Impact of water quality on macroinvertebrate assemblages along a tropical stream in Kenya

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Abstract

Prudent management of lotic systems requires information on their ecological status that can be estimated by monitoring water quality and biodiversity attributes. To understand environmental conditions in Gatharaini drainage basin in Central Kenya, a study was carried out to establish the relationship between water quality and macroinvertebrate assemblages between the months of March and September 1996. Six sampling sites, each 25 m long were selected along a 24-km stretch of the stream, which drained land under agricultural, residential and industrial use. Water physico-chemical data was explored using multivariate analysis of Principal Component Analysis to detect environmental trends downstream. Both macroinvertebrates and water physico-chemical data of suggested trends were analysed for variations and correlations. Temperatures and invertebrate densities changed significantly between the dry and wet season ($P < 0.01$) but the fluctuations were not evident downstream. Water physico-chemical characteristics (total dissolved solids (TDS), pH, turbidity, dissolved oxygen) and biodiversity indices (species richness, diversity, dominance, evenness) changed markedly downstream ($P < 0.01$). Biodiversity indices correlated inversely with TDS, pH and turbidity but positively with dissolved O_2. It was evident macroinvertebrate assemblages changed significantly downstream as opposed to functional feeding groups. Diptera was important in most sites whilst Oligochaeta dominance increased downstream corresponding to the deterioration in water quality. Collectors/browsers were the dominant functional feeding groups at most sites. This study showed that significant changes in aquatic macroinvertebrate assemblages were primarily due to water quality rather than prevailing climatic conditions.

Key words: biodiversity indices, macroinvertebrates, pollution, stream, water quality

Résumé

Une gestion prudente des systèmes lotiques exige une bonne connaissance de leur statut écologique, lequel peut être évalué en contrôlant la qualité de l'eau et des caractéristiques en matière de biodiversité. Pour bien comprendre les conditions environnementales du bassin de Gatharaini, au centre du Kenya, on y a mené de mars à septembre 1996 une étude pour connaître la relation entre la qualité de l'eau et les assemblages de macro-invertébrés. On a choisi six sites d'échantillonnage de 25 m de long chacun, sur une bande de 24 km de long du cours d'eau qui arrose des zones agricoles, résidentielles et industrielles. Les qualités physico-chimiques de l'eau ont été étudiées par des analyses multivariées de l'Analyse du Composant Principal pour déceler les tendances environnementales en aval. Les macro-invertébrés, tout comme les qualités physico-chimiques des tendances de l'eau, ont été analysés pour leurs variations et corrélations. La température et la densité des invertébrés changeaient significativement entre la saison sèche et la saison des pluies ($P < 0,01$), mais les fluctuations n'étaient pas èvidentes en aval. Les caractéristiques physico-chimiques de l'eau (total des solides dissous - TDS, pH, turbidité, oxygène dissous) et les indices de biodiversité (richesse en espèces, diversité, dominance, régularité) changeaient sensiblement ($P < 0,01$) en descendant le courant. Les indices de biodiversité étaient en corrélation inverse avec le TDS, le pH et la turbidité, mais en corrélation positive avec l'O_2dissous. Il était évident que les assemblages de macro-invertébrés changeaient de façon significative en descendant le courant contrairement aux groupes fonctionnels d'alimentation. Les diptères étaient importants sur la plupart des sites tandis que la dominance des oligochètes augmentait en descendant, ce qui correspondait à la détérioration de la qualité de l'eau. Les

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collecteurs/brouteurs constituaient les groupes d'alimentation dominants sur la plupart des sites. Cette étude a montré que les changements significatifs dans les assemblages de macro-invertébrés aquatiques étaient dus plutôt à la qualité de l'eau qu'aux conditions climatiques.

Introduction

Studies have shown that water quality in aquatic systems has a strong impact on biological components (Harding *et al.*, 1999; Ometo *et al.*, 2000). According to the River Continuum Concept (Vannote *et al.*, 1980), community structure and function conform with certain geomorphic, physical and biotic characteristics such as stream flow, channel morphology, detritus loading, size of particulate organic matter, characteristic of autotrophic production and thermal loading. However this concept seldom holds in many lotic systems due to longitudinal changes in environmental conditions caused by agricultural, human settlements or industrial activities (Harding *et al.*, 1999; Ometo *et al.*, 2000; Roy *et al.*, 2003).

Macroinvetebrates constitute an important component of biodiversity in lotic systems (Merritt & Cummins, 1996). They are diverse, have short generation times and are easily dispersed. As a group, macroinvertebrates are sensitive and respond to both natural and man-induced changes in their environment (De Pauw & Hawkes, 1993). The diversity and assemblages of running water invertebrates (shredders, collectors, grazers and predators) reflects shifts in types and location of resources with stream size (Vannote *et al.*, 1980) and human-induced factors (Harding *et al.*, 1999; Ometo *et al.*, 2000). Several techniques, protocols and indices have been developed to monitor stream quality using changes in species composition, diversity and functional organization of aquatic insects (e.g. Lenat, 1993). Pielou (1975) observed that the concept of biodiversity (species richness and evenness) is a central theme in community/ecosystem ecology and can be used to explain other ecosystem properties such as biological productivity, habitat heterogeneity, habitat complexity and disturbance. Species diversities are moderate in stable ecosystems, highest in intermediate and low in severely degraded ecosystems (Connell, 1978). According to intermediate disturbance hypothesis (IDH) high species diversity in moderate disturbed ecosystems are attributed to co-existence of pioneer, stress-tolerant and ruderals species (Connell, 1978).

In Kenya and to larger extent the whole of Africa, the use of macroinvertebrates characteristics for assessment and monitoring of stream conditions is still uncommon. However, a South Africa Scoring System for rapid bioassessment of water quality in rivers is currently being tested in a National Biomonitoring Programme in South Africa (Dallas, 1997). In East Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lotic systems. For instance in Kenya, Mathoko (2002) looked at the colonization of artificial substrates by aquatic insects in Naro-Moru River, Barnard & Biggs (1988) studied macroinvetebrates in the catchment streams of Lake Naivasha whilst Kinyua & Pacini (1991) surveyed macroinvertebrates of Nairobi River. Tumiwesigye, Yusuf & Makanga (2000) investigated the structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda. These studies however did not relate macroinvertebrate densities, diversities or assemblages to the aquatic environmental conditions.

This study sought to investigate water quality and macroinvertebrate communities in Gatharaini River, which traverses through several land use systems. Our objectives were to determine water physico-chemical characteristics, describe macroinvertebrate composition and relate water quality to macroinvertebrate densities and biodiversity indices along the stream.

Study area

The study was carried out in the upper part of Gatharaini Stream in Kiambu District in Central Kenya (Fig. 1). The stream covered a 24-km stretch, lying between 1891 and 1556 m a.s.l. The depth, width and discharge of the stream were in the range of 10–95 cm, 45–200 cm and 0.04–0.15 $m^3 s^{-1}$, respectively. The stream flowed slowly (0.3–0.35 $m s^{-1}$) over a mud-dominated bed. The climate of the area is of the dry equatorial type and annual rainfall is 1000–1500 mm (Waters & Odero, 1986). Rainfall is bimodal with long rains occurring during the months of March to May and the short rains from October to November. Dry seasons occur between December and February as well as August and September. The mean annual temperature ranges between 14 and 28°C.

Gatharaini stream originates in marshes in the lower reaches of the Aberdare mountains and flows through human settled areas. The stream is affected by various human activities along the channels and in the catchment

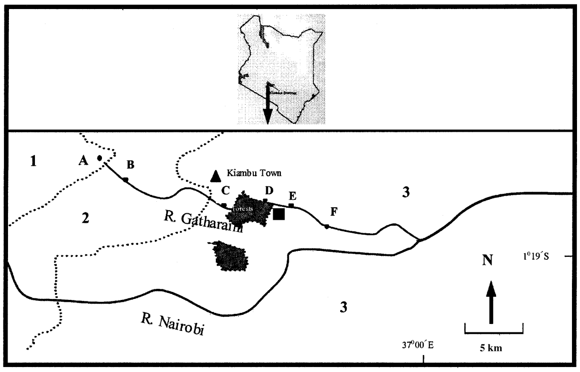

Fig 1 Inset is a map of Kenya showing the study area. Black dots signify sampling sites while the black square shows the location of the Kamiti Tannery Factory. The two black shaded areas represent forests. Dotted lines and numbers represent sectors as suggested by PCA ordination analysis in Fig. 2. The sectors are not sketched to scale. Site local names are given in Table 1

(Table 1). Site A is in the upper parts of the stream, situated in Kiambaa and Kanunga areas which are characterized by swamp and marsh. Subsistence agriculture and human settlement are the main type of land use. Intensive mixed farming are the major forms of land use around site B. Sites C and D are situated in areas with coffee farming and their associated industries. Intensive mixed farming and pockets of forests are common. Site E is situated 100 m below Kamiti Tannery Factory. The stream water was brackish and characterized by a foul smell. Site F is situated around Zimmerman and Githurai urban centres. Riverine subsistence agriculture of cocoyams and kales are common throughout the studied area.

Methods of study

Site selection and laboratory procedures

Six sites were selected on the basis of the prominent land use in the stream catchment's, discharge of point and nonpoint pollutants. Water quality and macroinvertebrates samples were collected monthly for a period of 7 months, which included wet season (March, April, May and June) and dry season (July, August and September). Dissolved oxygen concentration was determined using the Winkler method as outlined in standard methods for examination of wastewater manual [APHA (American Public Health Association), 1995]. pH was determined using a portable pH meter, Rabenau-Londorf, Model 6301 (MAGV Rabenau-Londorf, Germany). Temperature and total dissolved solids (TDS) were measured *in situ* using TDS/Temperature meter, Jenways Model 4075 (Jenway, Essex, UK) with the reading of TDS corrected to 25°C. Turbidimeter (Model Hach 2100A (Hach, Loveland, Colorado, USA)) was used to determine turbidity.

Macroinvertebrates were sampled using a modified core sampler, 1 m long and 14 cm in diameter. Mud was obtained up to a depth of 10 cm. It was first examined, all large (visible) invertebrates removed with forceps and put in specimen bottles containing 4% formalin. The remaining mud was loosened with more water, put in polythene bags and then preserved using 4% formalin. In the laboratory, the mud was washed through a 500 μm sieve and all macroinvertebrates picked from the sieve. Macroinvertebrates were sorted, identified and counted at the Centre for Biodiversity, National Museums of Kenya. Taxa were

Table 1 Sampling sites, local name and main types of land uses

Site	Site name, altitude (m)	Cumulative distance from source (km)	Human activities around the sampling sites
A	Kiambaa Market, 1891	0	Human settlement coupled with subsistence agriculture in swamps and marshes
B	Karuri, 1884	4	Coffee farming, subsistence agriculture and rearing of livestock
C	Kiambu Road, 1708	12	Coffee farming and their associated processing. Subsistence farming along the stream and livestock rearing
D	Kamiti Road, 1587	20	Coffee farming and their associated industries. Subsistence farming along the stream and livestock rearing
E	Kamiti Tannery, 1571	20.1	Kamiti Tannery Factory. Wetland reclamation to create land for unplanned and planned human settlement, subsistence farming and livestock rearing
F	Githurai, 1556	24	Wetland reclamation to create land for subsistence farming, livestock rearing, unplanned and planned residential areas of Zimmerman and Githurai

categorized to functional feeding groups according to Merritt & Cummins (1996). Macroinvertebrate diversity was calculated using biodiversity indices of the Hill's Family (Hill, 1973; Pielou, 1975):

Species richness (N_0) = Σp_i^0 = total number of taxa present per site.

Species diversity (N_1) = $\exp[-\Sigma p_i \ln(p_i)] = \exp(H')$ = exponential Shannon–Wiener index.

Species diversity (N_2) = $(\Sigma p_i^2)^{-1}$ = reciprocal of Simpson's index.

Species dominance (N_{inf}) = $(p_i)^{-1}$.

Evenness (J') = $\ln(N_1)/\ln(N_0)$.

Where N_0 and N_{inf} refer to species richness and dominance, respectively. N_1 and N_2 are directly related to each other and both measure species diversity with the former always greater than the latter. J' reflects evenness of abundance across species and is usually summarized by the relationship between different members of Hill's family (Pielou, 1975).

Data summarization and analysis

To detect changes and trends in water quality between sites and seasons, water physico-chemical data was explored using a multivariate technique of ordination (ter Braak & Smilauer, 1999). An indirect ordination analysis, principal component analysis (PCA), was preferred because the length of the gradients was <2. PCA uses the distance rule, which is an extension of the centroid principle which says that a site that is close to a water parameter is more likely to be associated with that parameter than a site that is far from it. The value of water parameters changed linearly across the biplot in the direction of the arrow. PCA grouped sites with similar characteristics close together and positively correlated water parameters had small angles between their arrows. Water quality characteristics for suggested groups of sites were analysed using ANOVA to establish whether they were significantly different. Macroinvertebrate data was used to calculate biodiversity indices and later summarized and presented as relative abundance. Indices were then compared between sites using ANOVA and significant levels accepted at $P < 0.05$. Spearman's correlation analysis was performed to establish the association between biodiversity indices and water quality parameters. All calculations and statistical analyses were performed using STATISTICA (StatSoft Inc., 1996). All data were log-transformed $\log_{10}(x + 1)$ prior to analysis to meet the statistical criteria of normality.

Results

Characterization of sites using water physico-chemical variables

The indirect ordination method (PCA) ordered environmental variables and sites along axes (Fig. 2). The analysis showed that the first axis had a variance of 90%, was positively associated with O_2 and temperature and negatively with turbidity. It was positively associated with site A and negatively with sites B–E. Second axis explained a variance of 6%, was negatively associated with TDS, positively correlated with sites B–D and negatively with sites E and F. Using the biplot scatter, sites were subjectively split into three groups: (1) upper stream (site A); (2) mid-stream (sites B–D); and (3) lower stream (sites E, F). Upper stream sites were characterized by high O_2, mid stream sites were mainly influenced by turbidity while lower stream sites were highly correlated with TDS.

Variation of environmental variables between seasons and sites

The results showed significant fluctuations in temperature (20.7 ± 1.1 to 18.4 ± 2.2, $F = 13$, $P < 0.001$, n = 28)

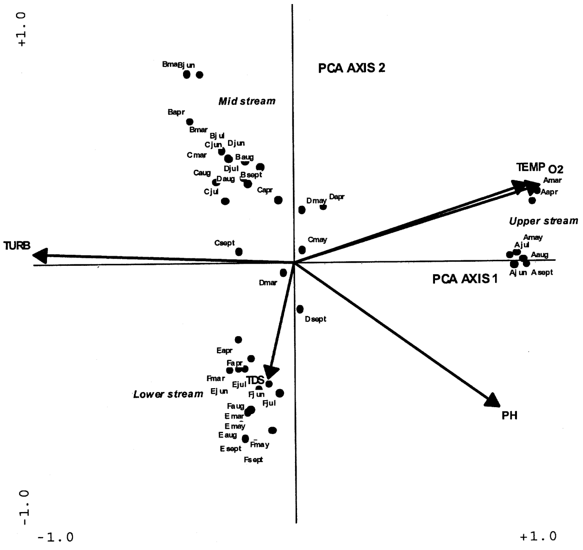

Fig 2 A PCA biplot showing the association between environmental variables and sites. Axes have total eigenvalues of 1.0 and variance explained by first and second axis was 90.8% and 5.1%, respectively. The first letter refers to the sites (A, B, C, D, E, F) and the labels refer to months (mar = March, apr = April, may = May, jun = June, jul = July, aug = August, sept = September). For location of sites, see Fig. 1

Table 2 Comparison of environmental variables of the three groups of sites (suggested by PCA) along the upper, middle and lower parts of Gatharaini Stream. Also given are sites' environmental variables (mean ± SE) for a period of 7 months, March to September 1997

Suggested groups	Upper stream (1), n = 7	Mid stream (2), n = 21			Lower stream (3), n = 14		Groups ANOVA P values		
Sites	A	B	C	D	E	F	1 × 2	2 × 3	1 × 3
Total dissolved solids (mg l^{-1})	50 ± 3	65 ± 22	120 ± 34	139 ± 16	653 ± 409	533 ± 250	0.001^{c}	<0.001^{c}	<0.001^{c}
pH	7.1 ± 0.4	7.0 ± 0.3	7.2 ± 0.3	7.5 ± 0.7	7.8 ± 0.4	7.5 ± 0.5	0.31	0.02^{a}	0.006^{b}
Temperature (°C)	19.3 ± 0.6	19.9 ± 1.4	20.3 ± 1.8	19.7 ± 1.4	19.7 ± 2.1	19.2 ± 1.6	0.29	0.36	0.88
O$_2$ (mg l^{-1})	5.6 ± 0.5	4.7 ± 0.5	4.7 ± 0.5	5.8 ± 0.7	0.4 ± 0.5	0.8 ± 0.6	0.14	<0.001^{c}	<0.001^{c}
Turbidity (NTU)	0.8 ± 0.3	37 ± 13	35 ± 11	27 ± 9	61 ± 10	42 ± 14	<0.001^{c}	<0.001^{c}	<0.001^{c}

Superscript alphabets indicate significant P levels at 0.05, 0.01, 0.001, respectively.

and pH (7.2 ± 0.6 to 7.6 ± 0.6, $F = 3.5$, $P = 0.008$, n = 21) from wet to dry seasons. Turbidity, dissolved oxygen and TDS did not change significantly between seasons. Further analysis using Tukey HSD test for unequal N revealed that temperature readings were significantly different for all months of wet and dry seasons whereas pH measurements were only significantly different between the months of June and September. Down the stream, environmental variables showed a marked decrease or increase (Table 2). Turbidity, O$_2$ concentration and TDS significantly differed among the upper, mid and lower sections of the stream. However, O$_2$ readings were significantly different even among mid stream sites B and C when compared with site D. This scenario was captured by PCA (Fig. 2) whereby site D with high O$_2$ values was shifting towards site A. Lower sites (E and F) had almost no O$_2$ and were grouped together. Overall, O$_2$ seemed an important and sensitive water physico-chemical characteristic. Temperature did not change significantly downstream while pH of lower sites was significantly different when compared with that of upper and mid sites. But pH values of upper and mid sites were not significantly different. Therefore, fluctuations in environmental variables were most pronounced between sites rather than between seasons.

Macroinvertebrates assemblages

A total of 26 taxa were collected from the six sites studied (Table 3). Macroinvertebrate populations increased downstream with the highest densities recorded at site F (Tables 3 and 4). However, they were not significantly different between sites and seasons apart from September when density in the lower stream was significantly higher than mid and upper stream ($P < 0.05$). Upper and mid stream sites were dominated by Diptera primarily the Tipulidae, Sciomyzidae, Ceratopogonidae and Muscidae but their importance declined downstream. *Chironomus* spp. were common in all sites expect site E. Similarly, Hemiptera, Ephemeroptera and Odonata were present in the upper stream sites but virtually disappeared in the lower parts of the stream. The importance of Oligochaeta increased downstream with *Brachiura sowerbyi* and *Alma almini* being the most dominant species. Other invertebrate groups, Mollusca and Decapoda especially *Melanoides tuberculata* and *Procambarus clarkii*, were present but not abundant in the mid sections of the stream. Low populations of Crustacea were recorded in the upper sections of the stream. Little change was noted in the functional feeding groups between sites. Collectors-browsers were the dominant group in all sites except C and E. Grazers and predators contributed a significant component at site C while predators and shredders were minor components at sites A–D. Biodiversity indices decreased significantly downstream with no marked changes between seasons (Table 4). High biodiversity indices (N_0, N_{inf}, N_1, N_2, J') were recorded at site A but significantly declined at site B. They recovered and were higher at sites C and D. There were no macroinvertebrates immediately after the tannery factory (site E). However, several species reappeared at site F.

Association between environmental variables and biodiversity indices

Spearman's rank correlation showed that TDS, pH and turbidity were significantly and positively correlated ($r > 0.8$, $P = 0.001$). However, they were negatively

Table 3 Taxa found in Gathariani Stream with their relative abundance (percentage of the total number of individuals) per station. Marked '–' means absence

	Sites and frequency (%)				
Taxa	A	B	C	D	F
Diptera					
Chronomidae	34.5	42.8	20	16	30
Tipulidae	15.5	6	1.4	–	–
Sciomyzidae	4.4	4.8	–	1.2	–
Ceratopogonidae	6.6	3.6	–	0.7	–
Muscidae	14.7	6	2.8	1.8	0.9
Decapoda					
Procambrus clarkii	–	–	2.8	0.9	–
Coleoptera					
Helochares mediastinus Orch	–	–	–	0.2	0.2
Amphizoidae	1.5	–	–	–	–
Dytiscidae	0.7	–	–	0.5	–
Elmidae	2.2	–	–	–	–
Trichoptera					
Hydropsychidae	0.7	–	–	0.5	–
Orthoptera					
Grylotalpa spp.	–	–	–	0.9	–
Hemiptera					
Micronecta scutellaris	2.2	3.6	2.1	0.5	–
Laccotrephes afer L.	1.5	–	–	–	0.1
Lygaiedae	–	–	–	0.5	–
Ephemeroptera					
May fly	–	–	1.4	0.2	–
Odonata					
Libellulidae	1.5	–	3.4	–	–
Pseudagrion spp.	–	–	–	0.9	–
Cordulidae	1.5	–	0.7	0.2	–
Crustacea					
Crab	3	–	–	–	–
Oligochaeta					
Brachiura sowerbyi	–	–	0.7	18	39.1
Alma almini	8.8	30.9	23.3	52.3	29.4
Hirudinea					
Placobdella	0.7	–	9.6	4.6	–
Rotifera	–	–	–	–	0.1
Mollusca					
Melanoides tuberculata	–	2.4	32.1	–	–

associated with O_2 concentration ($r = -07$, $P = 0.001$). Association between environmental variables and biodiversity indices showed that temperature was only negatively correlated with species density ($r = -0.5$, $P = 0.05$). TDS, pH and turbidity negatively interacted with biodiversity indices ($r > -0.8$, $P = 0.001$). O_2 was positively correlated with all biodiversity indices ($r > 0.6$, $P = 0.01$) apart from species densities. All biodiversity indices correlated positively among themselves except with densities ($r > 0.8$, $P = 0.001$).

Discussion

It was evident from our study that water quality worsened downstream in Gatharaini Stream mainly due to local land use rather than prevailing climatic conditions. Only temperature and to some extent pH showed significant difference between wet and dry seasons. Changes in water quality downstream was clearly indicated by decreasing O_2, increasing TDS, pH and turbidity. Improper land use practices have been reported to contribute a considerable

Table 4 Comparison of biodiversity indices (mean ± SE) among sites in Gatharaini Stream for period of 7 months. Also shown is summary of ANOVA (*F*) and *P* values of all sites except site E (where no organisms were collected). Full names for abbreviated biodiversity indices are given in site selection and laboratory procedures section

	Sites and mean (±SE) values (n = 7)					ANOVA test	
Indices	A	B	C	D	F	*F*	*P*
Density	409 ± 215	251 ± 201	430 ± 256	1301 ± 731	3326 ± 1592	9.5	0.09
N_0	7.71 ± 0.95	4.00 ± 1.41	5.29 ± 1.80	6.43 ± 2.37	3.71 ± 0.76	24.37	<0.001*
N_{inf}	2.93 ± 0.52	2.09 ± 0.53	2.35 ± 0.68	2.06 ± 0.46	2.04 ± 0.38	30.58	<0.001*
N_1	6.06 ± 0.77	3.06 ± 0.59	3.96 ± 1.34	3.72 ± 1.36	2.92 ± 0.42	23.84	<0.001*
N_2	4.97 ± 0.82	2.62 ± 0.40	3.33 ± 1.12	2.90 ± 0.88	2.66 ± 0.47	35.11	<0.001*
J'	0.88 ± 0.05	0.85 ± 0.11	0.83 ± 0.13	0.69 ± 0.11	0.82 ± 0.09	94.94	<0.001*

*Significant levels at $P = 0.001$.

amount of allochthonous materials in lotic systems (Harding *et al.*, 1999; Ometo *et al.*, 2000; Ndiritu *et al.*, 2003). Subsistence agriculture was evident in the upper stream (site A) where low turbidity and moderate O_2 readings were recorded. Site B was situated in an intensive subsistence agricultural area unlike sites C and D, which were situated in coffee plantation zones with river-fed subsistence agriculture. Lower stream sites (E and F) had high TDS and turbidity levels that were attributed to point pollution by Kamiti Tannery Factory. Its discharges were also suspected to contain high organic matter, which completely impaired O_2 concentration downstream.

Temperature significantly fluctuated between seasons and was only mildly associated with macroinvertebrates densities. Although its strong effect in structuring macroinvertebrate communities has been documented (Shieh & Yang 2000), its influence during this study appeared to have been moderated by other environmental factors. TDS, pH and turbidity were found to inversely associate with biodiversity indices but not densities. According to Rosillon (1989), catastrophic and unpredictable fluctuations of abiotic factors provoke perturbation in stream invertebrate communities but the response to such events varies between species. This view was also supported by Flecker & Fleifarek (1994) who observed that physical disturbance could exert a major influence on the community structure of streams. Moreover, during the dry season, biotic interactions gradually replaced disturbance in controlling patterns of community distribution and abundance. Death (1995) concluded that habitat stability and biotic interactions could be a dominant force in structuring benthic invertebrate community in most streams.

Observed increase in invertebrate densities downstream did not translate into high biodiversity indices. The findings were consistent with Connell's (1978) explanation that heavily impacted areas have low number of species and high densities due to low interspecific competition. According to IDH, high species diversity in moderately disturbed ecosystems are attributed to co-existence of pioneer, stress-tolerant and ruderal species (Connell, 1978). Death (1995) found that macroinvertebrate communities in stable sites were higher than those in unstable sites with communities in unstable streams being dominated by mobile collector/browsers. On the other hand, with an increase in stream stability other macroinvertebrate communities tend to increase and dominate, although the dominance by other species does not necessarily lead to removal or reduction of mobile collector/browser densities.

Changes in macroinvertebrate assemblages were mostly observed in terms of species composition rather than in functional feeding groups. Diptera dominated the turbid upper stream sites while Oligochaeta were common in the lower sites with high TDS levels. High nutrient enrichment and sedimentation are known to favour chironomids and Oligochaetes at the expense of snails, algal piercing Trichoptera, Ephemeroptera and Plecoptera (Vaate, 1995; Harding *et al.*, 1999). Sediment load hinders the growth of periphyton and reduces the availability of algae to grazers (Minshall, 1984). Consequently, sedimentation may lead to a decrease in the densities of certain groups, especially the scrapers, shredders and predators (Shieh & Yang, 2000). The lower numbers of Ephemeroptera, Plecoptera and Trichoptera taxa (EPT taxa) coincided with water quality degradation in the Gatharaini drainage basin and the EPT taxa can therefore be good indicators of water quality change.

In summary, this study revealed that macroinvertebrate communities responded to changes in water quality and this was seen in changes in the composition of species assemblages, and in biodiversity indices and densities. Improper land use practices, such as intensive subsistence agriculture on valley sides, industrial pollution from Kamiti Tannery Factory and residential urban settlements around Zimmerman and Githurai areas, were suspected to negatively influence environmental conditions in Gatharaini Stream. Currently, there are no mitigation measures in place to reverse or contain this disturbing situation. There is a need for the Kenyan government to strictly prohibit disposal of raw industrial effluent in rivers and streams by enforcing existing and new environmental legislation. Urban Councils together with other relevant government ministries should control unfriendly land use and development plans on riparian land. Future development plans of residential and industrial areas should cater for proper sanitation and solid waste disposal systems. Cultivation of stream channels, riparian lands as well as reclamation of wetlands for human settlements should be properly planned and executed to minimize negative effects on water resources and biodiversity. Marshy and swampy areas along streams should be protected during implementation of development projects. In the meantime, more studies should be carried out to document macroinvertebrate assemblages and confirm their potential value for biological monitoring of water quality in lotic systems, especially in developing countries.

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