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Original Article

Spatio-temporal Effects of Anthropogenic Disturbances on Macroinvertebrates in Subukia River, Kenya

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Anthropogenic disturbances modify river habitat conditions and influence the distribution of biotic communities. However, the effect of anthropogenic disturbances on macroinvertebrates is unknown for the Subukia River, despite its importance as a source of water for the local people and a habitat for organisms. This study was conducted to evaluate the effect of study site locality and seasonal variability on macroinvertebrate characteristics in the Subukia River. Nine study sites were chosen to correspond with livestock watering and human activities such as laundry washing, water abstraction, cultivation, dumping of solid wastes, settlements along the riparian zone and clearance of riparian vegetation. Mean invertebrate abundance, Shannon-Wiener diversity index, a Multimetric index, Taxa richness, Ephemeroptera, Plecoptera, Trichoptera (EPT) abundance and richness and Dominance index were determined. The results of the study showed that study site locality had a significant effect on Taxa richness ($p=0.003$), EPT abundance ($p = 0.003$) and richness ($p=0.02$), Shannon-Wiener diversity ($p=0.003$) and Multimetric index ($p=0.003$). Seasonal variability only had a significant effect on Taxa richness ($p=0.01$). In conclusion, most macroinvertebrate characteristics are influenced by anthropogenic disturbances and are less influenced by seasonal variability.

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INTRODUCTION

Freshwater ecosystems have a major role in sustaining the livelihoods of many people through provision of goods and services such as water, food, wood, and transport. Additionally, freshwater ecosystems act as a habitat for about 10% of the world's total known species, 40% of the global fish species and 30% of all vertebrate species (Strayer & Dudgeon, 2010). However, freshwater ecosystems have been greatly impacted by human activities such as sedimentation, mining, clearance of riparian vegetation, water abstraction, damming, and grazing (Matthews, 2016; Sabater et al., 2018). Pollution associated with rapid population growth and climate change has exacerbated the deterioration of freshwater habitats and biodiversity loss (Woodward et al., 2010; Peters et al., 2013; Wen et al., 2017).

Some tropical freshwater ecosystems have been greatly impacted by humans through loss of forests to agriculture and biomass harvesting, input of toxicants and grazing among other perturbations (Kobingi et al., 2009; Mathooko et al., 2009; Masese & McClain, 2012; Aura et al., 2017). However, there is still lack of information on the effect of anthropogenic disturbances on stream habitat conditions and biota for some of the affected aquatic ecosystems, such as the Subukia River, despite their importance as a source of water for the local communities and habitat for diverse organisms. Such information can guide river managers on the choice of conservation and rehabilitation measures to implement for the affected river sections.

In Kenya, for example, Gichana et al. (2015) evaluated the effect of human activities on benthic macroinvertebrates composition and water quality in the Mara River basin and found that there were increases in nutrient concentrations in agricultural and settlement areas. The Ephemeroptera,

Plecoptera, and Trichoptera (EPT) taxa dominated the least disturbed sites while Diptera dominated the disturbed areas receiving point and non-point solid and liquid wastes from urban areas and settlements. The authors recommended that dumping of solid wastes near streams and rivers should be discouraged to maintain the quality of surface waters, and that there is a need to protect the riparian vegetation and for the treatment of sewerage wastes before release into water resources.

On the other hand, in Brazil, Kuhlmann et al. (2014) assessed the effect of anthropogenic activities on the Paraibuna River habitat conditions and macroinvertebrates and showed that physical-chemical variables such as conductivity, turbidity, nitrates, and phosphates decreased in the downstream protected areas, when compared with the perturbed upstream areas. The Biological Monitoring Working Party index and Taxa richness also portrayed a similar gradient. The results indicated that the anthropogenic activities in the upstream area of the river modified the natural condition of the river and its biota and that the protected zone reduced environmental impacts of anthropogenic disturbances.

In another study, Chi et al. (2018) evaluated the effect of water flow regulation in two Chinese rivers and found that the regulated river reaches had lower mean values for Taxa richness, Shannon-Wiener diversity index, Margalef index, and Fisher index. The study also found that Oligochaeta had higher mean abundance values in the regulated river sections with limnophilic characteristics and high concentration of organic matter in the sediments. Also, the mean abundances of shredding and scraping macroinvertebrate taxa were reduced at the regulated river reaches, compared with connected channels, whereas predatory taxa increased at the regulated reaches. In summary, the

aforementioned studies revealed strong relationships between distribution patterns of invertebrates and longitudinal and lateral connectivity and provided fundamental baseline information for assessing the hydro-ecological effects of river regulation in the future.

Assessment of the effect of anthropogenic disturbances on macroinvertebrates is vital because macroinvertebrates play an important role in nutrient cycling, through breakdown of particulate organic matter, and are vital food resources for some birds, amphibians, and fish (Covich et al., 1999; Dutra & Callisto, 2005; Fogelman et al., 2018). Moreover, macroinvertebrates are abundant and ubiquitous, have relatively low mobility and live in direct association with river substrates, enabling site specific evaluation of river habitat conditions and offer a wide range of observable responses to anthropogenic disturbances (Wallace & Webster, 1996; Aura et al., 2010). Macroinvertebrate-based biomonitoring takes various forms, such as multimetric indices which synthesize data from various levels of biological organisation with the objective of obtaining a single index (Couceiro et al., 2012; Silva et al., 2017).

Other indices take into account species diversity measures, such as Shannon-Wiener Diversity and Dominance index, and the sensitivity of individual taxa such as EPT to environmental changes (Yazdian et al., 2014; Mabidi et al., 2017). Aquatic assessments also use predictive bioassessment tools like the River Invertebrate Prediction and Classification System (RIVPACS), the Australian River Assessment System (AusRivAS) or Assessment by Nearest Neighbour Analysis (ANNA) (Wright et al., 1998; Li et al., 2010; Nichols et al., 2014). Additionally, protocols for rapid bioassessments and for classification of macroinvertebrates into traits are applied (Rawer-Jost et al., 2000; Barbour et al., 2006; White et al., 2018). The current study aimed to evaluate the effect of anthropogenic disturbances on macroinvertebrates in the Subukia River, Kenya, as a representation of riverine ecosystems dependent upon by the local community as a water source. It was hypothesized that anthropogenic disturbances would have an effect on macroinvertebrates composition and abundance by influencing stream habitat conditions.

METHODOLOGY

Study River and Sites Description

The study was conducted at the Subukia River, Kenya, between 27-31 December 2017 (wet season) and 24-28 February 2018 (dry season), to assess potential seasonal variability in macroinvertebrates (Mesa, 2012). Subukia River is a second-order (Strahler, 1957) stream that emanates from the Aberdare ranges and flows into Lake Hannington (Ambraseys, 1991). In the upper reaches, the river flows through an area of intensive agricultural activities (e.g., coffee and tomato farming, livestock farming), where there is heavy use of chemical fertilizers and pesticides (Mugambi, 2009). Other anthropogenic disturbances in the upper reaches emanate from urban areas. In the downstream reaches, the river flows through an area dominated by bush and scrub vegetation, before entering into the aforementioned lake. During the dry period the river is illegally diverted for irrigation purposes in the upstream areas causing it to dry up in the downstream section (Ambraseys, 1991). Much of the rain falls between April and December, while dry periods typically occur between January and March. The major soil types in the area include clay, clay-loam, and silt-loam. The soils in river-line areas are primarily eroded as volcanic sediments and alluvial deposits (John, 2013). Nine sampling sites were selected along the river and were categorized as least, moderately, and heavily disturbed based on observable human and livestock-related impacts (Appendix A). Details of the study sites geographical positions and habitat characteristics are presented in Table 1.

Physico-chemistry and Habitat Assessment

Total dissolved solids, pH, temperature, dissolved oxygen, ammonium, turbidity, conductivity, and chlorophyll-a were measured *in situ* using a multi-parameter water quality sensor (YSI Sonde 6600, Environmental monitoring system, Yellow Springs, OH, USA) during every sampling occasion. Vegetation canopy cover and benthic substrates were assessed visually following Jennings et al. (1999) and Clapcott et al. (2011). Habitat assessment was performed following the qualitative habitat assessment approach described by Kleynhans (1996). Both in-stream and riparian habitat assessments were conducted and were based on a number of habitat modifiers such as water abstraction, river bed and channel

alterations, flow modification, presence of exotic macrophytes, exotic fauna, and solid wastes (Kleynhans, 1996). River habitat impact categories ranging from 0 (no observable impact) to 25 (critically impacted) were assigned to each modifier and multiplied by the weight for each modifier. The results were integrated and divided by a critical value of 25. The score obtained was applied in the designation of a river reach into management classes (*Table 2*).

Table 1: GPS Position and habitat characteristics of the study sites. w and d refer to wet and dry seasons, respectively. Study sites arranged from downstream to upstream.

Site name	Main Land use	Location	Altitude (m asl)	Canopy cover (%)	Pools (p)/ Riffles (r) (%)	Substrates	Habitat assessment scores
Subukia down	Informal Settlements	0°14'14.61"N 36°23'61.30"E	2013	5	r: 90 p: 10	Boulders 40%; cobbles 30%; pebbles 20%; gravel 5%; sand and silt 5%	w: 38.7 d: 26.9
Subukia town 1	Urban	0°11'23.13"N 36°23'13.71"E	2025	50	r: 95 p: 5	Boulders 30%; cobbles 20%; pebbles 30%; gravel 10%; sand and silt 10%	w: 59.3 d: 48.8
Subukia town 2	Urban	0°07'84.05"N 36°22'54.22"E	2028	2	r: 5 p: 95	Bedrock 5%; boulders 30%; cobbles 10%; pebbles 10%; gravel 10%; sand and silt 35%	w: 40.3 d: 39.8
Subukia 3	Riparian Forest. Grassland	0°05'63.95"N 36°23'19.66"E	2029	70	r: 90 p: 10	Bedrock 40%; boulders 30%; cobbles 10%; pebbles 10%; gravel 5%; sand and silt 5%	w : 72.7 d: 75.6
Subukia 4	Riparian Forest/grassland	0°01'17.80"N 36°23'13.71"E	2029	60	r: 5 p: 95	Boulders 2%; cobbles 2%; pebbles 1%; sand and silt 95%	w: 73.9 d: 71.3
Subukia 5	Cultivated land	0°00'84.45"S 36°22'95.86"E	2041	2	r: 90 p: 10	Boulders 10%; cobbles 20%; pebbles 40%; gravel 20%; sand and silt 10%	w: 24.2 d: 24.9
Subukia 6	Cultivated land	0°02'80.76"S 36°22'54.22"E	2161	1	r: 50 p: 50	Bedrock 10%; boulders 30%; cobbles 10%; pebbles 15%; gravel 15%; sand and silt 20%	w: 16.3 d: 14.2
Subukia 7	Livestock farming	0°05'30.60"S 36°22'30.43"E	2187	2	r: 5 p: 95	Cobbles 2%; pebbles 2%; gravel 2%; sand and mud 94%	w: 8.9 d: 9.5
Subukia 8	Livestock farming	0°06'67.42"S 36°22'42.32"E	2226	4	r: 80 p: 20	Cobbles 5%; pebbles 5%; gravel 5%; sand and mud 85%	w: 43.8 d: 52.5

Table 2: Classes for assessment of river habitat conditions (adopted from Kleynhans 1996).

Class	Description	Score (%)
A	Unmodified, natural	100
B	Largely with few modifications. There is a small change of natural habitats and biota, though the functioning of ecosystems is largely unmodified	80 - 89
C	Moderately modified. There has been loss of natural habitats and biotas, but the basic functions of ecosystems are still largely unmodified	60 - 79
D	Largely modified. A large loss of natural habitats, biotas and basic ecosystem functions has occurred	40 - 59
E	The losses of natural habitats, biotas and basic ecosystem functions are extensive	20 - 39
F	Modifications have reached a critical level and the lotic ecosystem has been completely modified, with almost complete loss of natural habitats and biotas. In the worst instances, basic ecosystem functions have been destroyed and changes are irreversible	0 - 19

Macroinvertebrate Sampling and Processing

Triplicate stream benthic macroinvertebrate samples were collected randomly from every site using a kick net sampler (500 μm mesh size) during each sampling occasion. Sampling was performed for a standard period of two minutes at every site by holding the open end of the net against the water current while kicking upstream to dislodge macroinvertebrates (Barbour et al., 1999). The collected samples were placed in plastic sample bottles and preserved with 70% ethanol. The samples were sorted in the laboratory using a dissecting microscope, placed in individual vials, counted, and identified to order and family levels following Nilsson (1996), Gerber and Gabriel (2002), and Bouchard (2012). The abundance values were expressed per unit time (individuals min^{-1}).

Several biotic indices were computed and include Shannon-Wiener diversity index, Taxa richness, EPT richness, and a multimetric index (Shannon & Weaver, 1949; Washington, 1984; Herman & Nejadhashemi, 2015). Taxa richness and EPT richness are determined by counting the overall taxa and EPT taxa present, respectively. The Shannon-Wiener diversity index considers different characteristics of macroinvertebrates such as taxa richness, evenness in distribution, and abundance (Spellerberg & Fedor, 2003). A multimetric index is determined by combining several macroinvertebrate characteristics (e.g., diversity) and evaluates the condition of biotic communities based on the ecological quality ratio, i.e., the ratio between observed conditions and a predicted reference condition (Poikane et al., 2016). The value varies from 0 to 1, with 0

indicating poor (degraded) ecological condition, and a value near 1 indicating a very good ecological condition, with no or only minimal deviation from the unperturbed ecological condition (Poikane et al., 2016).

The Shannon-Wiener diversity index (H') was calculated as given in the following equation:

$$H' = - \sum_{(i)} \left[\frac{n_i}{N} * \ln \left(\frac{n_i}{N} \right) \right] \quad (i)$$

where n_i is the number of individuals belonging to i species and N is the total number of individuals (Shannon & Wiener, 1949). Dominance index (d) was calculated as follows:

$$d = \ln(n/N)$$

(ii)

where n is the number of individuals belonging to species and N is the total number of individuals in a sample.

Data Analysis

The effect of study site locality and seasonal variability on macroinvertebrate biotic indices was tested using Linear Mixed-Effect Models (LMM) (Bates et al., 2015), with study site locality and seasonal variability as fixed factors, and seasonal variability as an interaction term with study site locality. The p -values were corrected in multiple tests following Holm (1979) and the distribution of data was assessed according to Zuur et al. (2009). Post-hoc assessments were performed using Tukey

contrasts (Hothorn et al., 2008) and statistical analysis were performed using R statistical Package (R Core Team, 2012).

RESULTS

Habitat and Physico-chemical Characteristics

The altitude (metres above sea level) of the study sites varied from 2013 m (Subukia down) to 2226 m (Subukia 8) (Table 1). The Subukia 3, Subukia 4, and Subukia town 1 study sites had higher (>50 %) canopy cover intensities compared to the other study sites (Table 1). Most study sites had relatively low percentage of fine substrates (i.e., sand and silt), apart from Subukia 4, Subukia 7 and Subukia 8 where fine substrates constituted greater than 80% of total substrates. The qualitative habitat assessment scores ranged from 8.9% at Subukia 7 to 75.6% at Subukia 3. Water temperature ranged from 11.8°C at Subukia 6 to 17.7°C at Subukia 8 (Table 3). Dissolved oxygen content ranged from 3.3 mg L⁻¹ (Subukia 4) to 8.6 mg L⁻¹ (Subukia 5). Ammonium, turbidity, conductivity, chlorophyll-a, pH, and total dissolved solids ranged from 0.01 mg L⁻¹ (Subukia 7) to 0.54 mg L⁻¹ (Subukia town 1), 0.3 NTU (Subukia 4) to 10.9 NTU (Subukia town 1), 80 µS cm⁻¹ (Subukia 6) to 166 µS cm⁻¹ (Subukia 3), 1.8 µg L⁻¹ (Subukia 3) to 7.8 µg L⁻¹ (Subukia 7), 6.8 (Subukia town 2) to 9.1 (Subukia 3) and 0.06 g L⁻¹ (Subukia 8) to 0.14 g L⁻¹ (Subukia 3) respectively (Table 3)

Table 3: Water physico-chemical characteristics of study sites in the Subukia River.

Site name	Main Land use	pH	TDS	TEMP	DO	NH ₄ ⁺	TUR	CON	CHL
Subukia down	Settlement	8.8 (w)	0.09 (w)	13.1 (w)	5.4 (w)	0.42(w)	9.5 (w)	110 (w)	2.2 (w)
		7.8 (d)	0.13 (d)	13.2 (d)	7.8 (d)	0.11(d)	2.2 (d)	160 (d)	3.8 (d)
Subukia town 1	Urban	8.6 (w)	0.09 (w)	13.6 (w)	4.4 (w)	0.54(w)	10.9(w)	110 (w)	2.9 (w)
		6.9 (d)	0.13 (d)	13.6 (d)	7.9 (d)	0.13(d)	1.1 (d)	157 (d)	4.0 (d)
Subukia town 2	Urban	8.9 (w)	0.09 (w)	14.6 (w)	5.3 (w)	0.13(w)	9.9 (w)	112 (w)	2.2 (w)
		6.8 (d)	0.12 (d)	13.6 (d)	8.4 (d)	0.10 (d)	0.4 (d)	150 (d)	4.9 (d)
Subukia 3	Riparian	9.1 (w)	0.09 (w)	16.3 (w)	4.7 (w)	0.13(w)	8.3 (w)	124 (w)	3.5 (w)
	Forest/grassland	7.5 (d)	0.14 (d)	14.6 (d)	7.7 (d)	0.11(d)	6.4 (d)	166 (d)	1.8 (d)
Subukia 4	Riaprian	8.2 (w)	0.08 (w)	15.9 (w)	3.3 (w)	0.09(w)	9.7 (w)	105 (w)	2.6 (w)
	Forest/grassland	7.5 (d)	0.11 (d)	15.6 (d)	8.1 (d)	0.02 (d)	0.3 (d)	138 (d)	4.3 (d)
Subukia 5	Farmland	8.8 (w)	0.08 (w)	12.2 (w)	4.5 (w)	0.10(w)	8.1 (w)	98 (w)	2.3 (w)
		7.4 (d)	0.10 (d)	15.3 (d)	8.6 (d)	0.06 (d)	0.8 (d)	135 (d)	4.0 (d)
Subukia 6	Farmland	8.8 (w)	0.07 (w)	11.8 (w)	4.2 (w)	0.11(w)	6.3 (w)	80 (w)	2.6 (w)
		7.7 (d)	0.10 (d)	12.3 (d)	8.4 (d)	0.01(d)	4.7 (d)	127 (d)	3.1 (d)
Subukia 7	Grazing	8.9 (w)	0.07 (w)	11.9 (w)	8.3 (w)	0.10(w)	9.2 (w)	82 (w)	2.8 (w)
		7.5 (d)	0.09 (d)	12.7 (d)	8.3 (d)	0.01(d)	4.1 (d)	113 (d)	7.8 (d)
Subukia 8	Grazing	8.8 (w)	0.06 (w)	17.7 (w)	4.6 (w)	0.11(w)	11.6(w)	92 (w)	3.2 (w)
		na	na	na	na	na	na	na	Na

TDS, TEMP, DO, NH₄⁺, TUR, CON, CHL, d, w and na refers to total dissolved solids (mg L⁻¹), temperature (°C), dissolved oxygen (mg L⁻¹), ammonium (mg L⁻¹), turbidity (NTU), conductivity (μS cm⁻¹), chlorophyll-a (μg L⁻¹), dry season, wet season and not available. Study sites arranged from downstream to upstream.

Macroinvertebrates

A total of 32 macroinvertebrate taxa were collected from the study sites and the most abundant included Baetidae, Heptageniidae, Chironomidae, Simuliidae, and Ostracoda. Baetidae and Heptageniidae were found in large numbers (> 50 individuals min^{-1}) at Subukia town 1, and Chironomidae were found in large numbers (> 150 individuals min^{-1}) at Subukia 3 and Subukia 8 sites. Simuliidae were found in large numbers (> 80 individuals min^{-1}) at Subukia 3, Subukia 5 and Subukia 8 sites. Similarly, Ostracoda were most abundant (89.3 ± 83.4 individuals min^{-1}) at the Subukia 8 site. Subukia 8 study site dried up during the dry season and, therefore, could not be sampled then. Seasonal

variability had a statistically significant effect on taxa richness, but invertebrate abundance, EPT abundance, EPT richness, Shannon-Wiener diversity, Multimetric index, and Dominance index were not significantly influenced by seasonal variability (Table 4). The seasonal variability $\times$ site locality interaction terms were only statistically significant for taxa richness and EPT abundance (Table 4).

Table 4 shows *F*-ratio and *p*-values for the mixed effects models assessing the effect of site locality and seasonal variability on macroinvertebrate characteristics. Significant values ($p < 0.05$) are highlighted in bold. df = degrees of freedom. The Holm-corrected *p*-values are indicated.

Table 4: -ratio and *p*-values for the mixed effects models assessing the effect of site locality and seasonal variability on macroinvertebrate characteristics

Effect	Site locality			Seasonal variability			Site locality $\times$ Seasonal variability		
	df	<i>F</i> -ratio	<i>p</i> -value	df	<i>F</i> -ratio	<i>p</i> -value	df	<i>F</i> -ratio	<i>p</i> -value
Invertebrate abundance	8	0.9	0.5	1	2.2	0.3	8	2.7	0.06
Taxa richness	8	10.1	0.003	1	8.8	0.01	8	2.2	0.04
EPT abundance	8	7.6	0.003	1	1.7	0.19	8	2.6	0.04
EPT richness	8	6.9	0.02	1	1.8	0.38	8	0.6	0.76
Shannon-Wiener diversity	8	14.8	0.003	1	3.9	0.1	8	2.0	0.1
Multimetric index	8	7.6	0.003	1	0.01	1	8	0.4	1
Dominance index	8	1.7	0.4	1	2.0	0.4	8	1.0	0.4

The highest mean macroinvertebrates abundances were recorded at Subukia 8 (438.7 ± 349.1 individuals' min^{-1}), Subukia down (354 ± 47 individuals min^{-1}), and Subukia 3 (349 ± 90.1 individuals min^{-1}), while the lowest mean macroinvertebrates abundance was recorded at Subukia 7 (16 individuals min^{-1}) (Figure 1). Mean EPT abundance ranged from 10.7 ± 5.3 individuals min^{-1} at Subukia 7 to 181.7 ± 63 individuals min^{-1} at Subukia town 1 (Figure 2). Invertebrate abundance was not significantly

influenced by site locality or seasonal variability ($p > 0.05$). However, abundances of EPT taxa were statistically significantly influenced by site locality and the site locality $\times$ seasonal variability interaction term was significant (Table 4). Mean Shannon-Wiener diversity index ranged from 0.2 (± 0.2) at Subukia 7 to 2.0 (± 0.07) at Subukia town 2 (Figure 3), and Tukey contrasts showed that Subukia 7 had lower mean values for Shannon-Wiener diversity index than the other sites ($p < 0.05$).

Figure 1: Mean macroinvertebrates abundance (individuals min⁻¹) at the Subukia River study sites during wet and dry seasons. Error bars denote SE.

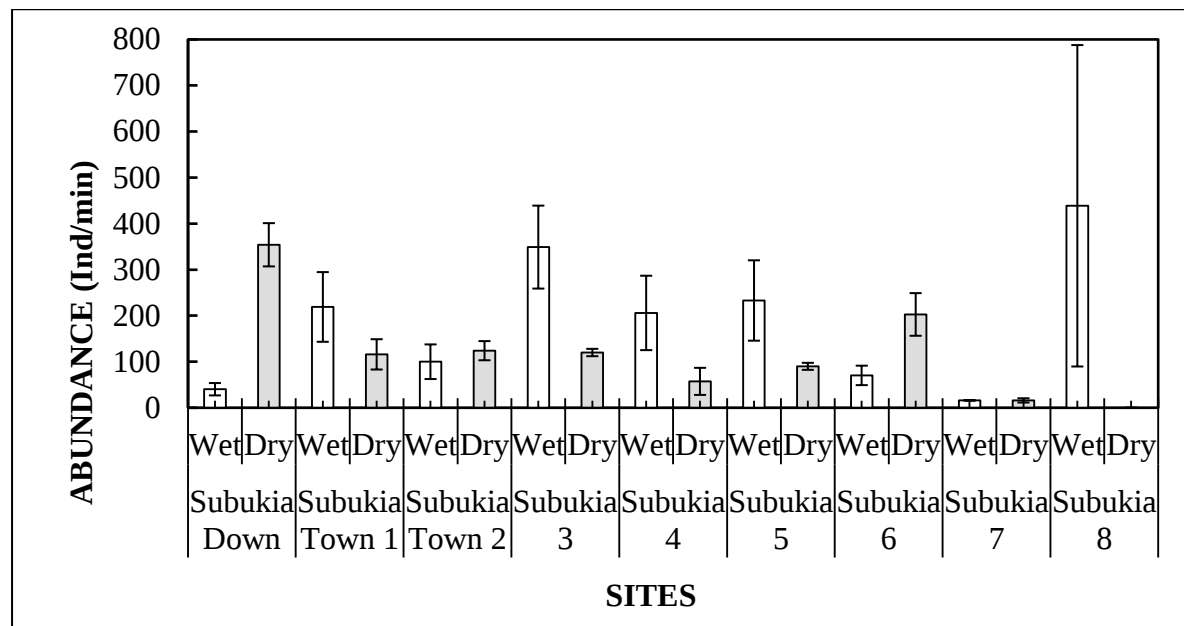


Figure 2: Mean Ephemeroptera, Plecoptera, Trichoptera (EPT) abundance (individuals min⁻¹) at the Subukia River study sites during wet and dry seasons. Error bars denote SE.

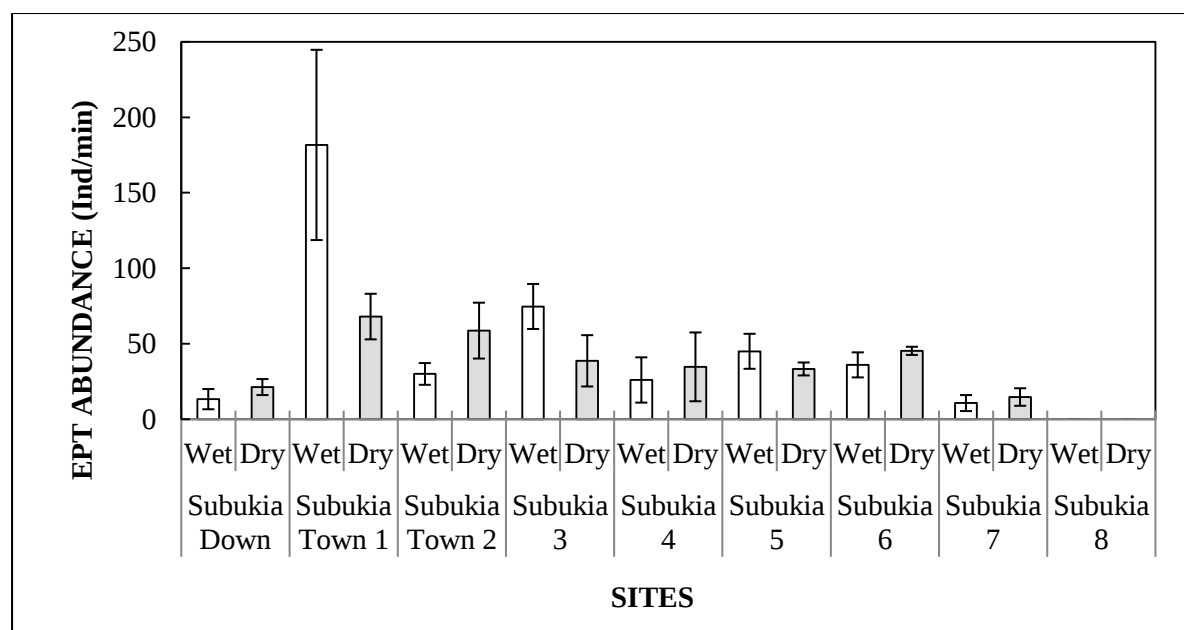
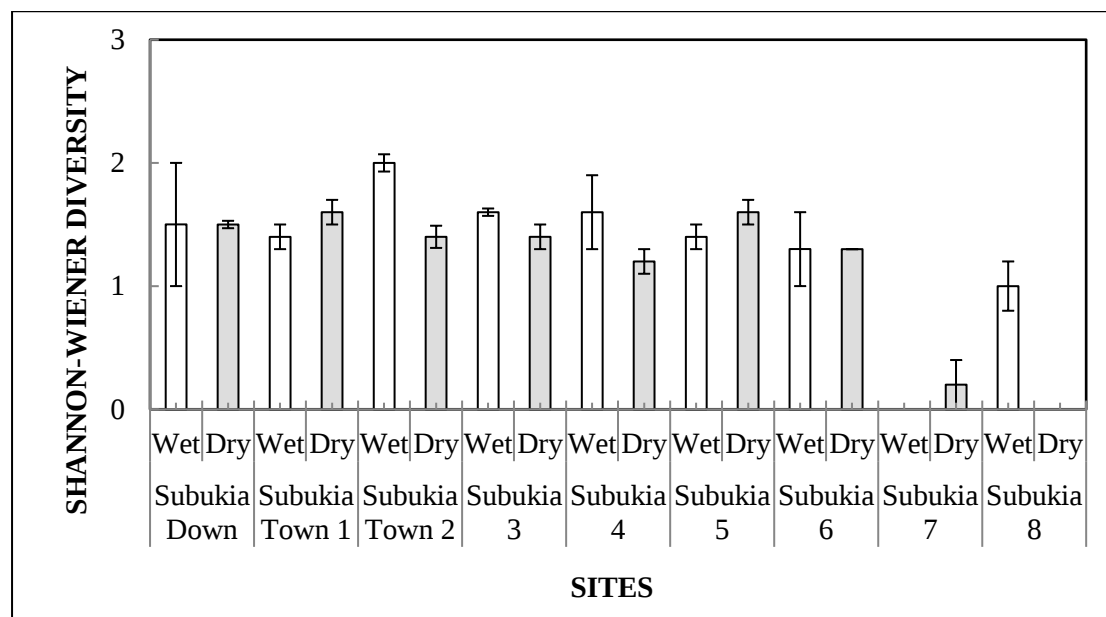


Figure 3: Mean Shannon-Wiener Diversity values at the Subukia River study sites during wet and dry seasons. Error bars denote SE.



Subukia town 1 had the highest mean multimetric index value (0.7) while Subukia 8 had the lowest (0.2) mean multimetric index value (Figure 4). With regard to Dominance index, the highest mean value (2.1) was recorded at Subukia 6 while the lowest mean value (0.2) was recorded at Subukia town 2 (Figure 5). The Shannon-Wiener diversity index and Multimetric index were statistically significantly influenced by site locality, although no significant effects were

found for seasonal variability and site locality $\times$ seasonal variability interaction terms (Table 4). Tukey contrasts indicated that Subukia 7 had lower mean values for Shannon-Wiener diversity values than the other sites (all $p < 0.05$). Tukey contrasts indicated that Subukia 8 had lower mean values for EPT richness than the other sites, and that the Multimetric index value at the site was significantly lower than at Subukia 1, Subukia 2, Subukia 3 and Subukia 6 ($p < 0.05$).

Figure 4: Mean multimetric index values at the Subukia River study sites during wet and dry seasons. Error bars denote SE.

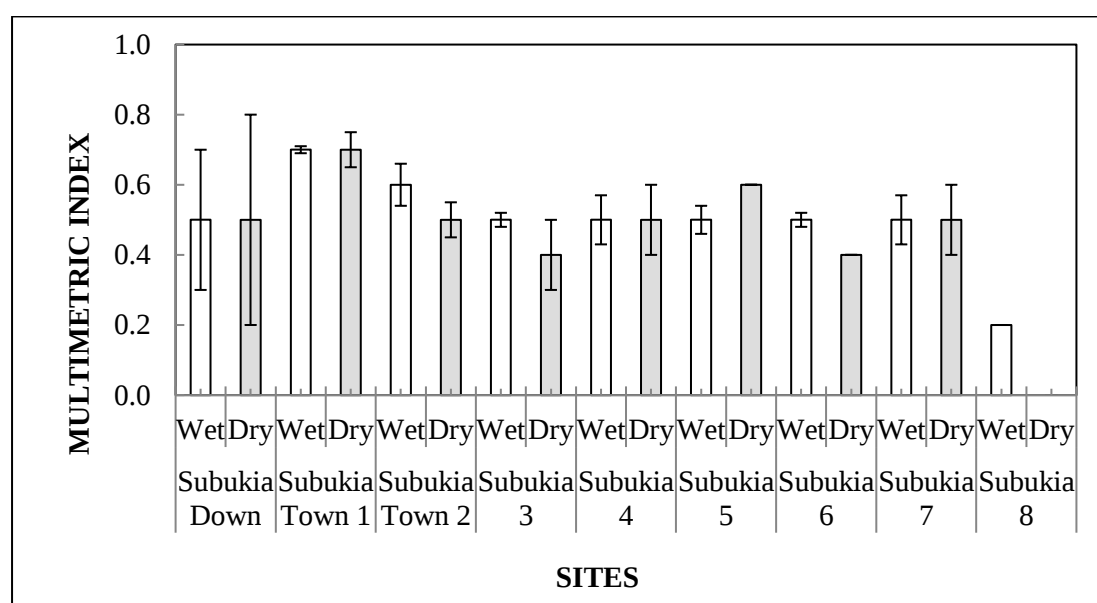
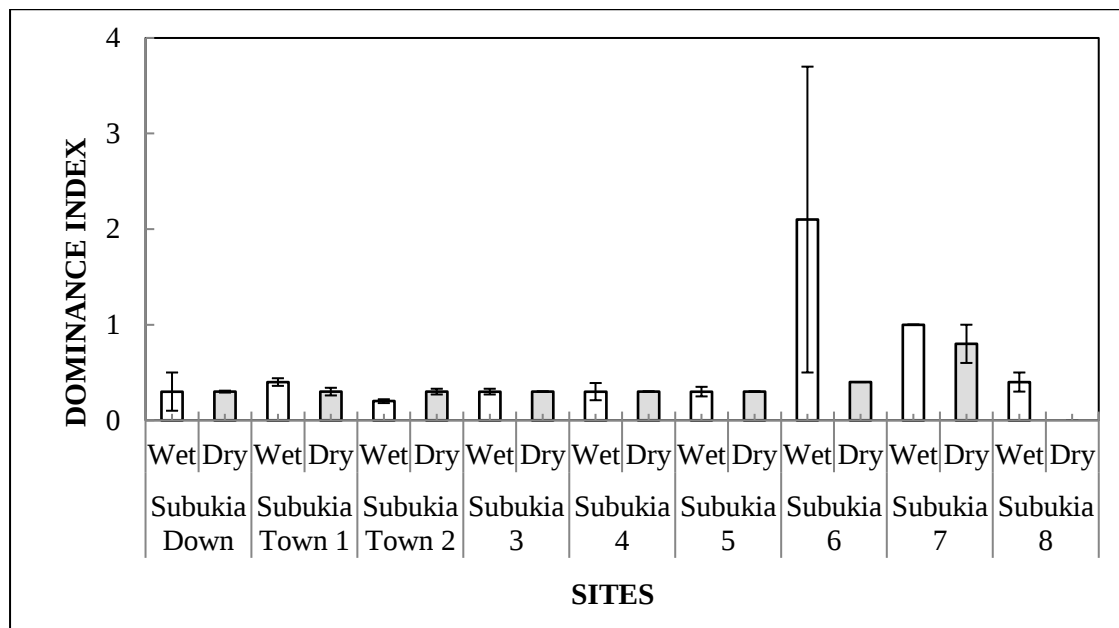


Figure 5: Mean Dominance Index values at the Subukia River study sites during wet and dry seasons. Error bars denote SE.



DISCUSSION

Habitat and Physico-chemical Characteristics

The high water temperature recorded at Subukia 8, compared with other sites such as Subukia 7, is most likely caused by release of water with high temperature from the Tetu water storage reservoir. For example, Ménendez et al. (2012) reported that mean water temperature was significantly increased below a small reservoir that released deep water when compared with free flowing river sections. Maxted et al. (2005) and Lessard and Hayes (2003) also found that water temperature was significantly increased below small reservoirs that released surface water. However, reservoirs can also have limited effects on river habitat and physico-chemical factors depending on factors such as water retention time, depth from which water is released to the downstream areas and reservoir volume (Principe, 2010; Mendoza-Lera et al., 2012; Mbaka & Schäfer, 2016).

The high riparian vegetation canopy cover intensity (>50 %) at Subukia 3, Subukia 4, and Subukia town 1 can be attributed to the fact that there were limited livestock and human induced disturbances. Presence of humans and livestock near rivers lead to increased trampling and clearance of vegetation causing a decline in canopy cover. Mathooko and Kariuki (2000) demonstrated that human-induced disturbances, such as grazing, led to reduction in riparian

vegetation cover and that the impact was particularly severe near livestock watering points.

In sites severely affected by livestock trampling, such as Subukia 7, the banks may be eroded leading to increased sedimentation and percentage of fine substrates in the river bed. However, the hydro-morphological characteristics of a site (e.g., Subukia 4), such as percentage pools, may make a site to be more depositional in nature and to have a high percentage of fine substrates, albeit being less influenced by human and livestock related activities. Thus, it is important to differentiate such sites from sites affected by anthropogenic disturbances when interpreting human-related impacts on biota.

The high ammonium concentrations recorded at the study sites during the wet season may be due to increased runoff that brought dissolved substances from the riparian areas. Also, the high water turbidity recorded during the wet season can be attributed to input of suspended and dissolved particles into the river from the riparian zones by runoff. Water quality parameters such as turbidity and ammonium concentration may also be influenced by surrounding human activities (Peters & Meybeck, 2000). For example, the highest ammonium values were recorded in areas surrounded by settlement and urban areas. Similarly, the highest turbidity values were recorded from sites surrounded by urban and grazing lands.

The high water conductivity recorded during the dry period can be attributed to factors such as increased presence of livestock near the river which may have introduced urine and faeces into the water or conductivity may have increased with temperature during the dry period (Pal et al., 2015). The high chlorophyll-a mean concentrations recorded at the study sites during the dry season can be attributed to the low mean turbidity values recorded during this period. High turbidity reduces light penetration into the water column, reducing autotrophic production by aquatic plants. Additionally, high discharge during the wet season may dislodge benthic algae and other plants from the substrates and impede autotrophic production, reducing chlorophyll-a concentrations.

Macroinvertebrates

The number of macroinvertebrate taxa recorded in this study (32) was higher than that recorded (8-18) in some catchments in Kenya (Anyona et al., 2014; M'Erimba et al., 2014). This difference can be attributed to differences in major factors that influence macroinvertebrates distribution such as substrates, riparian vegetation type, or seasonal variability (Abelho & Graça, 1996; Duan et al., 2008; Stark & Phillips, 2009; Bossley & Smiley, 2019). For example, Duan et al. (2008) evaluated the effect of substrate type and showed that macroinvertebrate taxa richness was much higher in the substrate composed of cobbles, hewn stones and pebbles, compared to substrate composed of coarse and fine sand. Riparian vegetation type was shown to affect the abundance and composition of macroinvertebrate taxa by Abelho & Graça (1996). The authors showed that streams flowing through deciduous forests had higher invertebrates abundance and more taxa than streams flowing through eucalyptus forests. The authors suggested that the type of vegetation influences macroinvertebrates by altering the quality and quantity of organic matter, a basal food resource for stream communities (Tank et al., 2010). Stark and Phillips (2009) investigated the effect of seasonal variability on macroinvertebrates and found that taxa richness and EPT richness were significantly influenced by seasonal variation. The equipment used during sampling and levels of anthropogenic disturbances between streams are also important factors that may explain the differences in taxa richness between our study and previous studies

(Muzaffar & Colbo 2002; Florencio et al., 2012; Letovsky et al., 2012; M'Erimba et al., 2014).

Chironomidae had the highest mean abundance at the dammed Subukia 8 site, whereas Baetidae and Heptageniidae had the highest mean abundances at Subukia town 1 site. Temperature is an important factor that influences the distribution of macroinvertebrates that may have led to high mean abundances of Chironomidae at Subukia 8. For example, Lessard and Hayes (2003) investigated the effect of elevated water temperature below reservoirs on macroinvertebrates and found that sensitive taxa such as EPT reduced in richness and abundance while tolerant taxa such as Chironomidae increased in abundance. Another study investigated the effect of a changed temperature regime along a regulated river and found that chironomids were the dominant macroinvertebrate group below the reservoir (Saltveit et al., 1994). The authors suggested that a reduction in thermal range in connection with damming will cause a reduction in macroinvertebrate species diversity and species with specific temperature requirements may be eliminated.

The high abundance of chironomids at Subukia 8 can also be attributed to factors such as high percentage (85%) of fine sediments recorded at this site or grazing of livestock along the river banks. Fine sediment deposited at the downstream side of water storage reservoirs is likely to have a high amount of fine organic matter released from reservoirs (Newbern et al., 1981; Angradi & Kubly, 1995), and may favour invertebrates such as oligochaetes and chironomids which primarily feed on sedimentary organic matter (Hirabayashi & Wotton, 1998; Syrovátka et al., 2009). Additionally, localized bank erosion from livestock trampling and release of faeces may increase fine sediment and organic matter in-stream. Subsequently, this may increase the abundance of the aforementioned taxa.

Macroinvertebrate taxa such as Simuliidae, which filter fine particulate organic matter from the water column, may also achieve high abundances at the downstream side of water storage reservoirs (Bredenhand & Samways, 2009; Principe, 2010). However, such disturbed stream areas, including Subukia 6 and 7, may be inhabited by comparatively few taxa as indicated by the Dominance index (0.4 – 2.1). Sensitive taxa such

as EPT may be greatly reduced in such areas. For example, Bredenhand and Samways (2009) evaluated the effect of a reservoir on macroinvertebrates and found that the mean abundances of EPT taxa were greatly decreased below the reservoir. However, the mean abundances of Chironomidae and filter feeders increased substantially downstream from the reservoir. Another study found that a reservoir had minimal effect on macroinvertebrates at the downstream side and that Baetidae was the only major taxonomic group that showed significant variability with the composition of substrates (Sharma et al., 2005). It was observed that the effect of reservoir on river habitat conditions was primarily restricted to the area just upstream of the reservoir, potentially as a consequence of deposition of sediment and modification of water flow velocity. Thus, reservoirs may have varied effects on macroinvertebrates structural and functional composition depending on their effects on river habitat conditions (e.g., flow) and resource subsidies as demonstrated by Ellis and Jones (2013) through meta-analysis.

The low mean macroinvertebrate abundance recorded at Subukia 7 can be attributed to disturbances associated with livestock at the site. At this site, livestock drank water from within the river, causing severe erosion of the banks, physical trampling of river substrates and released faeces and urine into the river. Erosion of river banks potentially increases input of fine sediment into the river and clogs interstitial habitat spaces. Physical trampling by animals can also cause compaction of river substrates and reduce production of food resources, such as algae, and retention of woody debris which serve as refugia against currents and predators (Meadows, 2001; Scrimgeour & Kendall 2003; McIver & McInnis, 2007). Disturbed stream areas may also have high turbidity which may reduce autotrophic production, negatively affecting grazing macroinvertebrates. However, it appears that the effect of human and livestock induced disturbances on macroinvertebrates depend on whether the in-stream habitat is affected, given that study sites such as Subukia down and Subukia town 1, where people and livestock accessed the river from the banks, had comparatively higher mean macroinvertebrate abundance than Subukia 7. Thus, to minimize the effect of human and livestock induced anthropogenic disturbances in streams, in-stream perturbations should be minimal.

The low mean macroinvertebrate Shannon-wiener diversity and taxa richness values recorded at Subukia 6, 7 and 8 can be attributed to the human activities observed in these sites, such as clearance of riparian vegetation cover, livestock grazing, pollution, sedimentation, water abstraction and reduced flow. For example, Chatzinikolaou et al. (2006) investigated the effect of anthropogenic pressures, such as water abstraction, on macroinvertebrates and found that mean abundance, diversity and taxa richness were significantly reduced at the greatly impacted sites. A different study investigated the effect of stream-bed sediment on macroinvertebrates and found that taxa richness was mainly affected by substrate type and flow conditions (Duan et al., 2009). Stream areas covered by sand had no macroinvertebrates colonizing them and the mean abundance of sensitive EPT taxa was highest in cobble, gravel and moss-covered bedrock. These findings are in agreement with our study findings because Subukia 7, a site affected by fine sediment deposition, had lower mean EPT abundance than a study site less impacted by sedimentation such as Subukia town 1. Subukia 8 site had the lowest mean multimetric index value (0.2), indicating degraded ecological conditions. This finding is in agreement with other studies where degraded sites had comparatively low multimetric index values (e.g., Menetrey et al., 2011; Aazami et al., 2015; Silva et al., 2017).

The significant interaction between site locality and seasonal variability for taxa richness and EPT abundance indicates that the effect of seasonal variability on the two biotic indices is significantly modified (Bauer & Curran, 2010; Hayes et al., 2012) by site locality and vice versa. Thus, the two factors can be taken as dependent factors primarily affecting taxa richness and EPT abundance. Although study site locality had a significant effect on macroinvertebrate biotic indices such as EPT richness, Shannon-Wiener diversity and multimetric index, seasonal variability only had a significant effect on taxa richness. The significant effects of site locality on the aforementioned macroinvertebrate metrics suggests that these metrics are robust enough to apply in lotic biomonitoring during the varied seasons.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, study site locality had significant effects on macroinvertebrate characteristics such as diversity. Seasonal variability only significantly affected taxa richness. In-stream disturbances such as trampling have the greatest impact on stream habitat and biota and restoration efforts should be initiated for the impacted sites. Future studies should consider other common disturbances affecting lotic systems such as road construction, physical structures such as culverts and mining.

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APPENDICES

Appendix A: Site name and human and livestock-related activities at the Subukia River study sites. Sites arranged from downstream to upstream.

Site name	Human and livestock-related related activities
Subukia down (Sub. D)	Site located downstream of Subukia town. Left bank: cattle grazing on banks, plantation of bananas and maize. Right bank: human settlement, small-scale farm, <i>Grevillea</i> sp. and <i>Eucalyptus</i> sp. trees growing within 10 m from the river, washing of farm implements from the banks. Paths leading to river on both banks. Water abstraction from both banks mainly during dry season, compared to wet season. In-stream activities by humans and livestock minimal during study period. Site categorized as moderately disturbed.
Subukia town 1 (Sub. T1)	Site located in Subukia town. There were shops at the left and right banks. The shops dealt in electronics, hair salon, barber shop and sale of food stuffs. The main human related activity at the site was water abstraction from the right bank and no livestock were observed at the site. Instream activities by humans and livestock were minimal. Site categorized as moderately disturbed.
Subukia town 2 (Sub. T2)	Located near the road leading to Nakuru town. Left bank: activities included a small-scale farm, bar and restaurant, car garage. Right bank: shops, bar and restaurant, washing of cars. Left bank was eroded and water abstraction using a pump and jerrycans from the banks was common during dry season. Site had been dammed using sand bags increasing water level. Site was categorized as moderately disturbed.
Subukia 3 (Sub. 3)	Located upstream of Subukia town. Left bank: had vegetation such as grass and shrubs that formed a closed canopy. Right bank: shrubs grew along the river. No livestock or erosion were observed and there was no evidence of water withdrawal. Site was categorized as least disturbed and the bottom substrates were dominated by bedrock.
Subukia 4 (Sub. 4)	Located along road leading to the Subukia National Shrine. Left bank: Grass grew to the river banks and there were <i>Grevillea</i> sp. trees. There was a church nearby. Right bank: there were tall trees and shrubs. River banks were not eroded and there were no livestock at the site. Also there was no water abstraction. Site was designated as least disturbed.
Subukia 5 (Sub. 5)	Located on the road leading to Subukia National Shrine. Left bank: farming of bananas, maize, beans. Right bank: there was a murram road leading to Subukia town and a small-scale farm. The river banks were eroded by livestock that came into the river to drink water. There were cattle droppings along the river banks and instream. Water abstraction by humans was prevalent during dry season. Site designated as heavily disturbed.
Subukia 6 (Sub. 6)	Located near the Subat flower farm. Right bank: heavily used by humans and animals in water abstraction during both wet and dry season, vegetation and grass cleared and multiple paths leading to river noted, animal droppings on bank. Left bank: flower farm and a vegetation strip. This was one site with heavy water abstraction by humans and livestock. Site categorized as heavily disturbed.
Subukia 7 (Sub. 7)	Located at the Tetu bridge. Right bank: there was a field with <i>Eucalyptus</i> sp. trees. Left bank: there was a vegetable farm. Left and right banks were heavily eroded by cattle that came to drink water. Animal excreta observable on both banks and in the river. Site had highest density of livestock (goats and cows) among all sites and bottom was dominated by fine substrates. Site designated as heavily disturbed.
Subukia 8 (Sub. 8)	Located at downstream side (~ 5 m) of Tetu water storage reservoir. Right bank: mainly grassland and grazing. Left bank: grassland and <i>Eucalyptus</i> sp. trees. Left bank eroded by livestock. Reservoir released surface water. Reservoir water was as a result of Subukia River diversion and the outlet of reservoir led to a marshy area at the downstream side. The site dried up during the dry period after decrease in reservoir water levels. Site designated as moderately disturbed.