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Species composition and distribution of mayflies (Ephemeroptera) in relation to land use systems along the Thika River, Kenya

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Mayflies (order Ephemeroptera) are widely distributed and commonly used in biological assessment of water quality because of their sensitivity. Their application as bio-indicators in tropical streams and rivers, however, is hampered by lack of adequate information about their status in many such ecosystems. The current study investigated their species composition, distribution and abundance in relation to land use and water quality characteristics of the Thika River, Kenya. The Thika River emanates from the Aberdare Ridges and flows through forest, agricultural and urban catchments. Sampling was carried out at three sites representing forest, agricultural and urban land use systems. Dissolved oxygen, conductivity, total dissolved solids, temperature and transparency were measured *in situ* at each sampling station. Macroinvertebrates were sampled using a modified Hess sampler and the Ephemeropterans were later identified and sorted in the laboratory. Thirteen Ephemeroptera genera belonging to six families were obtained. Mean larvae abundance was 1 238 ind. m^{-2}. *Acanthiops* (70.4%) and *Afronurus* (13.3%) dominated the community at all sites. The current study revealed that decreasing Ephemeroptera taxa abundance along the river channel indicates decreasing water quality.

Keywords: abundance, *Acanthiops, Afronurus,* macroinvertebrates, water quality

Introduction

Good water quality is essential because it maintains the ecological processes that support aquatic biodiversity. Rivers emanating from forested catchment areas are generally of good water quality, as a result of minimal human activities (Garcia et al. 2014). However, declining water quality as a result of environmental perturbation affects the stability of the biodiversity, hence hindering the ecosystems services and functions of aquatic ecosystems (Ndung'u 2014). Water quality deterioration is, therefore, a significant threat in many rivers (Ndaruga 2004; Arimoro et al. 2007), which is as a result of growth in human population (DeSA 2013). In particular, industrialization, urbanization and agricultural activities have led to increased nutrient levels in the water bodies (Heathwaite et al. 1996). The Thika River emanates from a heavily forested catchment and then flows through various land use types including large coffee plantations, horticultural and animal farms, where it is heavily impacted by agricultural, industrial and domestic pollution.

The method of water quality assessments using macroinvertebrates as indicators has been widely exploited in temperate areas. Ephemeroptera is a widely distributed order of insects with >2 500 described species worldwide (Hubbard 1990). There are 23 families and 371 genera worldwide (Hubbard 1990). In Lake Erie, Ephemeroptera is successfully utilised in bio-monitoring (Schloesser and Nalepa 2002). A recent study showed peak emergence of burrowing mayfly nymphs (*Hexagenia* spp.) that was associated with an improvement of the ecosystem health (Schloesser and Nalepa 2002). Mayflies play an essential role in almost all undisturbed freshwater communities, and their larvae frequently form a considerable part of the material sampled during bio-monitoring procedures (Bauernfeind and Moog 2000). In tropical areas, the method has been given less attention while most water quality assessments are done using the physical and chemical processes. Aschalew and Moog (2015) found that until present, conventional physico-chemical techniques are used in some streams for monitoring the river water quality. The current study therefore aimed at investigating the community structure of mayflies in relation to water quality changes along the Thika River, Kenya. This is by first assessing the water quality status of the Thika River as it flows downstream through the various land use systems, and relating this to the composition, distribution and abundance of Ephemeroptera in relation to water quality changes.

Materials and methods

Study area

The centroid for the Thika River catchment lies at 36°47′31.3″ E, 0°46′52.2″ S (Figure 1). Annual precipitation and temperature are relatively stable with the coolest months occurring from June to August. The hottest air temperatures are normally from December to March. The average annual rainfall in Thika Town and its surrounds ranges between 900 and 1 250 mm per year. Lake Ol-borosat influences the hydrology of Aberdare

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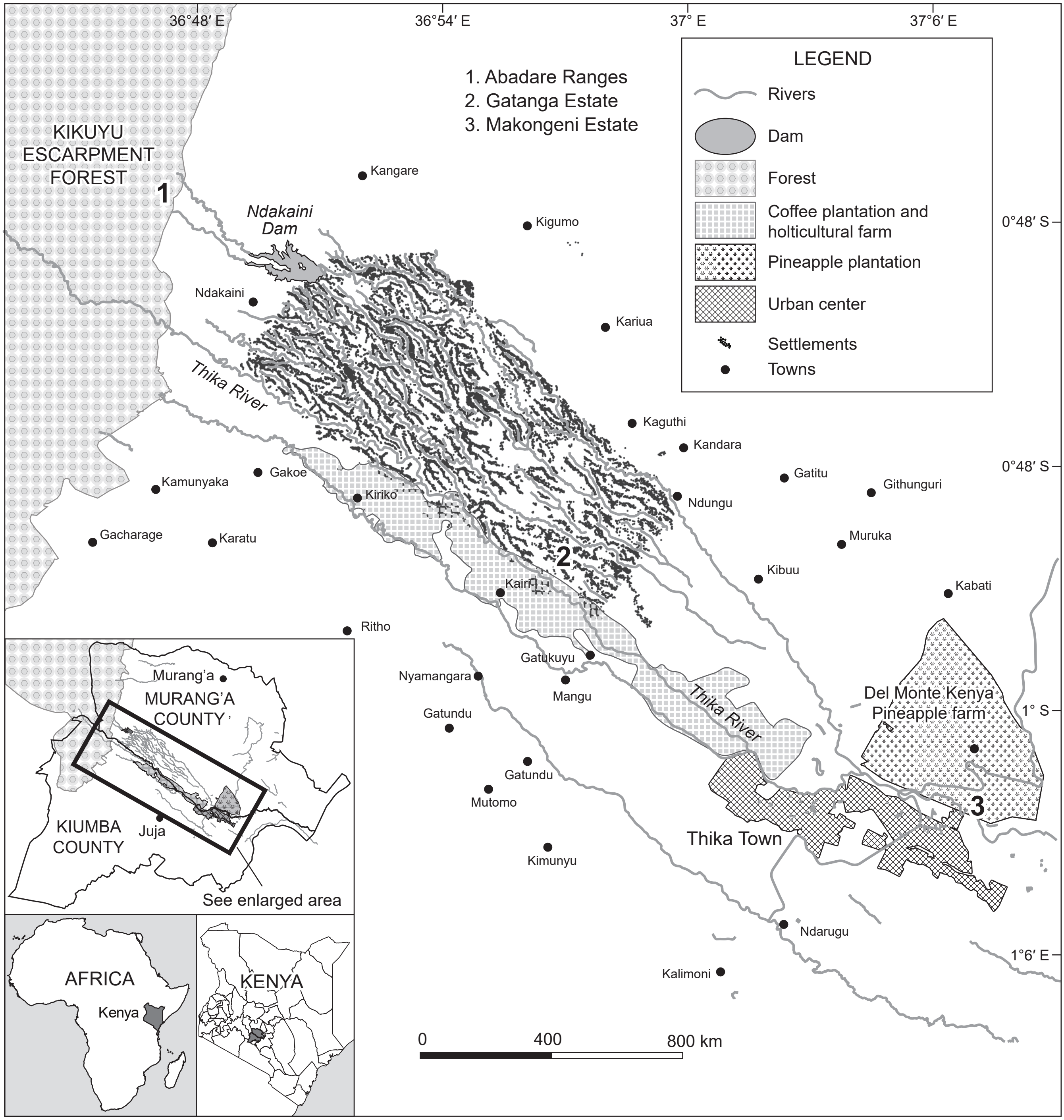

Figure 1: Map of study area showing sampling sites 1, 2 and 3 within the Thika catchment in Muranga county, Kenya. Site 1 was surrounded by natural forest in the Aberdare ranges, Site 2 by agricultural farmlands and Site 3 by industrial and urban settlements

ranges region, and the natural forest vegetation, both of which impact on the process of evapotranspiration. This eventually produces precipitation in the region. The precipitation replenishes the underground water content that feeds the river (Kotchoni et al. 2019). The river is also fed by surface runoff that is often contaminated with agrarian, municipal and industrial effluents (Kimani et al. 2016). The river flows through the bounder of Murang'a-Kiambu and empties in River Tana. The river substratum consists mainly of a mixture of red volcanic, black cotton soils and murram. Decomposing macrophytes and plant remains also form part of the river substrate. Three sites were selected along this river system from the forest to the downstream reaches.

The Thika River is impacted heavily by industrial and domestic wastes as it flows downstream from its source

(Karuri et al. 2003). For instance, the levels of heavy metals at a downstream site near Blue Post hotel were found to be higher than levels at upstream sites (Karuri et al. 2003). Inoti et al. (2012) found out that the concentration of heavy metals like iron, cadmium, chromium, and lead in the soil along the Thika River catchment areas was above the maximum permitted levels.

Site 1 is located approximately 1 km from the river's source (Figure 1). The shallower river channel is heavily shaded by the thick forest canopy, with more exposed pools at various points along its reaches. The dominant water flora was sub-merged and floating macrophytes, such as *Azolla africana, Salvania molesta* and *Nymphaea lotus.* Emergent macrophytes were also present, for instance, *Vossia cuspidate*, *Pycreus lanceolatus* and *Scirpus jacobi.* The streambed is granite with fallen leaves and huge rocks. The water in the site was clear with no visible siltation. The river margin was colonized by terrestrial vegetation. Trees dominating were *Elaeis guineensis, Cedrus deodara* and *Bambusa* spp. in addition to several grass species, like *Zostera marina* and *Ruppia maritima*. There were minimal human activities adjacent to the waters' edge, and the site was therefore selected to be used as a control point.

Site 2 (cultivated) was 29 km from site 1 (Figure 1). The riparian vegetation consists of *Lantana camara, Maranta arundinacea,* farming plants such as *Zea mays,* and napier grass. Riparian zones were heavily infested with non-native alien trees including *Eucalyptus* species and *Grevillae robusta.* The site was devoid of aquatic vegetation thus water was exposed to sunlight. Algal growth was extensive, which made the water turn green with a bad smell emanating from the water. The area had a low abundance of macrophytes such as *N. lotus* and *Salvania* sp. The substratum in this section is sandy loam. The location is downstream from extensive coffee plantations and horticultural farms, growing crops such as vegetables, tomatoes, flowers and French beans. There are also settlements, and livestock farming that have free access to the river.

Site 3 (urban) was 3 km from site 2 down the confluence of the river with Chania River (Figure 1). Although no vegetation occurred in the riparian zone, there were more aquatic plants at site 3 compared to site 2, with *Salvinia* sp., *N. lotus* and *M. arundinacea* predominating. The riparian zone was dominated by non-native alien trees such as *Acacia* spp. and *Eucalyptus globulus.* The substratum is principally clay and silt, and the water is exposed to direct sun. Thika Town dumps its sewage and industrial waste into the river after treatment at the site.

Sampling and laboratory analysis

Sampling was done monthly at each site for six months (September 2015–February 2016). Water depth was measured using a metre ruler, according to Arimoro and Muller 2010. River width was measured across the river using a tape measure. During the wet season of 2015, sites 2 and 3 became heavily flooded as a result of extensive rainfall requiring a boat to cross the river. Water transparency was measured in the field using a white and black Secchi disc (20 mm diameter). The Secchi disc was gently lowered into the water and the depth of disappearance and reappearance recorded (Wetzel 2000). Water temperature was measured using a pocket thermometer. Water conductivity, pH and total dissolved solutes (TDS) were measured using a multi-probe meter (Hanna Instruments Model H199130, Romania). DO was measured using a portable dissolved oxygen meter (MRC, model DO-5510, UK). Three readings were taken per sampling event.

Macroinvertebrates were collected using a disturbance removal sampling technique (DRST) (Kage 2003) and a Hess sampler was used in shallow sites with a rocky substrate. An Eckman grab sampler was used on deeper sites with a muddy substratum. At each sampling site, three samples of macroinvertebrates were collected. These were from the middle and approximatly 1 m from the left and right banks. The three samples were then pooled, representing a single sample for each site and fixed with 4% formalin. In the laboratory, the macroinvertebrates sampled, were filtered and washed free of sediments through a 250 μm sieve. All Ephemeroptera were identified to the lowest identifiable taxonomic level, using a dissecting microscope (×10 magnification) and relevant taxonomic keys at the National Museums of Kenya (Merit and cummins 1996; Barber-James and Lugo-Ortoz 2003; Huxley 2003). The unidentified individuals were taken to South Africa for further identification.

Data analysis

The data were checked for homogeneity of variance using Levene's *F*-test. A one-way ANOVA was used to determine differences in water quality parameters between sites. A Kruskal–Wallis test was used for determining the differences in Ephemeroptera abundances among the three sampling sites. The difference between community structure for dry and wet sampling seasons was tested using a *t*-test, because two means had to be compared. Correlation coefficient (*r*) analyses were done on the individual water quality parameters to identify the magnitude of relationships between them. It was also used to test the relationship between water quality and abundance of Ephemeroptera larvae along the Thika River. All the statistical analyses were done using SPSS program (version 22), and rejection of Null hypothesis set at $p \leq 0.05$.

Results

Physico-chemical parameters

Water depths increased significantly from site 1 downstream to site 3 ($F_{(2, 51)} = 40.3$; $p < 0.001$; Table 1). Water depths did not vary significantly between dry and wet seasons irrespective of sites ($t = 3.325$; df = 52; $p > 0.5$) (Table 2). River widths were significantly different among the sites ($F_{(2, 51)} = 83.71$, $p < 0.001$). Site 1 had the lowest mean 8.6 ± 0.54 m while site 3 had the highest mean of 17.1 ± 0.49 m (Table 1). Seasonal variation in river width was statistically different between the dry and wet seasons ($t = 2.556$; df = 52; $p < 0.5$) (Table 2). Spatial water transparency was not significantly different ($F_{(2, 51)} = 2.785$, $p > 0.5$). The seasonal variation in water transparencies was significantly different ($t = 3.663$; df = 52; $p < 0.5$) (Table 2). Water temperatures were significantly different among

Table 1: Physico-chemical characteristics (mean ± SE) of the three sampling sites along the Thika River (September 2015–February 2016)

	Site			
	Forested	Cultivated	Urban	
Parameter	Mean ± SE	Mean ± SE	Mean ± SE	*p*-value
Temperature (°C)	14.3 ± 0.28[a]	21.9 ± 0.48[b]	21.9 ± 0.36[b]	<0.001*
DO (mg l^{-1})	12.1 ± 0.26[b]	8.7 ± 0.11[a]	8.8 ± 0.09[a]	<0.001*
Conductivity (µS cm^{-1})	16.9 ± 0.69[a]	79.5 ± 2.58[b]	93.5 ± 5.37[c]	<0.001*
pH	6.1 ± 0.60	6.3 ± 0.10	6.4 ± 0.90	0.112
TDS (mg l^{-1})	10.1 ± 0.53[a]	40.5 ± 1.49[b]	47.9 ± 2.93[c]	<0.001*
Transparency (m)	0.7 ± 0.30	0.5 ± 0.10	0.4 ± 0.50	0.071
Width (m)	8.6 ± 0.54[a]	12.7 ± 0.33[b]	17.1 ± 0.49[c]	<0.001*
Depth (m)	0.5 ± 0.05[a]	1.1 ± 0.08[b]	1.4 ± 0.09[c]	<0.001*

Note: The same small letter within the same row indicates that means do not differ significantly from one another (One-way ANOVA, SNK-test, $\alpha = 0.5$). * Statistically significant: $p \leq 0.05$

Table 2: Seasonal variation of physico- chemical parameters of the Thika River in September 2015 to February 2016, mean ± SE

Parameters	Dry	Wet	*p*-value
Temperature (°C)	20.56 ± 0.77	18.19 ± 0.70	0.027*
DO (mg l^{-1})	10.21 ± 0.38	9.44 ± 0.26	0.106
Conductivity (µS cm^{-1})	60.46 ± 7.41	66.10 ± 6.74	0.576
pH	6.25 ± 0.40	6.31 ± 0.90	0.531
TDS (mg l^{-1})	30.53 ± 3.70	35.11 ± 3.35	0.364
Transparency (m)	0.67 ± 0.55	0.41 ± 0.50	<0.001*
Width (m)	11.48 ± 0.67	14.11 ± 0.78	0.014*
Depth (m)	0.81 ± 0.80	1.23 ± 0.10	0.380

* Statistically significant: $p \leq 0.05$

Table 3: Spatial variations in abundance (ind. m^{-2}) of Ephemeroptera of the Thika River at the sites 1, 2 and 3 during the study period, September 2015 to February 2016

Family	Ephemeroptera taxa		Sites		
	Species		Forested	Cultivated	Urban
Oligoneuriidae	*Oligoneuriopsis*	*dobbsi*	143	0	0
Heptageniidae	*Afronurus*	sp. 1	295	42	72
Heptageniidae	*Afronurus*	sp. 2	2	2	0
Baetidae	*Acanthiops*	*cooperi*	0	5	0
Baetidae	*Acanthiops*	sp. 1	2 231	111	407
Baetidae	*Acanthiops*	sp. 2	138	25	37
Baetidae	*Acanthiops*	sp. 3	0	0	4
Baetidae	*Tanzaniops*	sp.	2	0	5
Baetidae	*Afroptilum*	sudafricanum	0	37	0
Baetidae	*Dabulamanzia*	sp.	0	0	7
Caenidae	*Caenis*	sp.	41	9	23
Leptophlebiidae	*Euthraulus*	sp.	0	11	7
Ephemerythidae	*Ephemerythus*	sp.	0	25	27
Total density (ind. m^{-2})			2 852	267	595
Relative abundance (%)			76.8	7.2	16.0

sites ($F_{(2, 51)} = 134.37$, $p < 0.001$). Site 1 had the lowest mean 14.3 ± 0.28 °C, while site 2 had a mean of 21.9 ± 0.48 °C, which was the highest. Student Newman's Keul's multiple range test further showed that site 1 varied from sites 2 and 3 (Table 1). Water temperature was significantly different ($t = 0.027$; df = 52; $p < 0.5$) between the dry and wet season (Table 2).

Spatial DO levels were significantly different between sites ($F_{(2, 51)} = 131.14$, $p < 0.001$). Student Newman's Keul's multiple range test also revealed that DO at site 1 varied from sites 2 and 3 (Table 1). Seasonal variation in DO, however, was not significant ($t = 1.647$, df = 46, $p > 0.5$) (Table 2). Water pH was not significantly different among sites ($F_{(2, 51)} = 2.28$, $p > 0.5$).

Water conductivity was highly significant among the sites ($F_{(2, 51)}$ = 138.73, p < 0.001). Site 1 had lowest conductivity 16.9 ± 0.69 μS cm^{-1}. It further increased to 93.5 ± 5.37 μS cm^{-1} in site 3. Student Newman's Keul's multiple range test also revealed that the three sites were varied (Table 1). However, seasonal variation was not significant (t = 0.563; df = 52; p > 0.5) (Table 2). Spatial TDS differed significantly ($F_{(2, 51)}$ = 107.91, p < 0.001). It was lowest in site 1 (10.1 ± 0.53 mg l^{-1}) and sharply increased to 47.9 mg l^{-1} at site 3 (Table 2). It was not statistically different (t = 0.916; df = 52, p > 0.5) (Table 2) between the dry and wet season.

Mayflies were present along the entire system, with lower abundances in the middle reaches. In total, 13 taxa of Ephemeroptera in six families were found during the entire sampling season (Table 3).

The major mayfly families in decreasing relative abundance and abundance were Baetidae and Heptageniidae. *Acanthiops* was the preponderant genus of Ephemeroptera in all the sampling sites. Oligoneuriidae was represented by *Oligoneuriopsis dobbsi* and occurred sporadically only in site 1. Leptophlebiidae family was poorly represented in the Thika River system. Families Caenidae, Heptageniidae, and Baetidae were distributed in all the sites. Interestingly, *Caenis, Euthraulus* and *Ephemerythus* sp. occurred together and were all absent in October and November when the rainy season was at its peak.

Distribution of mayflies differed significantly among sites ($H_{(2)}$ = 10.294, p < 0.5, α = 0.5; Table 3). The distribution of mayflies were ten times greater in site 1 (2 852 ind. m^{-2}) compared to site 2 (267 ind. m^{-2}). *Acanthiops* dominated the mayfly community at all three sampling sites with 2 369 ind. m^{-2} at site 1, 141 ind. m^{-2} at site 2 and 448 ind. m^{-2} at site 3. Other Ephemeroptera species were rare in the studied sites (Table 3). Seasonal variation in abundance was not significantly different ($H_{(5)}$ = 3.58, p > 0.5, α = 0.5), irrespective of sites (Figure 2). With respect to realtive abundance, some of the correlations were weak while none of the correlations were significant (Table 4).

Discussion

Variations observed in background physico-chemical characteristics of the river are primarily governed by the local climatic conditions and catchment characteristics (Gibbs 1970; Arimoro and Muller 2010). Water temperature, DO, and the presence of appropriate mesohabitat structures are critical factors determining the occurrence and distribution of mayfly larvae (Bauernfeind and Moog 2000). The elevated levels of conductivity, TDS, temperature and low values of DO and transparency observed at sites 2 and 3 indicate deterioration of water quality impacted by several human activities taking place in these sites. Aura et al. (2010) recorded a similar trend in River Nzoia, Kenya, which receives sewage and urban effluents. Ideally, nutrient measures (PO_4^{3-}, NO_3^- and TP), although not measured in the current study, should be included in such a study.

Site 1 exhibited relatively clean water status, as was shown by the physico-chemical parameters in the section.

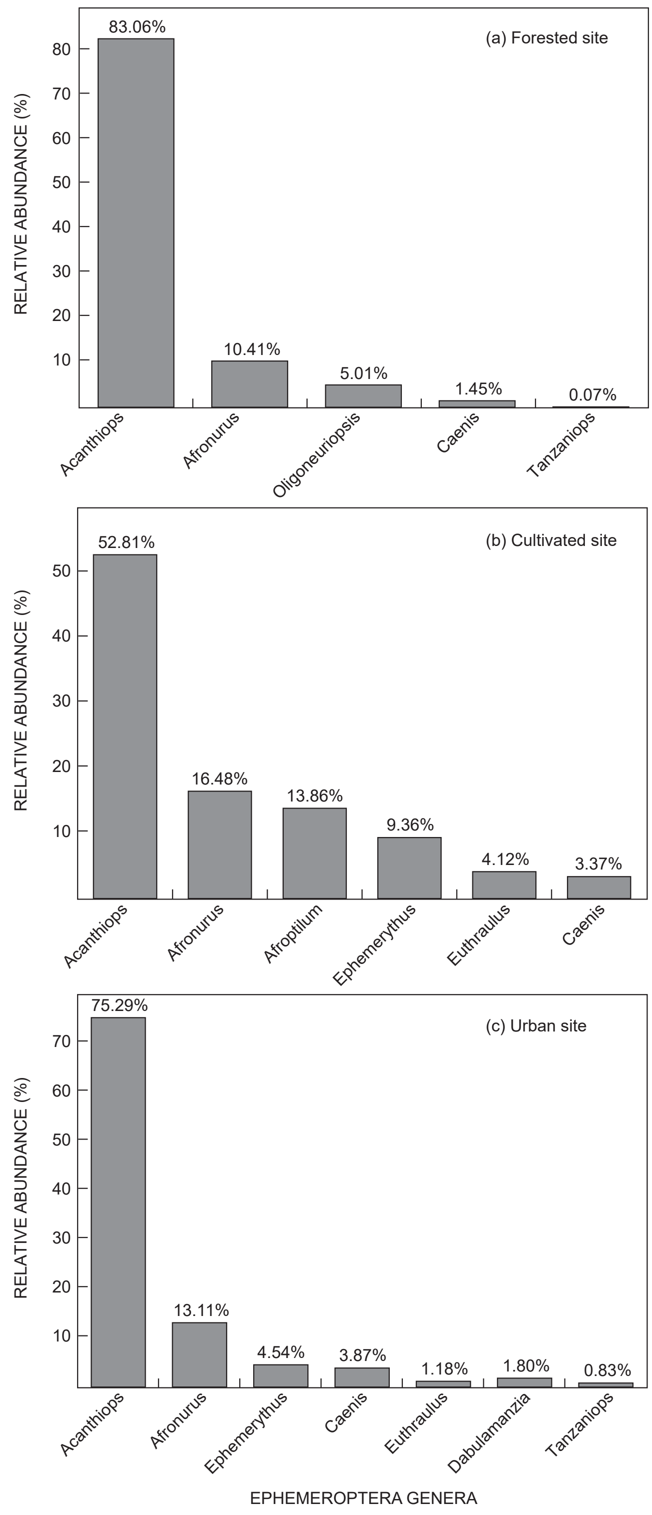

Figure 2: Relative abundance of Ephemeroptera genera of the Thika River at the forested site (a), cultivated site (b) and urban site (c) from September 2015 to February 2016

Sites 2 and 3 affected by discharges from agricultural and urban lands respectively, showed high values of conductivity, TDS, temperature, and is accompanied by

Table 4: Pearson correlation coefficient (*r*) of water parameters and abundance of Ephemeroptera of the Thika River during the study period, September 2015 to February 2016

	Temp (°C)	DO (mg l^{-1})	EC (µcm)	pH	TDS (mg l^{-1})	Transparency (m)	Depth (m)	Velocity (m s^{-1})	Abundance
Temp (°C)	1	–0.867**	0.400*	0.425**	0.497**	–0.787**	–0.804**	–0.865**	–0.233
DO (mg l^{-1})		1	–0.650**	–0.669**	–0.690**	0.425**	–0.404*	–0.583**	0.218
EC (µS cm^{-1})			1	0.385*	0.989**	0.156	–0.021	0.344*	–0.136
pH				1	0.326	–0.083	–0.054	0.233	–0.13
TDS (mg l^{-1})					1	0.037	0.113	0.446**	–0.154
Transparency (m)						1	–0.948**	–0.760**	0.159
Depth (m)							1	0.877**	–0.167
Velocity (m s^{-1})								1	–0.187
Abundance									1

* $p \leq 0.05$, ** $p \leq 0.001$

reduced values of DO and transparency. These values indicate that the water in the sites was impacted. The degree of silt-sand deposition was another factor that differentiated the sites. Human activities at sites 2 and 3 resulted in increased siltation that ultimately destroyed the microhabitats for the mayfly larvae. Arimoro and Muller (2010) found parallel results in River Orogodo (Nigeria) in sections exposed to anthropogenic disturbance. Studies carried out in most freshwater streams, show that mayflies are among the insect groups with the highest abundance in the macrobenthic community (Ogbeibu and Oribhabor 2002; Bonzemo 2013).

The total number of Ephemeropteran taxa obtained in the current study was high (13) when compared with other studies undertaken in different rivers in Kenya. Kage (2003) and Bonzemo (2013) reported three and nine taxa in Nairobi and Kisibi rivers, respectively. The occurrence may be as a result of the more extensive and more diverse meso-habitats in the Thika River, resulting in a higher mayfly abundance and diversity. A study with coinciding results was that of Arimoro and Muller (2010), who reported 13 taxa in River Orogodo in Nigeria.

The distribution of Ephemeroptera species along the Thika River was reasonably differentiated. The restricted presence of *Oligoneuriopsis dobbsi* in the forested site was predictable, because species in the genus had been recorded as dwellers of fast flowing streams and at high elevations (Day and Moor 2002). Bauernfeind and Moog (2000) found that Oligoneuriidae larvae are one of the families that indicate an ecologically intact environment. Site 1 showed a wide variety of microhabitats appropriate for mayflies. These may explain the high abundance of Ephemeroptera at the site. Baetidae family from the current study may be a potential indicator of water quality and ecological integrity primarily as a result of its presence in both the impacted and un-impacted reaches of the river. However, it appears to be sensitive to pollution as the numbers were remarkably reduced at the impacted sites (sites 2 and 3). Genus *Caenis* from several studies has been documented to be tolerant to organic contamination (Menetrey et al. 2008). The current study agrees with the findings because, *Caenis* was found in both impacted (sites 2 and 3) and unimpacted (site 1) sites, though in low relative abundance.

Ephemeroptera larvae are well represented in the Thika River, although they were considerably reduced in impacted sites. The highest abundances of mayfly was found in site1. It has been found that surface waters bounded by agrarian lands have a higher conductivity when compared with other land uses (Detenbeck et al. 1996). Despite the high conductivity and TDS in site 3, signs of recovery were evidenced by the slightly reduced temperature, increased DO and the rise in mayfly abundance than in site 2. Lock and Goethals (2013) found that mayflies are always present in water with a low conductivity, but if the conductivity is high, they are only present when both the phosphate concentration and BOD are low.

Ephemeroptera abundance varied spatially, but not temporally, in response to physico-chemical factors of the water. The significantly lower abundance in sites 2 and 3 can be ascribed to combined influences of changes in substrate composition as a result of human activities at the sites, as well as deteriorated water quality at these sites. Change of sampling method from using a Hess sampler on the shallow rocky substrates to a grab sampler in the deeper soft muddy substrates may also account for the reduced abundances. Land use at Sites 2 and 3 were different from Site 1. At Sites 2 and 3, land use was heavily impacted by agricultural and urban activities, respectively, contributing to the change in species. The resulting food shortage led to a significant decrease in numbers of Ephemeroptera in the wet season. In the current study, wet season coincided with *El Niño* rains in 2015, which reached a climax of November. This is the reason why the month had the lowest abundance. Macroinvertebrates were utterly absent at sites 2 and 3, as a result of floods. The results were similar to those found by Arimoro and Muler (2010), who observed that the wet season had the least mean abundance of mayflies in river Orogodo in Nigeria.

The abundance of mayflies was highest in the upper reaches of the Thika River (site 1), but reduced drastically in site 2 and 3. The principal ecological stresses being land use and anthropogenic activities. However, considering the abundance of sites 2 and 3, the later had slightly higher abundance. The higher abundance on site 3 showed that Ephemeropterans could recover from environmental

Table 5: Levene's test for equality of variances for temperature, dissolved oxygen, conductivity, pH, total dissolved solids, transparency and width at the forested, cultivated and urban sampling sites

Site			Levene's test for equality of variances		*t*-test for equality of means						
			F	Sig.	*t*	df	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference: Lower	95% confidence interval of the difference: Upper
Forested	Temperature (°C)	Equal variances assumed	0.138	0.715	5.226	16	0.000	1.81111	0.34659	1.07638	2.54585
		Equal variances not assumed			5.226	15.641	0.000	1.81111	0.34659	1.07500	2.54722
	Dissolved oxygen (mg l^{-1})	Equal variances assumed	29.049	0.000	6.158	16	0.000	1.77111	0.28763	1.16137	2.38085
		Equal variances not assumed			6.158	8.289	0.000	1.77111	0.28763	1.11185	2.43037
	Conductivity (µS cm^{-1})	Equal variances assumed	0.206	0.656	–4.239	16	0.001	–4.16667	0.98300	–6.25053	–2.08280
		Equal variances not assumed			–4.239	15.599	0.001	–4.16667	0.98300	–6.25489	–2.07844
	pH	Equal variances assumed	4.881	0.042	1.562	16	0.138	0.19222	0.12308	–0.06869	0.45313
		Equal variances not assumed			1.562	13.614	0.141	0.19222	0.12308	–0.07245	0.45690
	Total dissolved solids (mg l^{-1})	Equal variances assumed	0.172	0.684	–4.662	16	0.000	–3.29778	0.70740	–4.79739	–1.79816
		Equal variances not assumed			–4.662	15.925	0.000	–3.29778	0.70740	–4.79796	–1.79759
	Transparency (m)	Equal variances assumed	2.534	0.131	–2.573	16	0.020	–0.11444	0.04449	–0.20875	–0.02014
		Equal variances not assumed			–2.573	11.676	0.025	–0.11444	0.04449	–0.21167	–0.01722
	Width (m)	Equal variances assumed	4.580	0.048	–2.739	16	0.015	–2.50889	0.91605	–4.45083	–0.56695
		Equal variances not assumed			–2.739	12.308	0.018	–2.50889	0.91605	–4.49927	–0.51850
	Depth (m)	Equal variances assumed	0.181	0.676	–4.265	16	0.001	–3.04889	0.71482	–4.56423	–1.53354
		Equal variances not assumed			–4.265	15.763	0.001	–3.04889	0.71482	–4.56609	–1.53169
Cultivated	Temperature (°C)	Equal variances assumed	5.143	0.038	5.008	16	0.000	3.06667	0.61235	1.76855	4.36478
		Equal variances not assumed			5.008	12.835	0.000	3.06667	0.61235	1.74204	4.39129
	Dissolved oxygen (mg l^{-1})	Equal variances assumed	3.173	0.094	1.138	16	0.272	0.24889	0.21876	–0.21487	0.71264
		Equal variances not assumed			1.138	14.112	0.274	0.24889	0.21876	–0.21996	0.71774
	Conductivity (µS cm^{-1})	Equal variances assumed	31.701	0.000	–0.655	16	0.522	–3.44444	5.25782	–14.59052	7.70163
		Equal variances not assumed			–0.655	8.920	0.529	–3.44444	5.25782	–15.35473	8.46585
	pH	Equal variances assumed	5.344	0.034	–0.353	16	0.729	–0.07556	0.21416	–0.52955	0.37843
		Equal variances not assumed			–0.353	13.464	0.730	–0.07556	0.21416	–0.53659	0.38548
	Total dissolved solids (mg l^{-1})	Equal variances assumed	12.408	0.003	–1.336	16	0.200	–3.89222	2.91295	–10.06739	2.28295
		Equal variances not assumed			–1.336	11.442	0.207	–3.89222	2.91295	–10.27345	2.48901
	Transparency (m)	Equal variances assumed	17.329	0.001	4.547	16	0.000	0.64111	0.14100	0.34221	0.94002
		Equal variances not assumed			4.547	9.259	0.001	0.64111	0.14100	0.32350	0.95872
	Width (m)	Equal variances assumed	7.582	0.014	–4.978	16	0.000	–2.12667	0.42722	–3.03233	–1.22101
		Equal variances not assumed			–4.978	11.947	0.000	–2.12667	0.42722	–3.05795	–1.19538
	Depth (m)	Equal variances assumed	4.680	0.046	–4.141	16	0.001	–0.46000	0.11108	–0.69548	–0.22452
		Equal variances not assumed			–4.141	13.129	0.001	–0.46000	0.11108	–0.69973	–0.22027

Table 5: (cont.)

Site			Levene's test for equality of variances		*t*-test for equality of means						
			F	Sig.	*t*	df	Sig. (two-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference: Lower	95% confidence interval of the difference: Upper
Urban	Temperature (°C)	Equal variances assumed	12.691	0.003	4.487	16	0.000	2.21111	0.49279	1.16645	3.25577
		Equal variances not assumed			4.487	9.147	0.001	2.21111	0.49279	1.09908	3.32314
	Dissolved oxygen (mg l^{-1})	Equal variances assumed	5.298	0.035	1.709	16	0.107	0.28556	0.16707	–0.06862	0.63973
		Equal variances not assumed			1.709	13.118	0.111	0.28556	0.16707	–0.07505	0.64616
	Conductivity (µS cm^{-1})	Equal variances assumed	32.544	0.000	–0.862	16	0.402	–9.32000	10.81788	–32.25288	13.61288
		Equal variances not assumed			–0.862	8.945	0.411	–9.32000	10.81788	–33.81490	15.17490
	pH	Equal variances assumed	34.728	0.000	–1.977	16	0.066	–0.31111	0.15737	–0.64472	0.02249
		Equal variances not assumed			–1.977	8.391	0.082	–0.31111	0.15737	–0.67108	0.04886
	Total dissolved solids (mg l^{-1})	Equal variances assumed	39.924	0.000	–1.122	16	0.278	–6.53889	5.82538	–18.88814	5.81036
		Equal variances not assumed			–1.122	8.491	0.292	–6.53889	5.82538	–19.83816	6.76039
	Transparency (m)	Equal variances assumed	1.988	0.178	3.592	16	0.002	0.27667	0.07703	0.11337	0.43997
		Equal variances not assumed			3.592	14.759	0.003	0.27667	0.07703	0.11224	0.44109
	Width (m)	Equal variances assumed	2.142	0.163	–5.470	16	0.000	–3.26000	0.59594	–4.52334	–1.99666
		Equal variances not assumed			–5.470	14.410	0.000	–3.26000	0.59594	–4.53476	–1.98524
	Depth (m)	Equal variances assumed	0.373	0.550	–2.869	16	0.011	–0.45111	0.15725	–0.78446	–0.11776
		Equal variances not assumed			–2.869	15.900	0.011	–0.45111	0.15725	–0.78463	–0.11759

stressors. The increase in abundance of mayflies at site 3 is in agreement to the intermediate disturbance hypothesis, where higher abundance and species diversity is expected in middle reaches, where disturbance is neither lacking nor too severe (Townsend et al. 1997).

Correlation between the abundance of mayfly larvae and water quality parameters measured (temperature, dissolved oxygen, electrical conductivity, TDS and transparency)was not statistically significant (Table 4), owing to the weak relationship between abundance and all the water parameters. This weak association mayfly abundance and the water quality parameters suggests that other external factors not measured may be controlling the abundance of mayfly larvae in the Thika River. Site 2 had slightly higher temperature, lower DO and the highly reduced abundance of mayflies, which suggest that the site was the most impacted. Water temperature, conductivity, pH, TDS and depth were negatively related to the abundance of mayflies. Many studies in different rivers have found a similar result. For instance, Arimoro and Muller (2010) found that Ephemeroptera abundance was negatively correlated with conductivity in River Orogodo in Nigeria.

In conclusion, the current study revealed that decreasing Ephemeroptera taxa abundance along the river channel indicates decreasing water quality. The Oligoneuriidae family was unique for site 1, which had good quality, natural water. Sites 2 and 3 showed a sharp decline in abundance of mayfly larvae, with species of the genus *Acanthiops* dominating in numbers. The dominance of *Acanthiops* highlights that this genus is tolerant to the forms of disturbances in the two sites. It was further revealed that Site 3 increased in DO and temperature that was accompanied by a greater increase in abundance of mayfly than at Site 2. More importantly, the site aquatic vegetation improved which promoted increased mayfly abundances. Kage (2003) also noted that increased abundance of aquatic vegetation in downstream sites favours higher mayfly abundance, as a result of increased habitat heterogeneity. Moreover, organic load dilution is known to occur downstream, generating a species composition and abundance similar to the upstream stations (Garcia-Amisen et al. 2014). Because the abundance of mayfly larvae decreased with a decline in water quality, it is evident that they prefer moderate to excellent water quality. Although the quantitative method is a good indicator of the water quality status at different sites, the South African Scoring System (SASS) may also be a good tool for the rapid bioassessment of water quality (Dallas 1995).

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