other aquatic biota, though most of them seem to have developed physiological adaptations to unfavorable environmental conditions. A compromised aquatic ecosystem not only inhibits important ecological processes including the natural self purification capability but also puts the health of the people dependent on the waters of the Mara River at increased risk of water borne diseases. There is an urgent need therefore to protect the Mara River water resource. Maintenance of ecological integrity by controlling anthropogenic activities, protection of the river channel and its basin and increased public education and awareness with regard to environmental integrity is recommended.

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Conflict of interest

The authors declare that they have no conflict of interest.

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