



ERASMUS MUNDUS
MASTER OF SCIENCE IN ECOHYDROLOGY



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***SPATIAL VARIABILITY OF MACROINVERTEBRATE ASSEMBLAGES
AND THE INFLUENCE OF HYDROLOGY AND ENVIRONMENTAL
VARIABLES ALONG THE SIGI RIVER, TANZANIA- EAST AFRICA.***

ERASMUS MUNDUS MASTER OF SCIENCE IN ECOHYDROLOGY

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This research was conducted in the framework of the Master Degree in Ecohydrology and submitted to the University of Algarve, Portugal. It addresses the longitudinal variation of macroinvertebrate assemblages as well as the influence of hydrological and environmental variables in their distribution at Sigi River in Tanzania.

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RESUMO

O estudo de investigar a variabilidade espacial e temporal de macroinvertebrados e sua relação com a hidrologia, fatores hidráulicos e ambientais foi feito ao longo do Rio Sigi durante dois períodos de amostragem na estação seca (Março) e chuvosa (Maio) de 2012.

O rio foi demarcada com base nas taxas de inclinação e cinco zonas do rio foram identificadas como: riachos em montanhas, alto sopé, baixo sopé, rejuvenescente sopé e rio inferior. Amostras de macroinvertebrados foram coletadas a partir das cinco zonas fluviais e medições dos parâmetros hidrológicos (descarga), hidráulicos (profundidade, velocidade e número de Froude) e ambientais (pH, temperatura, substrato, condutividade), foram feitas em cada zona.

Ao caracterizar as assembléias de macroinvertebrados ao longo do Rio Sigi, índices de diversidade (número de táxons, abundâncias totais, índice de riqueza de Margalef e Shannon-Wiener) foram calculados e as espécies mais representativas foram identificadas para a variação espacial e temporal. *Melanoides*, *Amphipsyche*, *Elminae* e *Afronurus* mostraram diferenças na abundância em dois períodos amostrados, enquanto *Cleopatra*, *Potamonautes*, *Ephemerythus*, *Neoperla*, *Caenis*, *Ceratogomphus* e *Cheumatopsyche* apresentaram diferença significativa entre as zonas fluviais. Correlação de Sperman e Modelo de Distância Linear foram usados a fim de revelar os fatores físicos que regem a distribuição da comunidade de macroinvertebrados bentônicos.

O estudo demonstrou que a variação dos factores físicos, como a descarga, temperatura, condutividade e pH apresentam um papel importante na distribuição espacial na comunidade de macroinvertebrados ao longo do rio e do ciclo de vida dos macroinvertebrados (*Afronurus*) sendo importante para a determinação da variabilidade temporal.

Palavra-chave: Invertebrados aquáticos, Zonação do rio, variação temporal, Rio Sigi, fatores físicos.

ABSTRACT

The study of investigating the spatial and temporal variability of macroinvertebrate and their relation to hydrology, hydraulic and environmental factors was done along the Sigi River during two sampling periods in the dry (March) and wet (May) periods of 2012.

The river was demarcated based on slope ranges and five river zones were identified as mountains streams (MS), upper foothills (UF), lower foothills (LF), rejuvenated foothills (REJ) and mature lower river (MR). Samples of macroinvertebrate were collected from the five river zones and measurements of hydrological (discharge), hydraulics (Depth, velocity and Froude number) and Environmental (pH, Temperature, substrate, conductivity) parameters were done in each zone.

In characterizing the macroinvertebrate assemblages along the Sigi River diversity indices (number of taxa, total abundances, Margalef richness index and Shannon-Wiener index) were calculated and the most representative species for the spatial and temporal variation were identified. *Melanoides* and *Afronurus* showed differences in abundance in two samplings periods while *Cleopatra*, *Potamonautes*, *Ephemerythus*, *Neoperla*, *Caenis*, *Ceratogomphus* and *Cheumatopsyche* showed significant difference among the river zones. Spearman rank correlation and Distance Linear Model (DistLM) used to revealed physical factors governing the macroinvertebrate assemblages distribution.

The study demonstrated that the variation of physical factors like discharge, temperature, conductivity and pH have an important role in the spatial distribution of macroinvertebrate assemblages along the river and the life cycle of macroinvertebrate (*Afronurus*) is important in determining the temporal variability.

Keywords: Aquatic invertebrates, River zonation, temporal variation, Sigi River Tanzania, physical factors.

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1.0 INTRODUCTION

1.1 General introduction

Rivers are longitudinal systems that integrate the characteristics of the catchment they drain, are extremely complex ecosystems driven and affected by a multitude of physical and biological factors that interact to generate biotic patterns (Dallas 2004). Due to these interactions, the biological community in rivers exhibits a high degree of spatial and temporal variability (Cooper et al. 1997). Longitudinal variation of the river ecosystems has been associated with the biological distribution down the length of the river. Thus longitudinal zonation of rivers has been widely adopted by ecologists in order to explain the variations in biological distribution (Hawkes 1975, Parsons & Thoms 2007).

The spatial and temporal variability of biological community in particular aquatic macroinvertebrates is a widely studied characteristic in lotic ecosystems (Hawkins et al. 1997). Several studies on aquatic macroinvertebrates have used them as bioindicators for assessing water quality in surface waters, similar studies have been conducted in east Africa and Tanzania (Masese et al. 2009, Masese et al. 2010, Ngupulu & Kayanda 2010). Also macroinvertebrates have been used as indicators in determining the minimum flow (environmental flow assessment) required in rivers of east and southern Africa.

There is strong evidence that aquatic macroinvertebrate distribution is influenced by the physical variables dynamics and processes that occur in the river. These include hydrological dynamics, hydraulics or in-channel processes and environmental changes. Aquatic macroinvertebrates have been reported to be influenced by in-channel physical conditions (Kemp et al. 2000). The study of Gore & Judy (1981) and Rossaro et al. (2006) have described the different curves explaining the preference of many different species of macroinvertebrates for velocity, depth, discharge, Froude number, substrate size, demonstrating that a range of species preferences exists. Other physical factors like water temperature (Camur-Elipek et al. 2010), conductivity (Mesa 2010), dissolved oxygen (Gabriels et al. 2007), substratum (Goncalves et al. 2004) and channel geomorphology (Woodcock et al. 2006) have also shown to influence the distribution of macroinvertebrate assemblages.

The relative importance of these hydrology and environmental factors varied not only among the region, but also within a region (Park et al. 2007, Song et al. 2007). Hydrological, hydraulic and environmental conditions in a river have been identified by many authors as the best predictive variable of macroinvertebrate distribution (Barmuta 1990, Kemp et al. 2000, Brettler et al. 2012). Although there is a close linkage of these physical factors and macroinvertebrate assemblages but the understanding of how and which variables of hydrology, hydraulics and environmental processes influence the macroinvertebrate assemblages is still less explored, particularly in Tanzania this knowledge is very limited.

Understanding the interaction of physical variables and macroinvertebrate assemblages is essential for aquatic ecosystem conservation. Aquatic macroinvertebrate play an important role in the riverine ecosystem as they process detritus and algae and provide food to their aquatic animals therefore understanding their distribution pattern is useful.

1.2 Spatial and temporal variability of macroinvertebrates assemblages

The spatial variation of macroinvertebrate community depends on a range of abiotic factors that occur in a catchment, site and within a habitat scales (Wiley et al. 1997, Rowntree & Wadeson 1999). Catchment scale factors include differences in channel slope, climate, geology, altitude, longitude/latitude and distance from the source and upstream catchment (Wright 1995, Bailey et al. 1998, Dallas 2007). Factors operating at the site scale include the width, depth, flow pattern and canopy cover (Wright 1995, Collier et al. 1998, Linke et al. 1999, Dallas 2007). Habitat scale factors include the nature and extent of substrate type, availability of biotopes (Dallas 2007) and hydraulic conditions (Padmore 1998, Kemp et al. 2000).

The River continuum Concept (RCC) by Vannote et al. (1980) explained that species distributions and diversity of macroinvertebrates can display predictable changes from upstream to downstream. For instance, taxonomically related species of macroinvertebrates often show contrasting distributional patterns in relation to stream size (Edington & Hildrew 1990), changes in food availability e.g. allochthonous and autochthonous and diversity peaks at the middle reaches of large rivers (Vannote et al. 1980, Minshall et al. 1985). However usually the grouping of macroinvertebrate community is not in clearly discrete pattern thus predicting the structure and diversity of the community types in the land class became

challenging. The gradual change in factors such elevation, water temperature, flow rate and food resources along the longitudinal profile exerts a direct influence on the population dynamics of macroinvertebrates and other organisms, contributing to ecological river zonation. The importance of multiple scale of environmental control in local assemblage organization has been widely known, however still few studies have examined this patterns and processes across spatial scales in streams (Downes et al. 1993, Li et al. 2001).

River systems also show a daily and seasonal periodicity in physical factors. Seasonal and year- to-year variability in macroinvertebrates community have been closely linked with the unevenness in precipitation events (McElravy et al. 1989). In tropical regions fluctuations in precipitation which results to variation of the stream discharge, often represent the strongest seasonal variation, and change the environment to an extent comparable to temperature in temperate areas (Flecker & Feifarek 1994, Jacobsen & Encalada 1998). Variations in discharge often give differences in wetted perimeter, hydraulic conditions and biotope availability. For example, in case of stony bottom biotopes may become a riffle in low-flow conditions and as runs in high-flow conditions. These changes are closely related to their life history stages such as emergence, feeding and growth that are prompted into them. Temperature is among the important factors that exhibits temporal variation. Water temperature as being a climatically-driven variable can be controlled by other factors such as discharge, altitude, canopy cover and seasons. The variations in temperature affect the growth and distribution of macroinvertebrates, for instance summer maximum temperature may limit the occurrence of certain species (Hawkins et al. 1997). In a more complex way, seasonal variability may occur longitudinally down a river termed as spatial-temporal interaction, in which upland sites can have a single macroinvertebrate assemblage whilst in lowland sites can have a distinct winter and summer assemblage or a certain group of macroinvertebrate can occur downstream in early months and upstream during the late months (King 1981, Linke et al. 1999).

1.3 Hydraulics influence on macroinvertebrates assemblages.

Hydraulics conditions influence biota directly by exerting stress that will limit access and utilisation of habitat (Davis 1986) and through the influence on the supply of particulate food resources, dissolved gases and nutrients for metabolic processes (Biggs et al. 2005). Water depth, velocity, roughness and slope are the primarily parameters of the hydraulic conditions of the river channel, which usually shows temporal and spatial variations. These parameters may have influence on biota indirectly by modifying, creating and eliminating physical habitat (Biggs et al. 2005). They are recognised significant in determining the macroinvertebrate community organisation (Davis & Barmuta 1989, Carling 1992) by influencing their metabolism feeding and the behaviours (Statzner et al. 1988). However there have been limited studies of the relationship between these variables and macroinvertebrates. Froude number as a complex stream hydraulic variable has proposed among the major variable in influencing the macroinvertebrate assemblages distribution (Grown & Davis 1994, Jowett 1993). The relationship of hydraulic variables and benthic fauna has been found to be negative meaning that lower hydraulic values corresponded to higher benthic fauna abundances and taxonomic richness Brooks et al. (2005). Velocity has been recognised to be the important in determining pattern of macroinvertebrates abundances and diversity (Brooks et al. 2005, Reid & Thomas 2008), accounting for 67%-77% of the spatial variation. In the same study depth was found to have a lesser influence on spatial variation on the biodiversity and abundances of benthic fauna. In conclusion, the majority of benthic fauna is generally associated with the areas of lower hydraulic variables, presumably where metabolic requirements were lower and adequate food resources were present. The influence of physical factors ranges with the habitat scale, macrohabitat variation is primary caused by the variation in the hydrological processes like discharges and geomorphic factors (Sheldon & Walker 1998) while in the case of mesohabitat the variation has been related to the longitudinal gradients in discharges, particle size and hydraulic variables (Barmuta 1990, Downes et al. 2000).

1.4 Aim

Main objective of the study

The main aim of this study was to assess the spatial and temporal distribution of macroinvertebrate assemblages at different zones along the Sigi River and its relationship with the hydrological, hydraulics and environmental variables in wet and dry periods.

Specific objectives

- To determine the spatial pattern of the macroinvertebrate assemblages along the Sigi river.
- To assess the temporal variations in macroinvertebrate assemblages along the Sigi River during the two sampling periods (dry and wet periods).
- To determine the influence of hydrological (discharge), hydraulics (flow velocity, depth and Froude number) and environmental (pH, temperature and conductivity) variables on macroinvertebrate assemblages.

2.0 MATERIALS AND METHODS

2.1 Study area

Sigi River is a perennial water body located in Tanga Region, north-eastern of Tanzania Figure 1. The river lies between latitudes 4⁰48'S and 5⁰15'S and longitudes 38⁰34'E and 39⁰03'E with a catchment area of about 1,100km². It rises in the Amani Nature Reserve in the eastern slopes of the East Usambara Mountains at an altitude of 1130m. Sigi River has two main tributaries flowing from the north (Muzi stream) and south (Kihuhwi stream) and after their confluence it drains eastwards out of Usambaras and north of the city of Tanga into the Indian Ocean via the Mabayani Dam, a source for the Tanga Municipal Water Supply.

The upper reaches of the catchment are mountainous, consisting mainly of dense forest interspersed with tea plantations. Its lower parts are flat and some parts being rejuvenated comprising dry savannah-type bushes and low trees, as well as sisal estates. Along the coast coconut and palm trees are common.

2.1.1 Climate

Sigi river catchment is characterized by two rainy seasons (bi-modal). March to May is the long rain period while October to December marks the short rains. Occasionally long rains tend to be heavy but the annual average rainfall in Sigi catchment varies between 1000mm to 2000mm (IUCN 2003). These rains contribute in increasing the volume of the Sigi river. The annual mean temperature ranges from 20.8°C in the mountainous areas to 30⁰C in the lower zones (coastal areas).

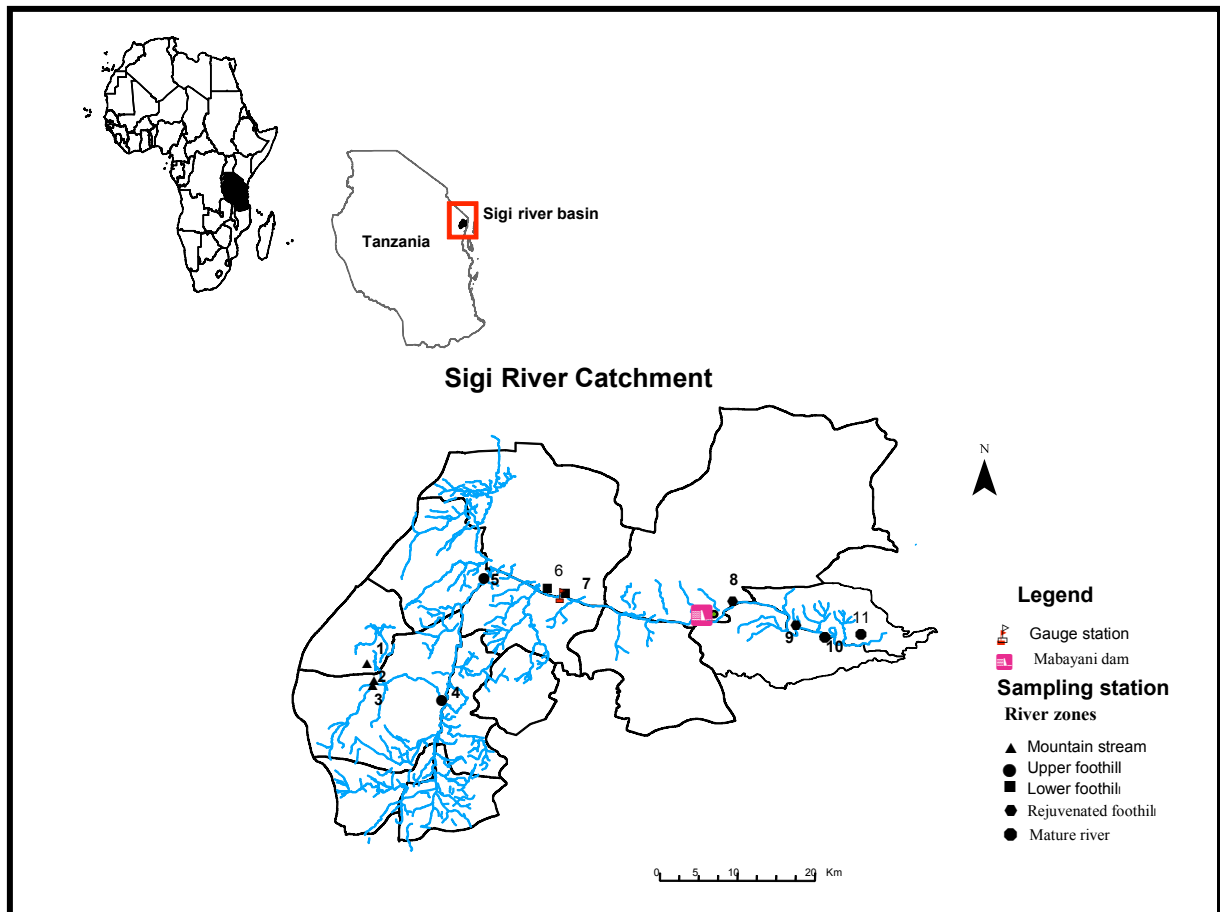


Figure 1: The map showing Sigi River Catchment and the sampling stations.

2.1.2 Geology

The upper and middle Sigi catchment comprises metamorphic rocks of the Usagaran system that have been migmatized and consist of the pyroxene and hornblende granulites and gneisses. The lower Sigi catchment is made up of a sedimentary succession of rocks from karro to Quaternary in age, from sequence of sand stones and shales giving way to Jurassic marine marls and Tanga limestones while younger Neogene sediments consists mainly of raised coral reef deposits (Hamilton & Bensted-Smith 1989).

2.1.3 Land cover and activities in the Sigi catchment

Agriculture

Agriculture is the main land use in the catchment covers about 617.69 km² (61,769ha) which account for 56.16% of the total area. Food crops such as maize, cassava, banana and fruit are cultivated, while cash crops such as sisal and tea are very common in the mountainous areas *e.g.* Derema and Longuza Tea Plantation project.

Forests

There is 450.99km² (45,099 ha) of forest in the Sigi Catchment, which include both natural and plantation forests. This account for 41% of the total area.

Water

The water in the catchment covers about 21.63 km² (2.163ha) which is 1.93% of the total area. Also the Sigi River provides domestic water to Tanga Municipality (population 300,000), associated industries, estates and adjacent local communities through the Mabayani dam. The Mabayani dam was constructed in late 1970's. It is approximately 3,500m long with an average width of 400m. Initially (in 1978), the reservoir had a nominal storage capacity of 7.7 million m³, but this has gradually decreased due to siltation caused by erosion and landslides.

Sand Mining

This has found to be major land use especially inside the Sigi river at the low land area where the substratum is sand. This has lead to habitat destruction, change of the flow regime *e.g.* creation of more pools and as the results affecting aquatic organism especially benthic macroinvertebrates which highly depend on the bottom substrate.

Domestic activities

Domestic activities such as washing, bathing are taking place directly in the river channel, this deteriorate the water quality due to addition of nutrients (Phosphate and nitrogen) from detergents and other organic matters. Domestic activities have mainly being observed in the middle zones areas where Sigi River is passing near the villages.

Fisheries

Fishing is carried out mainly along the coast of Indian Ocean, where the Sigi River's mouth is to be found. Small fisheries exist along its course, targeting fish such as *Clarias* sp. (a cat fish, 'kambare'), *Tilapia* sp. ('perege'), *Labeo* ('ningu'), *Synodontis* ('ngogogo'), *Barbus* ('kuyu') and others. Fishing on the Mabayani reservoir is forbidden because its water is intended as a source of domestic water for the Tanga Municipality.

2.2 River Zonation

Zonation of the Sigi River was derived from analyses of the gradients measured from 1:50,000 topographic map of Sigi catchment. The stream gradient (slope) in each site was calculated as the function of distance and change in elevation. From topographic maps, the stream gradient was calculated as the difference between the upper and the lower contour (contour interval) at each site, dividing by the length of the stream segment (Equation 1).

Equation 1: Calculation of stream gradient/slope

$$\text{Stream gradient (slope)} = \frac{\Delta \text{ in elevation}}{\text{River segment length}}$$

However the gradient scale described for South African rivers by Rowntree & Wadeson (1999) were lower for the Sigi catchment. The slopes ranges were defining a higher longitudinal zone than the actual zones. Longitudinal profiles of some Tanzanian rivers have been interfered due to the tectonic movements through uplifting and rifting. The uplifting and rifting in late Miocene caused rivers to be rejuvenated (Burgess & Clarke 2000). The Pangani rift segments of the Eastern Rift Branch extend their effects to the coast of Indian Ocean and have contributed significantly to the rejuvenation of the Sigi River. Prominent knick points in the Sigi River are associated to the bedrock nature of this catchment. Profiles of rivers incised into bedrock are characterised by prominent knick points even in areas not influenced with uplift, lithology or tributary confluence (Woodford 1951). In this study the gradient scales were modified to reflect the actual profile of study (Table 1)

Table 1: Showing the longitudinal classification of Sigi River based on stream gradient.

River zones	Gradient range	Description
Mountain Torrent	≥ 0.2	
Mountain streams (MS)	0.1 – 0.1999	Steep gradients, dominated by bedrock, boulders and locally gravel or cobble with pools
Upper foothill (UF)	0.050- 0.099	Gravel and cobbles: riffles, runs, and pools
Lower foothill (LF)	0.005 – 0.049	Wide river, run, sand, silt
Lower matured river (MR)	≤ 0.0049	Sand
Rejuvenated foothill (REJ)	0.05-0.2	Sections of the lower river with higher gradient and characteristics of the upper rivers. The channel is bedrock controlled with lateral development of alluvial reach types Bedrock and boulders; cascades, falls, isolated pools

Table 2: Sampling sites along the Sigi River with indication of river zones characteristics. Codes; MS = Mountain streams, UF= Upper foothill, LF= Lower foothill, REJ = Rejuvenated foothill and MR= Lower mature river

Site N ^o	Site names	Latitude (S)	Longitude (E)	Gradient	River zones
01	Derema	5.086003	38.64096	0.1225	MS
02	Nenguruwe	5.101836	38.6467	0.1551	MS
03	Bulwa	5.107169	38.64528	0.2033	MS
04	Longuza	5.117764	38.69215	0.0955	UF
05	Sigi Lydia	4.996806	38.72709	0.0623	UF
06	Sigi Darajani	5.011394	38.78616	0.0308	LF
07	Sig Lanconi	5.016944	38.80127	0.0406	LF
08	Sigi KwaMpare	5.017692	38.93521	0.0676	REJ
09	Sigi Kidudumo	5.049761	38.97742	0.0557	REJ
10	Sigi Cross Z	5.058469	39.01421	0.0048	MR
11	Sigi Sega	5.055686	39.04221	0.0050	MR

2.3 Sampling design

Macroinvertebrates were sampled at 11 sites along the Sigi River ([Figure 1](#)), the sites were selected to represent the different river gradient ([Table 2](#)). Two sampling periods were analysed: dry period (March, 5th to 9th 2012) and wet period (May, 25th to 28th 2012). In both sampling periods also river discharge, velocity, depth and environmental parameters (pH, temperature and conductivity) were measured.

In the dry season 9 sampling sites were sampled. In order to analyse all river zones, 2 missing sites were sampled during the following wet season making a total of 11 sites, in order to have at least more than 1 site in each of the river zones. In each site 3 replicates were collected which were referred to as samples and were treated separately. In total 60 samples were collected, 27 samples in the dry season and 33 samples in the wet season at 5 river zones (MS, LF, UF, REJ and MR). The samples collected were organised to represent the

five river zones. The substrate was described in each river zone and the following scale was used; Sands = 1, gravels = 2, cobbles = 3, boulders = 4 and Bedrock 5. Substrate was considered as an environmental variable. [Table 3](#) below summarizes the data organisation.

Table 3: Macroinvertebrate sampling design and data organisation.

River zones	N ^o of sites representing	Substrate	substrate Scale	Season Dry	Wet
MS	3	Boulders	4	9	9
UF	2	Cobbles& gravels	3	6	6
LF	2	sand	1	6	6
REJ	2	Bedrock	5	3	6
MR	2	Sand	1	3	6

2.4 Macroinvertebrates sampling

Qualitative sampling of macroinvertebrates was performed during wet and dry season. In each station the dominant biotope (Stones, sand and vegetation) was identified which was simply the habitat contribute to more than 50% of the area within the selected 50 m reach for sampling. Three replicates samples of macroinvertebrate were collected in the selected biotope. Macroinvertebrates were collected always by the same operator using a 30x30 cm kick net with a 1 mm mesh size and applying time limited samples (3 minutes). Samples were fixed in 80% ethanol, transported to the laboratory where they were rinsed using a sieve of 1 mm mesh size, sorted under magnification and preserved in 70% ethanol. All individuals in a sample were counted and most were identified to the Genus level except few of them to family level (Baetidae, Leptophlebiidae, Polycentropodidae, Polymitarcyidae, Tricorythidae, Veliidae and Hirudinea) and Chironomidae and Elmidae were identified to sub-family level.

2.5 Hydrological, hydraulics and environmental variables measurements

2.5.1 Hydrological variables

River discharge was used as a parameter representing hydrological conditions of the river. Signal counter, ADC (Acoustic Digital Current meter) and Q-liner were used in discharge measurements ([Figure 2](#), [Figure 3](#) & [Figure 4](#)). In dry period the Signal counter device was used for discharge measurements while in wet period ADC and Q-liner were used.

During flow measurements at each sampling station, the measuring tape was stretched between the endpoints of the river channel cross-section. Then the cross section distance was divided into intervals/cells depending on the river width. The cell or interval length was between 1m-2m, to make at least 3 cells across the river. At each interval or cells the distance, depth (m) and velocity (m/s) was measured. At low depths (<0.5m) 0.6D velocity measurements were done and at high depth (>0.5m) a 0.8D and 0.2D measurements were done in each cell/interval. To take the reading the rod was held in a vertical position with the meter directly into the flow. The sensor or propeller was kept completely under water, facing into the current (for 30 s) and free of interference. The meter was adjusted slightly up or downstream to avoid boulders, snags and other obstructions.

OTT Q-liner was used for hydrological measurements in only two sites due to higher depth (> 1m). The instrument consists of a robust and reliable ultrasound Doppler current profiler, a stable boat to hold the profiler, a Bluetooth transmitter, a watertight handheld (PDA) and the corresponding user software. Using the classical vertical process the Q-liner measures both the vertical velocity and the water depth at each interval. All measured data are transferred to the PDA via Bluetooth and processed online. After the measurement is complete, the discharge is available immediately.



Figure 2: OTT Qliner, A system for mobile discharge measurement in rivers



Figure 3: OTT Acoustic Digital Current meter (Source: <http://www.ott.com>)



Figure 4: OTT Signal counter (Source: <http://www.ott.com>)

Computation river discharge.

These computations were done when the signal counter device was used during the spot measurements. Unlike ADC and Q-liner, which automatically gives the mean velocity and discharge, Signal counter gave only the revolution time. The equations below were used to calculate the velocities.

For small propeller

$$\text{If } n = <1.75; v = 0.0670n+0.018$$

$$\text{If } 1.79 \leq n \leq 9.29; v = 0.0564n+0.037$$

$$\text{If } 9.29 \leq n < 17.49; v = 0.0536n+0.063$$

For Large propeller

$$\text{If } n = <0.84; v = 0.0670n+0.018$$

$$\text{If } 0.84 \leq n \leq 9.56; v = 0.0564n+0.037$$

Note: n = number of revolution counted * time (30s)

When the section velocity calculation was complete, the river discharge (Q) in each section was calculated as recommended by the U.S. Geological Survey.

- Area (A_n) of each subsection was computed by;
 $A_n = \text{subsection width } (W_n) * \text{subsection depth } (D_n)$
- The subsection discharge (Q_n) was obtained by multiplying the subsection area by its velocity (mean velocity of the subsection). The calculation was repeated for all cells/subsections.

$$Q_n = \text{subsection velocity } (V_n) * A_n$$

- The total discharge (Q) was obtained by summing subsections discharge.

$$Q = \sum (A_n * V_n) \text{ or } \sum Q_n$$

2.5.2 Hydraulic variables

The simple measurements of depth and velocities were used to calculate more complex variables in an effort to better identify the hydraulic microhabitats. The Froude number was used as a complex variable.

The below formula was used in calculating Froude number (Newman 1977)

$$\text{Froude number} = \frac{v}{\sqrt{gh}}$$

Where;

v = Mean velocity (m/s)

g = Gravitational (10 m/s²)

h = Mean water depth (m)

2.5.3 Environmental variables

On each sampling occasion, environmental variables were measured prior to invertebrate sampling and hydrological measurements. Water temperature, pH and conductivity were measured *insitu* using a multi portable probe.

2.6 Data Analysis

2.6.1 Macroinvertebrates Data

Diversity indices

Diversity indices which include number of taxa, total abundances, Margalef species richness index (d') and Shannon diversity index (H') were calculated. d' and H' indices were determined by the equation below.

$$H' = \sum_{i=1}^S -[P_i * \log e(P_i)] \quad \text{and} \quad d' = (S - 1) / \log (N)$$

Where:

H' = the Shannon diversity index

d' = Margalef species richness

P_i = fraction of the entire population made up of species i

S = numbers of species

N = Total individuals

Σ = sum from species 1 to species S

Univariate procedures were used in examining the differences in the number of species, total abundance, species richness index and diversity index of macroinvertebrate assemblages calculated among the five river zones. Two way Analyses of Variance (ANOVA) were used for testing whether there were significant differences in the diversity indices among the river zones and between the two sampling periods.

Macroinvertebrate assemblages

Multivariate procedures were used to analyse the macroinvertebrate assemblage data gathered in this study. The multivariate procedures consider each taxonomic group (in this study genus) to be a variable and the presence/absence or abundance of each taxonomic group to be an attribute of a site or time. All multivariate analyses in this study were performed using the *Primer Version 6* software package for windows.

In order to assess the variations in macroinvertebrate assemblages during the dry and wet period, samples from each sampling period were analysed independently. In each period the data used were in two forms: binary (*i.e.* presence/absence of each taxonomic group) and untransformed data (*i.e.* actual abundances of each taxonomic group). The analyses using untransformed data highlight the impact of abundance therefore *taxa* with less individuals will have little impact on ordination. The use of presence/absence data down-weights the effect of common species resulting in ordination based on community composition (Clarke 1993). Thus, using them together will eventually reveal the contribution and importance of *taxa* abundance and the species composition within the macroinvertebrate assemblage on their distribution. The Bray-Curtis coefficient has been recommended for the community structure analysis of the biological data on *Primer* software. The Bray-Curtis coefficient compares each sample with every other sample using a measure of similarity or dissimilarity which leads to a triangular matrix that can be used in cluster and ordination analysis (Clarke 1993).

Non- parametric multi-dimensional ordination (MDS) was used to visualize the spatial variation in macroinvertebrate community along the Sigi River. The classification of river zones, comprised of five levels (MS, UF, LF, REJ and MR) was used as a factor in the MDS plots. To determine whether variation of macroinvertebrate community among the river zones was significant one-way ANOSIM routine was applied followed by the Pairwise test. The significance level 0.05(5%) of the sample statistics was applied to test for null hypothesis that no differences in macroinvertebrate community among the river zones.

SIMPER analysis (Clarke & Warwick 1994) was performed to identify the *taxa* responsible for the difference between the river zones. All *taxa* were used in SIMPER analysis (Cut-off point was not selected) and identify their percentage contribution to the dissimilarity between the zones, at the end the average contribution of each *taxa* to the overall dissimilar existing among the river zones was calculated and ranked from the most contributing *taxa* to the least ones.

Single Species analysis

The identified taxa that highly contributed to the overall dissimilarity among the river zones and those taxa contributed within two group dissimilarity in both periods during SIMPER analysis were subjected to univariate analysis (two-way ANOVA) testing the influence of river zones and time to their distribution. Differences between means have been considered statistically significant for $p < 0.05$. When appropriate, multiple comparisons for means were done on significant main effects using Student–Newman–Keuls (SNK) tests. The univariate analyses were performed using the *Sigma Plot Version 11* software package for Windows.

2.6.2 Hydrology, hydraulic and environmental variables

Hydrology, hydraulic and environmental variables were considered in relation to macroinvertebrate assemblages, specifically how different hydrology, hydraulic and environmental variables are related to the spatial distribution of macroinvertebrates. The BIOENV routine (*PRIMER 6*) was used for this purpose. Spearman rank correlation methods were used which involved randomly selection of variables. Prior to BIOENV variables were subjected to ANOVA test using River zones and Time as factors.

The variables showed better correlations with biological data (10 number of best results was selected) were further analysed using Distance based Linear Model (DistLM) to assess the relative contributions of these variables to structuring biological assemblages and identify macroinvertebrate taxa that were best related to the variables.

3.0 RESULTS

3.1 Diversity indices (Number of taxa, total abundances, richness index and diversity index)

Diversity indices varied significantly among the river zones defined along the Sigi river (ANOVA, [Table 4](#)). Time was found to have no influence on the variation of the indices and thus the same pattern was detected in both sampling periods. The post- hoc tests showed that the mature rive (MR) zone had significantly less taxa, smaller abundances and smaller values of the indices, relative to the other river zones ([Figure 5](#)).

Table 4: Results of Analysis of variance (ANOVA) based on biotic indices for the five river zones and two sampling periods (Dry & wet periods). * = p <0.05.

Source of variation	df	N° of taxa			Total abundances			Specis richness (d')			Diversity index (H')		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Time	1	1.021	0.0623		364.026	0.9		0.017	0.02		0.03	0.22	
River zones	4	143.267	8.739	*	1060.097	2.62	*	7.947	10.6	*	2.837	21.1	*
Timexriver zones	4	6.942	0.423		307.504	0.76		0.297	0.4		0.114	0.85	
Residual	50	16.394						0.749			0.134		

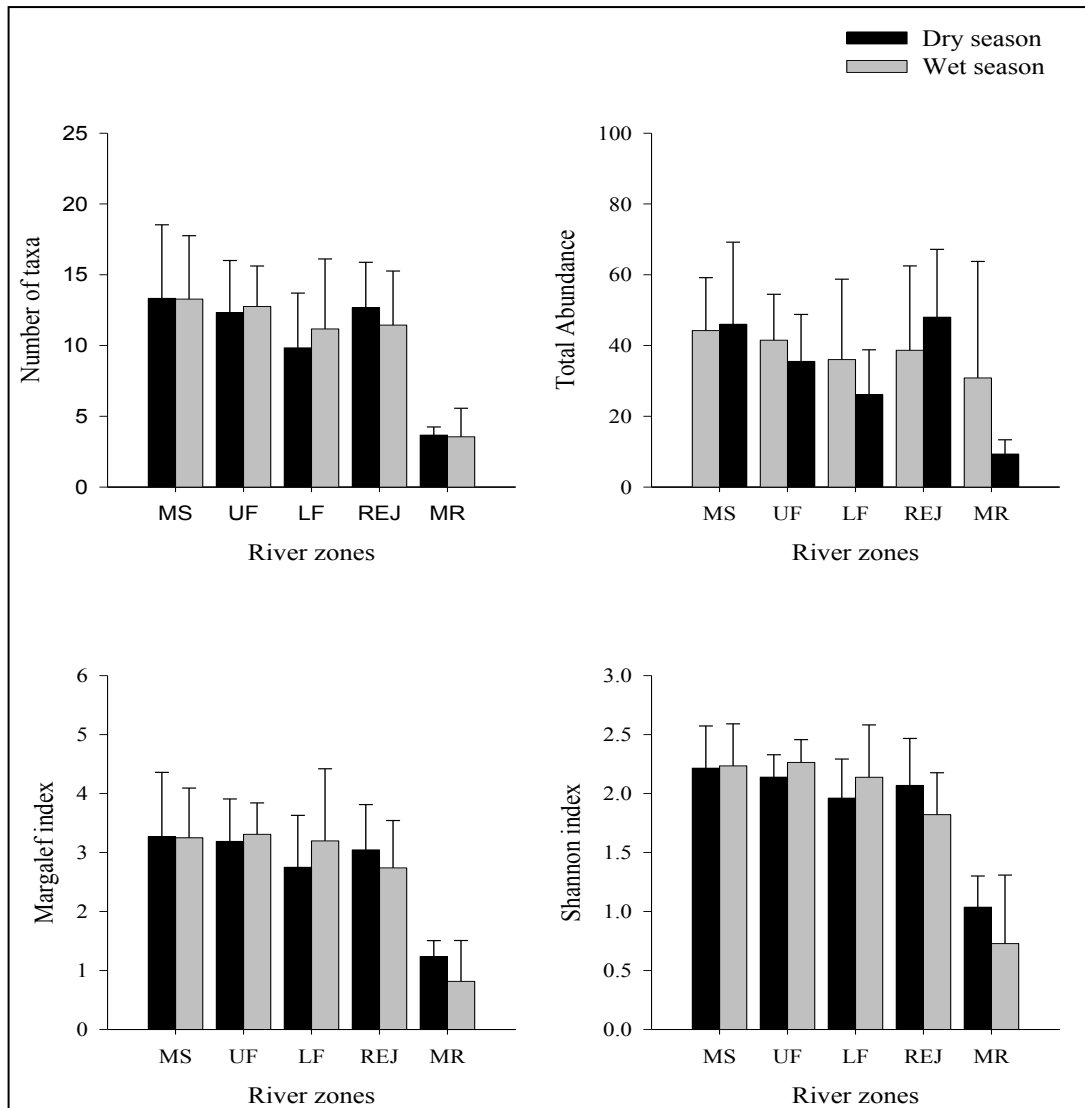


Figure 5: Diversity indices (*mean* ± *SD*) indicating number of taxa, Total number of individuals, Margalef's species richness index and Shannon-Wiener diversity index for the dry and wet seasons. MS = Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature lower river.

3.2 Macroinvertebrate assemblages

A total of 956 individuals, distributed by 54 taxa, were collected at 9 sites along the river in the dry period. The samples were numerically dominated by Ephemerithidae (*Epherythus sp.*), Potamonautidae (*Potamonautes sp.*), Hydropsychidae (*Hydropsyche sp.* & *Leptonema sp.*) and Thiaridae (*Cleopatra sp.*), as summarized in [Table 5](#). In the wet period 1280 individuals and 56 taxa of macroinvertebrates were collected in 11 sites along the Sigi river from its headwaters to the low land areas. Actyidae (*Caridina sp.*), Thiaridae (*Melanoides sp.* & *Cleopatra sp.*), Heptageniidae (*Afronurus sp.*) and Potamonautidae (*Potamonautes sp.*) were the most abundant taxa ([Table 6](#)).

The ANOSIM analyses indicated there were significant differences in the macroinvertebrate assemblages among the five zones defined along the river ([Figure 6](#)) in both sampling periods. [(for actual abundance data (**Global R =0.8, p<0.05; Global R =0.5, p<0.05** for dry and wet periods respectively) and presence/absence transformed data (**Global R =0.8, p<0.05 and Global R =0.5, p<0.05** for dry and wet periods respectively))]. The pair-wise tests showed there were significant differences in each pair of the river zones, except in dry period the MR and REJ zones (p=10%) both in terms of taxonomic composition and abundances. The high Global R was observed in this pair (MR and REJ), the lack significant difference which was not expected could be due to lowest number of permutation which was 10. In the wet period the three pairs of river zones MR& REJ, REJ & LF and LF & UF were not significantly different from each other. The remaining pairs were significantly different from each other both in terms of taxa composition and abundances ([Table 7](#)).

Taxa contributing to the dissimilarity in macroinvertebrate assemblages among the river zones are tabulated on basis of the overall average contribution to the difference among the river zones. In dry period *Amphipsyche*, *Elminae*, *Chironominae*, *Cleopatra* and *Potamonautes*, in wet period *Melanoides*, *Caridina*, *Afronurus*, *Potamonautes* and *Cleopatra* are the taxa contributed above 5% for the dissimilarity among the river zones based on their abundances. The greatest contributors to dissimilarities with respect to frequency of occurrence during the dry period were *Ceratogomphus*, *Cleopatra*, *Cheumatopsyche*, *Elminae* and *Plantala*; while in the wet season were *Cleopatra*, *Potamonautes*, *Enthraulus*, *Caridina* and *Rhagovelia* ([Table 8](#)).

Table 5: List of identified taxa (*av. abundance* \pm *SD*) of macroinvertebrates in the five zones of Sigi river in dry period. Codes; MS- Mountain streams, UF- Upper foothill, LF- Lower foothills, REJ= Rejuvenated foothill, MR- Mature river.

Family	Genus	MS	UF	LF	REJ	MR	Total individuals
Actyidae	<i>Caridina</i>				0.67 \pm 1.15	1.67 \pm 1.53	7
Athericidae	<i>Suragina</i>	0.22 \pm 0.45	0.17 \pm 0.48				3
Baetidae	<i>Acanthiops</i>	0.67 \pm 1.32	0.67 \pm 1.63		1 \pm 1.73		13
	<i>Baetidae</i>		1.5 \pm 1.38				9
	<i>Bugilliesia</i>	1.22 \pm 1.32	0.83 \pm 0.98				16
	<i>Cloeodes</i>	0.22 \pm 0.67			1 \pm 1.73		5
	<i>Pseudopannota</i>	1 \pm 2.35	4.17 \pm 7.33				34
	<i>Xyrodromeus</i>	0.22 \pm 0.45	0.33 \pm 0.52		1.33 \pm 1.53		8
Belastomatidae	<i>Appasus</i>				0.33 \pm 0.58	0.33 \pm 0.58	2
Caenidae	<i>Caenis</i>	0.56 \pm 0.53		4.33 \pm 2.53	1 \pm 1.73		34
Calopterygidae	<i>Umma declivium</i>	0.22 \pm 0.67					2
Ceratopogonidae	<i>Ceratopogoninae</i>			0.17 \pm 0.48	0.33 \pm 0.58		2
Chironomidae	<i>Chironominae</i>	1 \pm 1.12	1.67 \pm 2.88	1.17 \pm 1.63	1.33 \pm 1.53	4.67 \pm 5.69	44
Chlorocyphidae	<i>Platycypha</i>	0.33 \pm 0.77	0.33 \pm 0.52				5
Coenagrionidae	<i>Ceriagrion</i>					1.33 \pm 1.15	4
Corduliidae	<i>Phyllomacromia</i>			1.33 \pm 1.21			8
Diceromyzidae	<i>Diceromyzom</i>	2.33 \pm 3.88			0.33 \pm 0.58		22
Elmidae	<i>Elminae</i>		0.67 \pm 0.82	1 \pm 1.55	10 \pm 11.79	0.67 \pm 0.58	42
	<i>Larainae</i>	1.22 \pm 1.64	0.17 \pm 0.48	0.33 \pm 0.52	0.67 \pm 1.15		16
Ephemerythidae	<i>Ephemerythus</i>	7.11 \pm 8.90	0.17 \pm 0.48		1 \pm 1.73		68
Gerridae	<i>Aquarius</i>		0.17 \pm 0.48	0.17 \pm 0.48			2
	<i>Naboandelus</i>			0.33 \pm 0.82			2
Gomphidae	<i>Ceratogomphus</i>	0.44 \pm 0.73	2.83 \pm 2.32	4.17 \pm 4.78			46
	<i>Ictinogomphus</i>			1.33 \pm 1.75			8
	<i>Lestinogomphus</i>			0.33 \pm 0.82			2
Gyrinidae	<i>Orectogyrus</i>	0.22 \pm 0.45		0.17 \pm 0.48			3
Heptageniidae	<i>Afronurus</i>	2.78 \pm 3.32	1.17 \pm 0.98		1.33 \pm 1.15		36
Hydropsychidae	<i>Amphipsyche</i>		0.5 \pm 1.22	0.5 \pm 1.22	13.67 \pm 5.58		47
	<i>Cheumatopsyche</i>	4.78 \pm 3.87	1.50 \pm 1.64		2.67 \pm 3.79	0.33 \pm 0.58	61
	<i>Hydropsyche</i>	0.78 \pm 1.56	0.50 \pm 0.84		1 \pm 1.73		13
	<i>Leptonema</i>	5.22 \pm 7.12	0.33 \pm 0.82	0.17 \pm 0.48	0.33 \pm 0.58		51
Leptophlebiidae	<i>Enthraulus</i>	2.33 \pm 2.12	0.67 \pm 0.82	0.67 \pm 1.21	0.67 \pm 0.58		31
Leptopodamorphina	<i>Valleriella</i>		0.17 \pm 0.48				1
Libellulidae	<i>Plantala</i>		0.5 \pm 0.84	1.67 \pm 1.56	0.67 \pm 0.58		15
	<i>Zyxomma</i>		0.33 \pm 0.82			0.33 \pm 0.58	3
Machadorythidae	<i>Machadorythus</i>		0.33 \pm 0.82	0.17 \pm 0.48			3
Naucoridae	<i>Laccocoris</i>			0.17 \pm 0.48			1
Neritidae	<i>Neritina</i>				0.67 \pm 1.15		2
Notonectidae	<i>Anisops</i>			0.33 \pm 0.82			2
	<i>Nychia</i>			0.17 \pm 0.48			1
Perlidae	<i>Neoperla</i>	1 \pm 1.12	6.67 \pm 6.22				49
Polycentropodidae	<i>Polycentropodidae</i>	0.11 \pm 0.33					1
Polymitarcyidae	<i>Polymitarcyidae</i>				0.33 \pm 0.58		1
Potamonautidae	<i>Potamonautes</i>	5.56 \pm 3.57	2.83 \pm 3.37	0.17 \pm 0.48			68
Prosopistomatidae	<i>Africanum</i>	0.67 \pm 1.41	1.83 \pm 3.26	0.17 \pm 0.48			18
Psephenidae larva	<i>Afrobrianax</i>	0.33 \pm 0.5	0.17 \pm 0.48	0.33 \pm 0.52			6
Simuliidae	<i>Simulium</i>	0.33 \pm 0.5					3
Tabanidae	<i>Tabanus</i>	0.56 \pm 0.73	0.5 \pm 0.55				8
Thiaridae	<i>Cleopatra</i>	1.33 \pm 3.41	1.33 \pm 1.97	5.83 \pm 3.71	0.67 \pm 1.15		57
	<i>Melanoides</i>		0.17 \pm 0.48	0.67 \pm 0.82	1.67 \pm 1.53		10
Tipulidae	<i>Antocha</i>		0.5 \pm 0.55		2.33 \pm 3.21		10
	<i>Conostia</i>	1 \pm 0.87	0.5 \pm 1.22				12
Tricorythidae	<i>Tricorythidae</i>	0.11 \pm 0.33		0.17 \pm 0.48	1.67 \pm 1.53		7
Veliidae	<i>Rhagovelia</i>	2.11 \pm 2.571	1.33 \pm 1.97	0.17 \pm 0.48	1.33 \pm 2.39		32
	Total abundances	414	213	157	144	28	956
	N° of Taxa	31	33	27	26	7	54
	Shannon index (H)	2.22	3.19	1.96	2.07	1.04	
	Margalef index (d)	3.27	3.19	2.75	3.05	1.24	
	N° of samples	9	6	6	3	3	

Table 6: List of identified taxa (*av. abundance* ± *SD*) of macroinvertebrates in the five zones of Sigi river in wet period. Codes; MS- Mountain streams, UF- Upper foothill, LF- Lower foothills, REJ= Rejuvenated foothill, MR- Mature river.

Family	Genus	MS	UF	LF	REJ	MR	Total individuals
Actyidae	<i>Caridina</i>				8.5±1.31	12.4±18.47	113
Athericidae	<i>Suragina</i>	0.22±0.45	0.17±0.48				3
Baetidae	<i>Acanthiops</i>	1.89±3.14	0.33±0.82				19
	<i>Baetidae</i>	1.33±2.69	1.17±0.98	0.67±1.21	0.33±0.52		25
	<i>Glossidon</i>	0.33±0.77					3
	<i>Tanzaniela</i>		0.17±0.48				1
Belastomatidae	<i>Appasus</i>			0.33±0.52			2
Caenidae	<i>Caenis</i>		0.5±0.84	3.17±2.93	0.5±0.55		25
Chironomidae	<i>Chironominae</i>	1±1	1±1.26	0.67±0.82	4.5±5.55	0.2±0.45	47
Chlorocyphidae	<i>Platycypha</i>		0.33±0.82	0.17±0.48			3
Coenagrionidae	<i>Coenagrion</i>	0.89±2.28		3.17±4.26	0.83±1.17		32
Corduliidae	<i>Phyllomacromia</i>	0.11±0.33	0.17±0.48	0.33±0.82	0.33±0.82		6
Diceromyzidae	<i>Diceromyzon</i>	0.44±0.53		0.17±0.48	0.17±0.48		6
Dytiscidae	<i>Dytiscidae</i>	0.22±0.67		1.17±1.83	0.17±0.48		10
Ecnomidae	<i>Ecnomus</i>		0.33±0.82	0.17±0.48			3
Elmidae	<i>Elminae</i>	0.11±0.33	1.67±1.56		1.33±2.85		19
	<i>Larainae</i>	1.44±2.30	2.17±2.14	1.17±1.47	0.33±0.52		35
Ephemerythidae	<i>Ephemerythus</i>	3.33±2.40	1.33±1.75	0.67±1.33		0.2±0.45	43
Gerridae	<i>Naboandelus</i>			0.33±0.52	0.33±0.52	0.6±1.34	7
Gomphidae	<i>Ceratogomphus</i>	0.33±0.77	0.83±0.98	1±1.26	0.5±0.84		17
	<i>Ictinogomphus</i>			0.17±0.48			1
	<i>Lestinigomphus</i>			1.67±2.58	0.17±0.48	0.2±0.45	12
	<i>Neurogomphus</i>			0.17±0.48			1
Gyrinidae	<i>Orectogyrus</i>	0.89±1.55	0.17±0.48		0.17±0.48		10
Heptageniidae	<i>Afronurus</i>	4.67±5.5	1.67±2.66	6.67±7.28	2.5±2.59	0.2±0.45	108
Hirunidea	<i>Leeche</i>			0.17±0.48			1
Hydropsychidae	<i>Amphipsyche</i>	0.56±1.33			0.33±0.52		7
	<i>Cheumatopsyche</i>	4.11±5.78	2.17±3.71		0.67±1.63		54
	<i>Hydropsyche</i>	3.89±6.92	1±1.26	1.17±2.41			48
	<i>Leptonema</i>				0.5±1.22		3
Leptophlebiidae	<i>Enthraulus</i>	1.89±1.27	0.67±1.21	2±2.98	1.83±4.5		44
Libellulidae	<i>Plantala</i>		0.67±0.82	0.17±0.48			5
Lycosidae	<i>Lycosidae</i>	0.22±0.45					2
Lymnaeidae	<i>Lymnaea</i>				0.17±0.48	0.2±0.45	2
Machadorythidae	<i>Machadorythus</i>			0.5±0.84			3
Naucoridae	<i>Laccocoris</i>	0.22±0.67		0.5±0.84			5
Nepidae	<i>Ranatra</i>			0.5±0.84			3
Neritidae	<i>Neritina</i>				0.5±0.55	3.6±4.98	21
Notonectidae	<i>Notonecta</i>				0.17±0.48		1
	<i>Nychia</i>	0.22±0.67					2
Palaemonidae	<i>Macrobrachium</i>				0.17±0.48		1
Perlidae	<i>Neoperla</i>	1.22±1.72	5±5.51	0.17±0.48			42
Physidae	<i>Physa</i>	0.11±0.33	2.67±3.33	0.17±0.48	0.17±0.48		19
Polymitarcyidae	<i>Polymitarcyidae</i>				0.17±0.48		1
Potamonautidae	<i>Potamonautes</i>	6.11±4.26	4.5±5.32	1±2		1.6±2.6	96
Prosopistomatidae	<i>Africanum</i>	1.22±1.72	1±2				17
Psephenidae larva	<i>Afrobrianax</i>	0.44±1.14	0.33±0.52				6
Simuliidae	<i>Simulium</i>	0.89±1.54			0.33±0.52		10
Tabanidae	<i>Tabanus</i>	2±2.65	1.67±2.34	0.5±1.22	0.33±0.82		33
Thiaridae	<i>Cleopatra</i>	1.33±2.18	4.5±6.83	3.67±1.86	2.5±2.6		76
	<i>Melanoides</i>	0.11±0.33	2.83±3.13	1±1.95	6.5±7.45	17.8±16.34	152
Tipulidae	<i>Antocha</i>		0.67±1.33				4
	<i>Conosia</i>	0.11±0.33	0.5±0.84		0.17±0.48		5
Tricorythidae	<i>Tricorythidae</i>		0.17±0.48	0.17±0.48	0.33±0.52		4
Veliidae	<i>Rhagovelia</i>	2.11±1.45	0.83±2.41	2.5±3.17	3±3.69		57
	<i>Veliidae</i>	0.22±0.67	0.33±0.82		0.17±0.48		5
	Total abundances	398	249	216	232	185	1280
	N° of Taxa	34	32	33	33	10	56
	Shannon index (H)	2.23	2.26	2.14	1.82	0.18	
	Margalef index (d)	3.25	2.80	3.20	2.74	0.98	
	N° of samples	9	6	6	6	5	

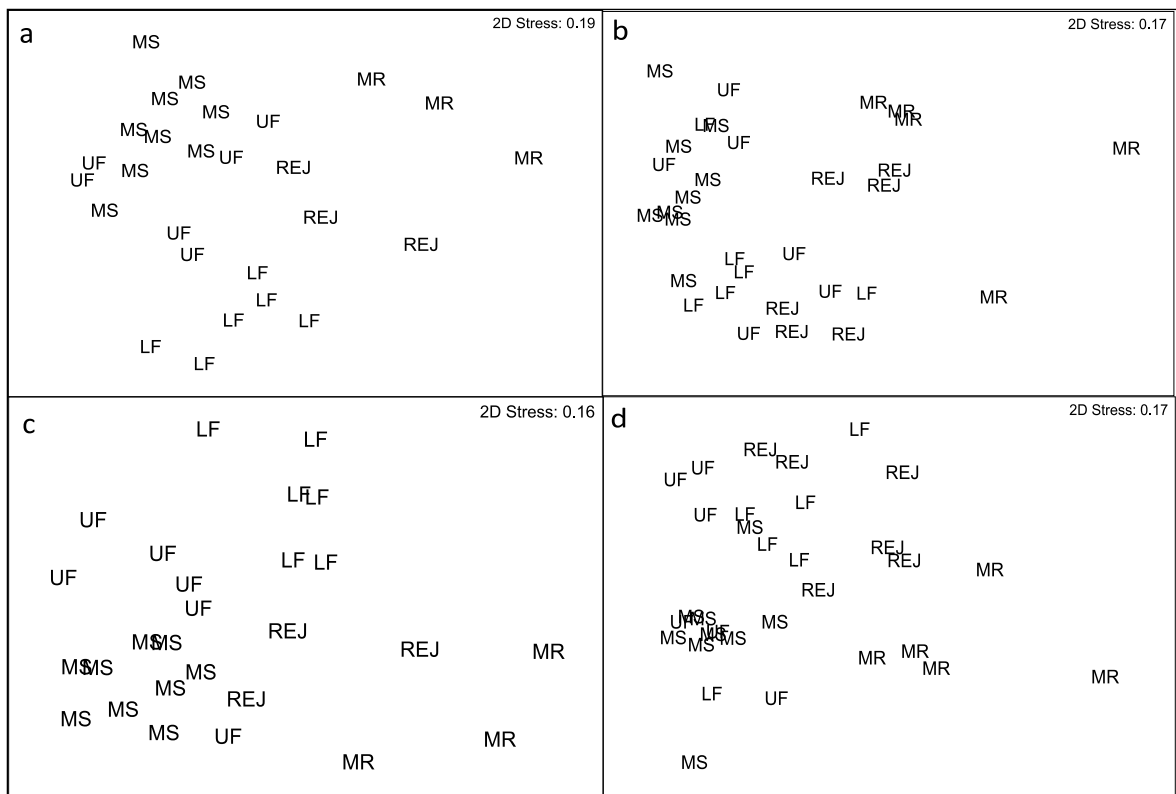


Figure 6: MDS ordination showing the spatial distribution of macroinvertebrate assemblages along Sigi River in dry and wet periods. a & b- MDS generated from untransformed data for dry and wet periods respectively, c & d- MDS from Presence/absence transformation for the dry and wet periods respectively. Codes; MS =Mountains streams, UF = Upper foothills, LF = Lower foothills, REJ = Rejuvenated foothills, MR =Mature river.

Table 7: Analysis of Similarity (ANOSIM) among river zones and between the sampling period (dry and wet periods). Significant, as determined by pair-wise test, are indicated with *= $p < 0.05$, NS =Not significant; MS = Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature lower river.

River zones	Dry period				Wet period			
	Untransformed		Presence/ Absence		Untransformed		Presence/ Absence	
	Global R	p	Global R	p	Global R	p	Global R	p
MS, MR	0.985	*	0.996	*	0.952	*	0.928	*
MS, REJ	0.78	*	0.782	*	0.682	*	0.649	*
MS, LF	0.962	*	0.968	*	0.326	*	0.382	*
MS, UF	0.34	*	0.493	*	0.257	*	0.345	*
MR, REJ	0.852	NS	0.593	NS	0.263	NS	0.436	*
MR, LF	0.975	*	0.991	*	0.884	*	0.884	*
MR, UF	0.79	*	0.907	*	0.787	*	0.904	*
REJ, LF	0.963	*	0.809	*	0.094	*	0.016	NS
REJ, UF	0.698	*	0.438	*	0.292	*	0.404	*
LF, UF	0.759	*	0.794	*	0.261	NS	0.251	NS

Table 8: Average contribution of each taxa to the dissimilarities among the river zones for dry and wet periods as determined in SIMPER analysis.

Dry period				Wet period			
Untransformed		Presence / absence		Untransformed		Presence / absence	
Species	Av. (%)	Species	Av. (%)	Species	Av. (%)	Species	Av. (%)
<i>Amphipsyche</i>	9.138	<i>Ceratogomphus</i>	3.788	<i>Melanoides</i>	11.804	<i>Cleopatra</i>	3.887
<i>Elminae</i>	6.308	<i>Cleopatra</i>	3.604	<i>Caridina</i>	9.697	<i>Potamonautes</i>	3.706
<i>Chironominae</i>	5.786	<i>Cheumatopsyche</i>	3.603	<i>Afronurus</i>	6.883	<i>Enthraulus</i>	3.625
<i>Cleopatra</i>	5.666	<i>Elminae</i>	3.465	<i>Potamonautes</i>	6.298	<i>Caridina</i>	3.59
<i>Potamonautes</i>	5.158	<i>Plantala</i>	3.463	<i>Cleopatra</i>	6.167	<i>Rhagovelia</i>	3.574
<i>Neoperla</i>	5.15	<i>Enthraulus</i>	3.408	<i>Chironominae</i>	4.567	<i>Afronurus</i>	3.559
<i>Cheumatopsyche</i>	4.776	<i>Chironominae</i>	3.359	<i>Rhagovelia</i>	3.837	<i>Ephemerythus</i>	3.546
<i>Ceratogomphus</i>	4.658	<i>Afronurus</i>	3.256	<i>Cheumatopsyche</i>	3.679	<i>Chironominae</i>	3.498
<i>Caenis</i>	4.073	<i>Neoperla</i>	3.211	<i>Neoperla</i>	3.649	<i>Melanoides</i>	3.363
<i>Ephemerythus</i>	4.067	<i>Caenis</i>	3.163	<i>Hydropsyche</i>	3.421	<i>Larainae</i>	3.271
<i>Leptonema</i>	3.807	<i>Potamonautes</i>	3.149	<i>Ephemerythus</i>	3.064	<i>Baetidae</i>	3.239
<i>Pseudopannota</i>	3.207	<i>Leptonema</i>	3.073	<i>Enthraulus</i>	2.844	<i>Caenis</i>	3.229
<i>Rhagovelia</i>	2.8	<i>Amphipsyche</i>	2.881	<i>Larainae</i>	2.553	<i>Neoperla</i>	2.999
<i>Afronurus</i>	2.595	<i>Ephemerythus</i>	2.8	<i>Ceriatrion</i>	2.49	<i>Ceratogomphus</i>	2.876
<i>Enthraulus</i>	2.126	<i>Rhagovelia</i>	2.741	<i>Tabanus</i>	2.404	<i>Hydropsyche</i>	2.87
<i>Caridina</i>	2.068	<i>Caridina</i>	2.626	<i>Caenis</i>	2.344	<i>Ceriatrion</i>	2.777
<i>Plantala</i>	1.836	<i>Melanoides</i>	2.506	<i>Neritina</i>	2.02	<i>Tabanus</i>	2.767
<i>Hydropsyche</i>	1.677	<i>Xyrodromeus</i>	2.466	<i>Physa</i>	1.977	<i>Neritina</i>	2.486
<i>Africanum</i>	1.668	<i>Antocha</i>	2.393	<i>Baetidae</i>	1.823	<i>Elminae</i>	2.399
<i>Acanthiops</i>	1.519	<i>Larainae</i>	2.29	<i>Elminae</i>	1.66	<i>Cheumatopsyche</i>	2.195
<i>Antocha</i>	1.475	<i>Tricorythidae</i>	2.267	<i>Ceratogomphus</i>	1.578	<i>Physa</i>	1.979
<i>Ceriatrion</i>	1.444	<i>Bugilliesia</i>	2.085	<i>Africanum</i>	1.342	<i>Naboandelus</i>	1.968
<i>Melanoides</i>	1.411	<i>Ceriatrion</i>	2.065	<i>Acanthiops</i>	1.25	<i>Orectogyrus</i>	1.83
<i>Bugilliesia</i>	1.36	<i>Tabanus</i>	1.947	<i>Lestinogomphus</i>	1.195	<i>Tricorythidae</i>	1.768
<i>Larainae</i>	1.345	<i>Acanthiops</i>	1.934	<i>Naboandelus</i>	1.004	<i>Lestinogomphus</i>	1.721
<i>Dicercomyzon</i>	1.332	<i>Conosia</i>	1.893	<i>Dytiscidae</i>	0.807	<i>Africanum</i>	1.704
<i>Baetidae</i>	1.197	<i>Hydropsyche</i>	1.816	<i>Orectogyrus</i>	0.715	<i>Dicercomyzon</i>	1.637
<i>Tricorythidae</i>	1.13	<i>Afrobrianax</i>	1.797	<i>Simulium</i>	0.713	<i>Amphipsyche</i>	1.507
<i>Xyrodromeus</i>	1.086	<i>Baetidae</i>	1.741	<i>Amphipsyche</i>	0.609	<i>Simulium</i>	1.468
<i>Phyllomacromia</i>	1.06	<i>Phyllomacromia</i>	1.702	<i>Plantala</i>	0.566	<i>Plantala</i>	1.463
<i>Ictinogomphus</i>	1.036	<i>Appasus</i>	1.614	<i>Afrobrianax</i>	0.533	<i>Conosia</i>	1.452
<i>Conosia</i>	0.907	<i>Africanum</i>	1.466	<i>Phyllomacromia</i>	0.528	<i>Acanthiops</i>	1.377
<i>Cloeodes</i>	0.906	<i>Ceratopogoninae</i>	1.35	<i>Conosia</i>	0.477	<i>Afrobrianax</i>	1.335
<i>Tabanus</i>	0.614	<i>Zyomma</i>	1.341	<i>Dicercomyzon</i>	0.465	<i>Dytiscidae</i>	1.327
<i>Afrobrianax</i>	0.596	<i>Platycypha</i>	1.271	<i>Tricorythidae</i>	0.459	<i>Phyllomacromia</i>	1.317
<i>Appasus</i>	0.558	<i>Dicercomyzon</i>	1.256	<i>Antocha</i>	0.444	<i>Machadorythus</i>	0.974
<i>Zyomma</i>	0.543	<i>Ictinogomphus</i>	1.19	<i>Laccocoris</i>	0.429	<i>Laccocoris</i>	0.92
<i>Machadorythus</i>	0.503	<i>Pseudopannota</i>	1.187	<i>Platycypha</i>	0.404	<i>Veliidae</i>	0.917
<i>Platycypha</i>	0.459	<i>Cloeodes</i>	0.986	<i>Veliidae</i>	0.388	<i>Suragina</i>	0.912
<i>Ceratopogoninae</i>	0.326	<i>Machadorythus</i>	0.906	<i>Ecnomus</i>	0.38	<i>Platycypha</i>	0.876
<i>Neritina</i>	0.315	<i>Orectogyrus</i>	0.812	<i>Machadorythus</i>	0.371	<i>Lymnaea</i>	0.855
<i>Lestinogomphus</i>	0.315	<i>Neritina</i>	0.738	<i>Ranatra</i>	0.243	<i>Antocha</i>	0.771
<i>Orectogyrus</i>	0.274	<i>Polymitarcyidae</i>	0.738	<i>Leptonema</i>	0.209	<i>Ecnomus</i>	0.757
<i>Anisops</i>	0.218	<i>Simulium</i>	0.726	<i>Suragina</i>	0.201	<i>Lycosidae</i>	0.678
<i>Naboandelus</i>	0.218	<i>Aquarius</i>	0.687	<i>Glossidon</i>	0.186	<i>Appasus</i>	0.667
<i>Aquarius</i>	0.213	<i>Suragina</i>	0.676	<i>Appasus</i>	0.171	<i>Ranatra</i>	0.667
<i>Simulium</i>	0.212	<i>Lestinogomphus</i>	0.451	<i>Lymnaea</i>	0.17	<i>Glossidon</i>	0.555
<i>Suragina</i>	0.187	<i>Valleriola</i>	0.401	<i>Lycosidae</i>	0.169	<i>Tanzaniela</i>	0.402
<i>Polymitarcyidae</i>	0.157	<i>Anisops</i>	0.31	<i>Tanzaniela</i>	0.134	<i>Notonecta</i>	0.39
<i>Valleriola</i>	0.113	<i>Laccocoris</i>	0.31	<i>Nychia</i>	0.131	<i>Polymitarcyidae</i>	0.39
<i>Laccocoris</i>	0.109	<i>Naboandelus</i>	0.31	<i>Notonecta</i>	0.119	<i>Neurogomphus</i>	0.351
<i>Nychia</i>	0.109	<i>Nychia</i>	0.31	<i>Polymitarcyidae</i>	0.119	<i>Leptonema</i>	0.344
<i>Umma declivium</i>	0.108	<i>Polycentropodidae</i>	0.276	<i>Neurogomphus</i>	0.1	<i>Macrobrachium</i>	0.344
<i>Polycentropodidae</i>	0.085	<i>Umma declivium</i>	0.186	<i>Ictinogomphus</i>	0.071	<i>Ictinogomphus</i>	0.316
				<i>Leeche</i>	0.071	<i>Leeche</i>	0.316
				<i>Macrobrachium</i>	0.07	<i>Nychia</i>	0.275

3.3 Single species analysis

Twelve of the most important taxa contributing for the dissimilarity among the five river zones identified during SIMPER analysis were *Amphipsyche*, *Afronurus*, *Melanoides*, *Caridina*, *Cleopatra*, *Elminae*, *Potamonautes*, *Ephemerythus*, *Neoperla*, *Caenis*, *Ceratogomphus*, and *Cheumatopsyche*.

The [Table 9](#) below summarises the results of the analyses of variance for the most important taxa among the river zones. ANOVA test showed a significant interaction between the sampling time and River zones on the abundances of *Amphipsyche* and *Melanoides* where the abundance of *Amphipsyche* and *Elminae* were both recorded to be high during dry period in the rejuvenated zone and *Melanoides* was found to be abundant in wet period at mature river zone which could be due to the addition of site at the mature river zone. *Afronurus* sp showed a significant difference in abundances between the two sampling periods where the higher abundances were recorded in the wet period, its distribution among the river zones did not vary significantly, showing to be present in river zones ([Figure 7](#)). The remaining taxa (*Cleopatra*, *Potamonautes*, *Ephemerythus*, *Neoperla*, *Caenis*, *Ceratogomphus* and *Cheumatopsyche*) showed a significantly different among the river zones ([Appendix](#)). *Potamonautes*, *Ephemerythus* and *Cheumatopsyche* were found to be abundant in the mountain streams zone, *Neoperla* dominated the upper foothill zone while *Caenis* and *Ceratogomphus* were abundant in the lower foothill zone ([Figure 8](#)).

Table 9: Results of Analysis of Variance (ANOVA test) of macroinvertebrate species contributed to the dissimilarity among the river zones. * = p <0.05.

Source of variation	df	Amphipsyche			Afronurus			Melanoides			Caridina		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Time	1	100.5	55.083	*	57.139	4.436	*	274.7	8.23	*	144.1	3.56	
River zones	4	79.373	43.505	*	24.58	1.908		89.1	2.67	*	83.12	2.06	
Timex river zones	4	76.886	42.142	*	19.831	1.54		86.01	2.58	*	49.46	1.22	
Residual	50	1.824			12.881			33.38			40.44		
Source of variation	df	Cleopatra			Elminae			Potamonautes			Ephemerythus		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Time	1	4.25	0.438		45.026	6.515	*	10.2	1.03		4.085	0.29	
River zones	4	34.864	3.593	*	48.77	7.057	*	83.18	8.43	*	71.51	5.14	*
Timex river zones	4	11.956	1.232		33.602	4.862	*	1.074	0.11		14.94	1.07	
Residual	50	9.703			6.911			9.872			13.9		
Source of variation	df	Neoperla			Caenis			Ceratogomphus			Cheumatopsyche		
		MS	F	P	MS	F	P	MS	F	P	MS	F	p
Time	1	0.864	0.114		1.57	0.898		12.09	3.73		2.882	0.282	
River zones	4	71.966	9.476	*	28.843	16.5	*	14.34	4.42	*	45.92	4.489	*
Timex river zones	4	1.949	0.257		1.159	0.663		6.78	2.09		2.335	0.228	
Residual	50	7.594			1.748			3.244			10.23		

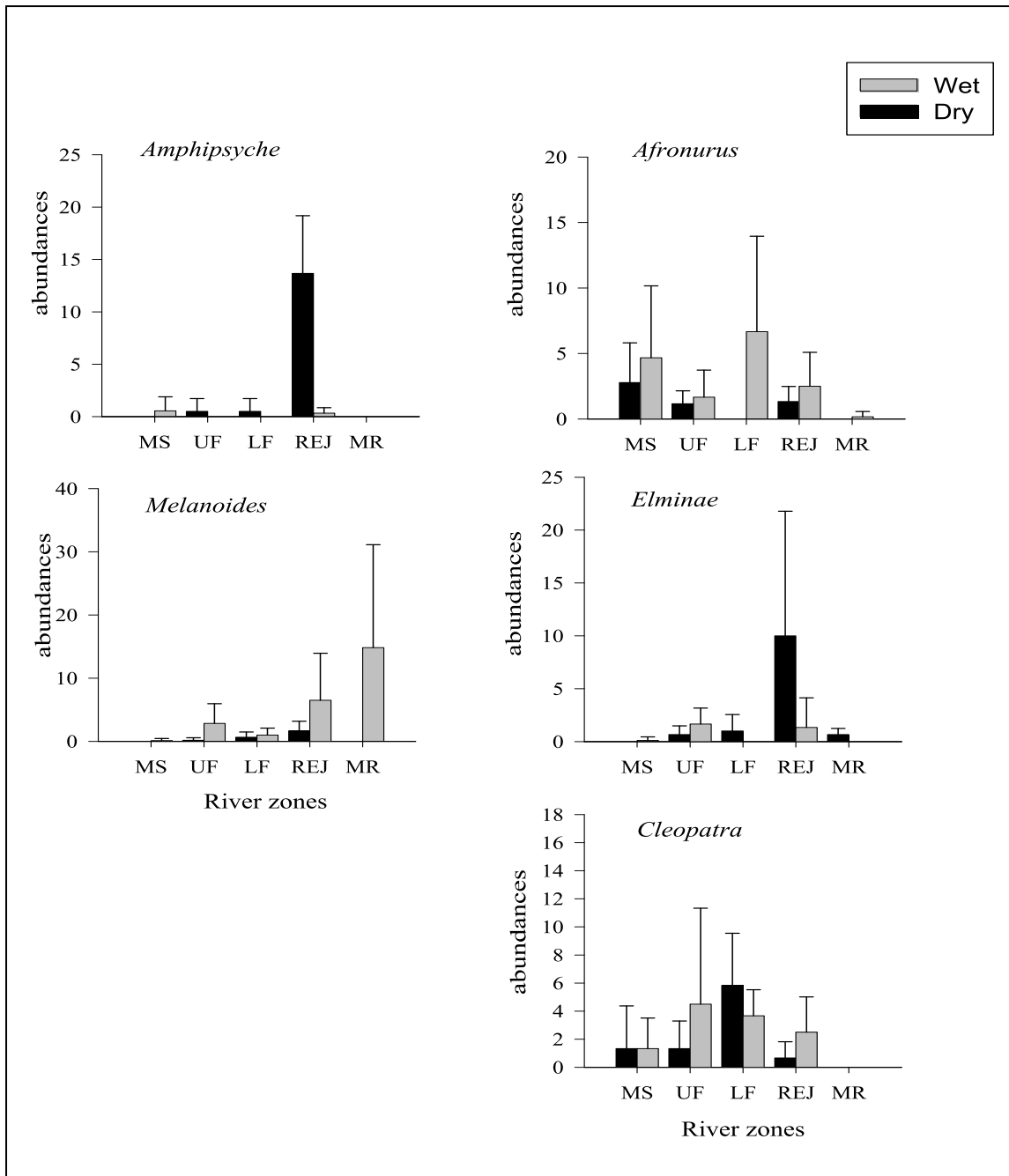


Figure 7: Abundance ($mean \pm SD$) of the major taxa contributing to the difference among the river zones and between the two sampling periods. Code; MS = Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature lower river.

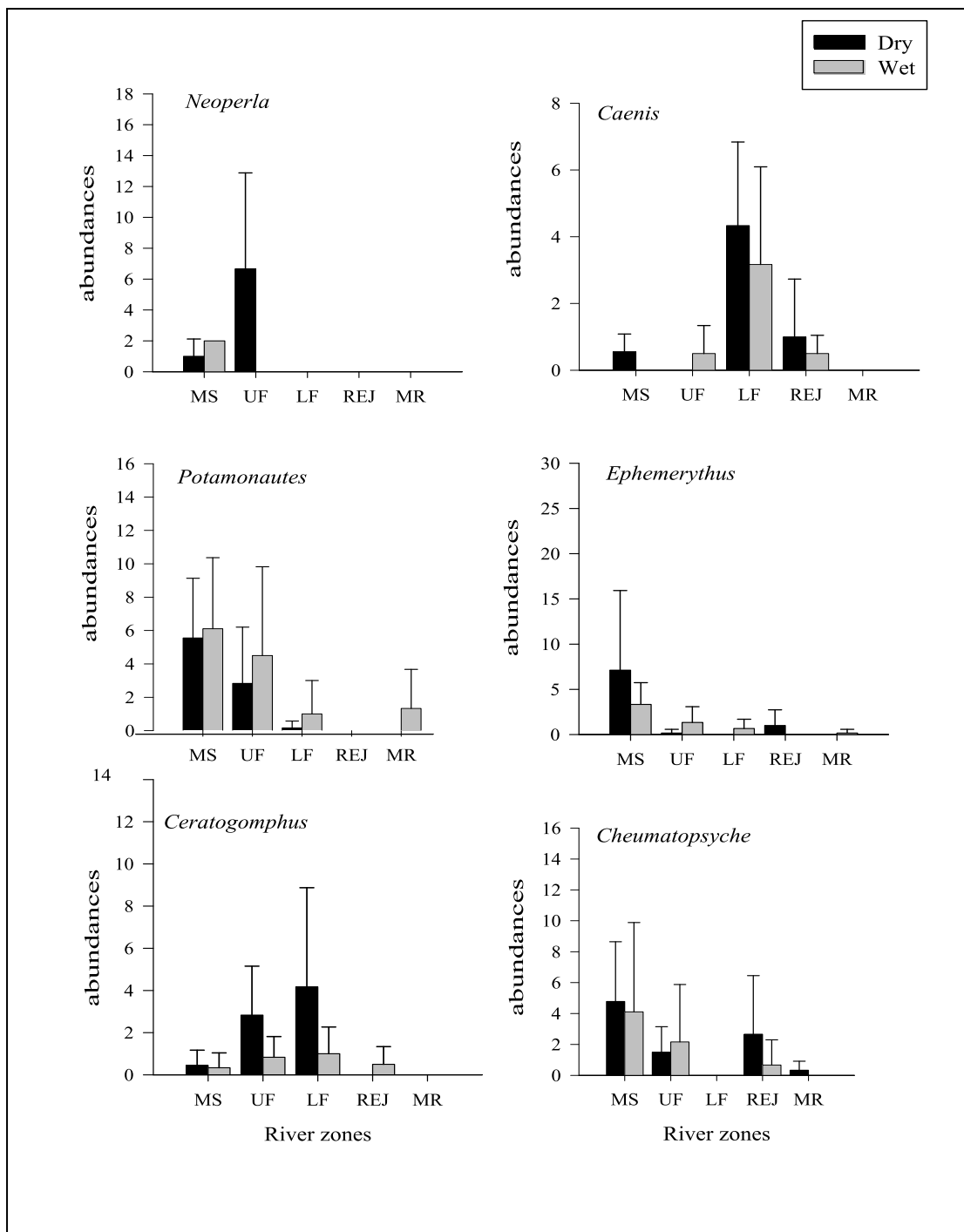


Figure 8: Abundance ($mean \pm SD$) of the major taxa contributing to the difference among the river zones and between the two sampling periods. Code; MS = Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature lower river.

3.4 Hydrological, hydraulic and environmental variables

Table 10 and Table 11 below summarises the hydrological, hydraulics and environmental variables measured in dry and wet seasons respectively. The mean conductivity showed an increasing trend from the upper reaches towards the lower reaches of the river. Upper reaches of the river (MS and UF) have lower pH, conductivity, temperature and discharge and in the lower reaches (LF, REJ & MR) showed to have the higher values of pH, conductivity, temperatures and discharge. Similar trend was observed in both sampling periods.

Table 10: Hydrology, hydraulic and Environmental variables in the five zones of Sigi River in the dry period (Mean \pm SD). MS = Mountain streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Lower mature river.

Parameters	River zones				
	MS	UF	LF	REJ	MR
pH	6.68 \pm 0.77	6.96 \pm 0.16	7.75 \pm 0.59	7.69 \pm 0.0	7.2 \pm 0
Temperature($^{\circ}$ C)	21.6 \pm 0.44	24.45 \pm 2.05	31.45 \pm 0.07	30.9 \pm 0.0	29.3 \pm 0.0
Conductivity (μ S/cm)	91.06 \pm 22.51	103.07 \pm 15.46	147.25 \pm 27.79	189.9 \pm 0.0	204.5 \pm 0.0
Depth(m)	0.66 \pm 0.71	0.19 \pm 0.04	0.28 \pm 0.0	0.3 \pm 0.0	0.75 \pm 0
Velocity (m)	0.15 \pm 0.20	0.13 \pm 0.06	0.24 \pm 0.08	0.37 \pm 0.0	0.15 \pm 0.0
Froude number	0.12 \pm 0.18	0.1 \pm 0.05	0.14 \pm 0.06	0.21 \pm 0.0	0.06 \pm 0.0
Discharge (m^3/s)	0.18 \pm 0.13	0.33 \pm 0.3	1.30 \pm 0.01	1.0 \pm 0.0	0.91 \pm 0.0

Table 11: Hydrology, hydraulic and Environmental variables in the five zones of Sigi River in the wet period (Mean \pm SD). MS = Mountain streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Lower mature river

Parameters	River zones				
	MS	UF	LF	REJ	MR
pH	6.48 \pm 0.34	6.45 \pm 0.29	6.76 \pm 0.26	7.69 \pm 0.21	6.47 \pm 0.04
Temperature($^{\circ}$ C)	20.93 \pm 0.21	23.8 \pm 0.99	26.45 \pm 0.07	24.85 \pm 0.78	28.5 \pm 0.28
Conductivity (μ S/cm)	66.10 \pm 45.37	120.35 \pm 27.65	171.20 \pm 0.85	202.1 \pm 8.63	352.75 \pm 214.18
Depth(m)	0.77 \pm 0.99	0.27 \pm 0.04	1.20 \pm 0.5	0.56 \pm 0.05	2.06 \pm 1.64
Velocity (m)	0.18 \pm 0.12	0.26 \pm 0.1	0.07 \pm 0.06	0.35 \pm 0.23	0.14 \pm 0.16
Froude number	0.12 \pm 0.11	0.16 \pm 0.05	0.02 \pm 0.02	0.15 \pm 0.11	0.05 \pm 0.05
Discharge (m^3/s)	0.48 \pm 0.48	1.47 \pm 1.60	2.14 \pm 0.36	4.43 \pm 1.35	3.22 \pm 1.96

The ANOVA test showed the significant variation in mean depth, discharge, temperature and pH among the river zone and between the two sampling periods while velocity, Froude number and conductivity showed significant variation with respect to the river zones while discharge, temperature and pH showed significant difference between the two sampling periods (Table 12). Conductivity increased lowland reaches, with MR and REJ zones registering the highest values in both sampling periods. The lowest temperatures were recorded in the upland reaches with MS and UF having the lowest.

Table 12: ANOVA test for hydrological, hydraulic and environmental variables

Source of variation	df	Average depth			Average velocity			Froude number			Discharge		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Time	1	3.76	10.57	*	0.0005	0.04		0.0086	1.26		36.353	67.69	*
River zones	4	1.8	5.053	*	0.0689	5.385	*	0.0203	2.97	*	10.78	20.07	*
Timexriver zones	4	0.78	2.203		0.0363	2.836	*	0.0132	1.94			7.355	*
Residual	50	0.36			0.0128			0.0068			0.537		

Source of variation	df	pH			Temperature			Conductivity		
		MS	F	P	MS	F	P	MS	F	P
Time	1	3.17	26.71	*	91.779	241	*	14929	3.92	
River zones	4	2.19	18.47	*	156.31	410.5	*	58711	15.4	*
Timexriver zones	4	0.43	3.655	*	18.665	49.02	*	8020.8	2.11	
Residual	50	0.12			0.381			3808.5		

3.5 Macroinvertebrate distribution in relation to hydrology, hydraulic and environmental variables.

Correlation of biota and physical variables revealed groups of variables considered to influence the macroinvertebrate assemblages among the five river zones. The results of this procedure are presented in Table 13 below, showing the importance of a single variable as well as a combination of environmental variables. Significance level used was $p = * < 0.05$.

Table 13: Results of the multivariate Spearman rank correlation of environmental data to macroinvertebrate assemblages data using BIOENV.

	Variables	R	P
Single variable	Conductivity	0.45	*
Combined variables	Temperature, Conductivity and Substrate	0.51	*
	Temperature, Conductivity, Substrate and discharge	0.485	*
	Temperature, conductivity, velocity, substrate and discharge	0.451	*
	pH, Temperature, conductivity, velocity, substrate and discharge.	0.44	*

Variable that showed up as best combination in explaining the macroinvertebrate assemblages in BIOENV analysis (Table 13) were subjected to Distance Linear Models (DistLM). The results of the distance based redundancy analysis (db-RDA) showed velocity was not significantly important in influencing the distribution of macroinvertebrate assemblages (Table 14).

Table 14: db-RDA test of hydrological and environmental variables

Variable	SS	F	P
pH	13048	3.8382	0.001
Temperature	22647	7.0089	0.001
Conductivity	20446	6.2531	0.001
Velocity	5629.2	1.5948	0.079
Substrate	10985	3.1974	0.002
Discharge	19349	5.883	0.001

It is seen from the [Figure 9](#) that the mountain stream (MS) and upper foothill (UF) sites were almost all clustered in a position featured by low conductivity. The lower foothill (LF) and rejuvenated foothill (REJ) sites clustered in a position indicating high pH, discharge and temperature while few sites in the mature river zone (MR) featured the position high conductivity.

The results of DistLM showed a relationship between macroinvertebrates distribution and hydrology and environmental variables. Conductivity tends to have a positive effect on the abundances of *Caridina* and *Melanoides*, substrate type showed to influence *Potamonautes*, *Ephemerythus* and *Cheumatopsyche* while temperature and discharge showed to have the same influence towards the macroinvertebrate community and pH showed to positively influence the distribution of *Cleopatra* ([Figure 9](#)).

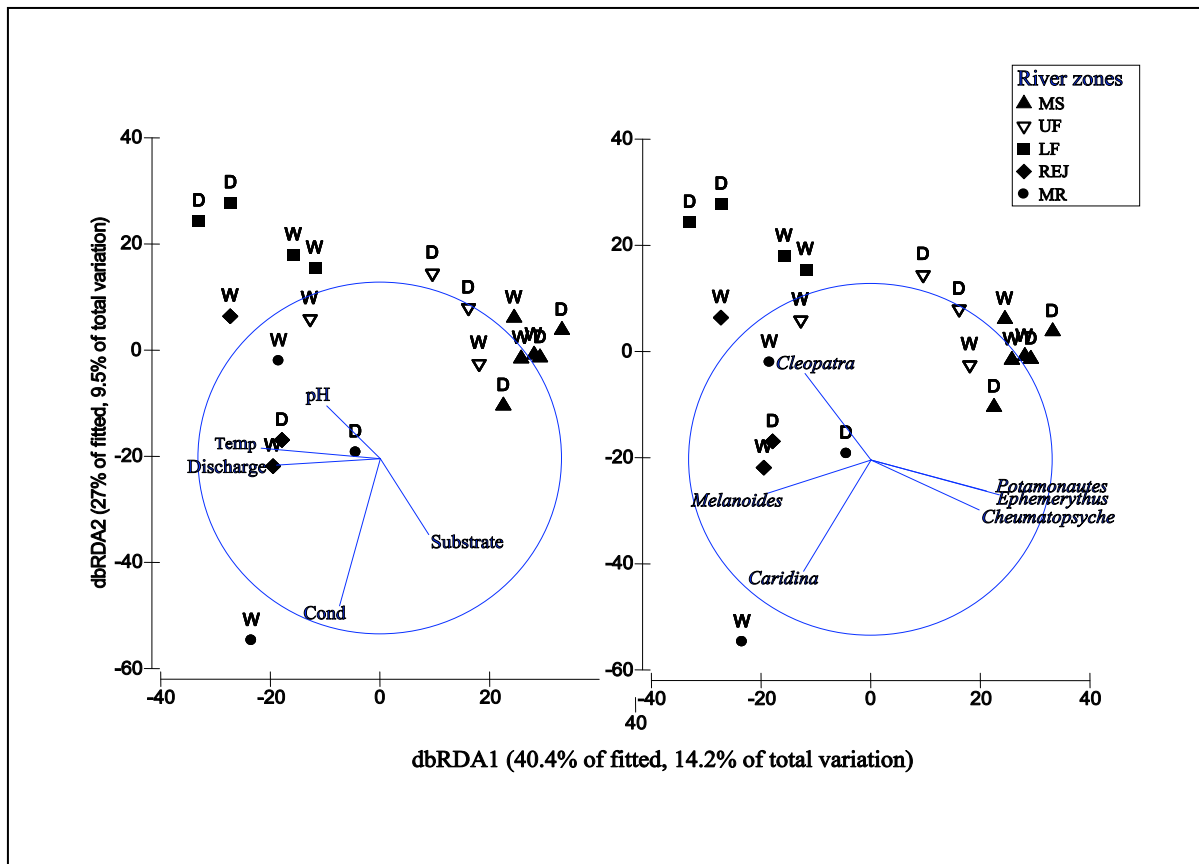


Figure 9: RDA plot on species abundances and hydrology and environmental variable in the studied area. MS = Mountain streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill, MR = Lower mature river, D = Dry period and W = Wet period

4.0 DISCUSSION

The macroinvertebrate assemblages varied significantly along the Sigi river, the five river zones existing showed to be significantly different from each other in terms of number of taxa, total abundances, species richness and species diversity indices. In the other side physical factors *i.e.* hydrological, hydraulics and environmental factors also were observed to vary along the river. However the sampling period (temporal variation) was unimportant factor influencing the distribution of macroinvertebrate assemblages along river, this could be due to lack or less variation in hydrological, hydraulic and environmental variables measured. In relation to macroinvertebrate assemblages conductivity, substrate type, discharge, temperature and pH were found to be important factors influencing their distribution.

Depth, velocity and Froude number have been mentioned in several studies (*e.g.* Kemp et al. 2000, Brooks et al. 2005, Allan & Castillo 2007) being strong hydraulic variables influencing aquatic macroinvertebrate distribution however in our study they appeared to be not significant. The scale of research is very important for the case of the influence of hydraulic variables. Velocity, depth and Froude number have been showed to be important in microhabitat (Brooks et al. 2005), the study was conducted in riffles with an area of 0.07 m². Other studies have observed and suggested the good and strong support of these variables to macroinvertebrate assemblages at the scale of 0.1m² or less (Merigoux and Doledec 2004). In our study we worked at site and catchment scale where the sampling and other measurement were done in a scale of 50m and across the river. Thus in large scale *e.g.* site and catchment the influence of hydraulic variables become of less important compared to the habitat level.

Mature river zone showed to have the lowest values in terms of diversity indices ([Figure 5](#)). This could be due to the harsh environment existing within this zone, the sites representing this zone are with 10km from the Indian ocean and the presence of dam upstream further prohibit the normal flow of river water. According to (B Benno, Pers. Comm.) during the spring tide salt water from the ocean goes about 10 km upstream and result to a completely change of the water constituents by becoming rich in chloride. This has lead to the exclusion of many taxa which are sensitive to the change. Therefore the zone become colonised by few taxa, for example Thiaridae (*Melanoides tuberculatus*) was the most abundant taxa in this zone. The lower mature zone (MR) can be compared to intertidal and estuarine areas which

are subjected to strong variations in physical and biological condition related to tidal cycles and as the results only few species are able to survive in such conditions (Salgado et al. 2007, Arimoro et al. 2011) and taxa of invertebrates able to survive and more tolerant were Gastropoda (*Melanoides tuberculatus*, *Cleopatra*) and Crustaceans (*Caridina*), which also observed in our study. For example *Melanoides tuberculatus* have been reported in the study of Giovanelli et al. (2005) being a good invader due to its ability to adapt a wide range of environmental conditions and high reproductive rate. The decreasing of the diversity indices downstream could be also due to an increase in human population and pressure such as sand mining, bathing, washing clothes. Sand mining is a more destructive activity as it tends to ruin the habitat and change of flow regime by the creation of pools. Also increase the residence time of water in these areas with pools will result to longer time expose of water to solar radiation and thus allow for more warming (McRae & Edwards 1994, Hawkins et al. 1997) which in turn negatively affect the metabolic and life cycle of many species of macroinvertebrate. Apart from sand mining bathing and washing clothes alter the water quality due to addition of nutrients (phosphates and nitrogen) from detergents and as the results the most sensitive taxa like Plecoptera (*Neoperla sp.*) and Ephemeroptera (Baetidae) disappear. This was also observed in the study of Arimoro et al. (2011) in Niger delta where the macroinvertebrate species diversity was decreasing due to human pressures. In sigi river the upper reaches of the river, MS and UF zones where dominated by taxa associated with pristine waters characterised by less anthropogenic activities, more sensitive groups of macroinvertebrates such as *Baetidae*, *Neoperla* which their abundances showed a decline downstream. In middle section areas represented by LF *Caenis* dominated and in the rejuvenated area *Amphipsyche* (Hydropsychidae) while in the more downstream end (MR) the single species abundance observed in which *Cardina* and *Melonoides* accounted for more than 50% of the total population.

MS and UF were observed to have higher diversity, richness, abundances and number of taxa compared to lowland zones (LF, REJ, MR). The higher diversity indices in MS and UF zones were expected because of the difference in habitat. Stones habitat which was the dominant habitat observed in upland zones have contributed to the higher diversity indices in these zones. Stones habitat has been used as a general term representing bedrock, boulders, cobbles and gravels substratum. The studies of Pridmore & Roper (1985), Collier (1995), Dallas (2007) have reported in general stones biotopes support a diverse array of macroinvertebrate assemblages while the sand substrate being poor and support fewer macroinvertebrate due to its instability and because tight packing sand grains reduces the

trapping of detritus and further can limit the availability of oxygen which is crucial to organisms as the results for the lower land areas (LF and MR) of Sigi river having few species of macroinvertebrate. REJ zones are bedrock habitat, which is part of stones habitat however it has been described that the abundance and taxa richness typically increased with substrate size at least up to gravels and cobbles which found to hold maximum abundance and taxa richness (Minshall 1984, Mackay 1992). Beyond that (bedrock, boulders) the richness and diversity of macroinvertebrate decreases due to increase of turbulence which sometimes can create falls (Minshall 1984, Mackay 1992, Bonado et al. 2006) especially during high flow and creates pools during low flow periods (dry periods).

Macroinvertebrate community in the mountain stream zone (MS) were found to be different from the other zones (UF, LF, REJ and MR) in terms of composition and species abundances. Mountain streams have different characteristics in comparison to other zones, Mountain streams sites are chaotic and complexly structured (Hawkins 1997), differences in temperatures, availability of habitat/biotope, flow velocity, water chemistry may contribute to the observed differences in macroinvertebrate assemblages. Similarly the study of Tate and Heiny (1995) in Platte River Basin U.S.A reported a clear difference of macroinvertebrate assemblages between the mountain stream and other zones of the river in both seasons of summer and winter. The MS zone in Sigi River is located in the Eastern Arc Forests which is the montane forests (Tanzania report on biodiversity 2009), in Whittier et al. (1988) research concluded the existing of a clear difference of aquatic macroinvertebrate assemblages between montane and non-montane regions which noted to be caused by temperature difference as streams in forested areas have small daily temperature changes as the results these stream exhibit more stable environment.

Geological differences between the upper and lower catchment of the Sigi River also contribute to the distinct difference in macroinvertebrates among zones. The mountainous areas of the catchment is made up of hard rock *i.e.* metamorphic rocks while the lower catchment which includes LF, REJ and MR is made up of soft rocks *i.e.* sedimentary rock and lime stone (Hamilton & Bensted-Smith 1989). The geology of the catchment affects the river's water chemistry particularly Total dissolved solids, pH, ions and cations (Dallas 2004a). Metamorphic rocks are resistance to weathering and erosion thus water flowing in these areas contains fewer ions while for the case of sedimentary and lime stone rocks, they are easily to be weathered and soluble thus produces drainage water high in dissolved materials, therefore waters in these areas are hard being rich in calcium and magnesium salts.

4.1 Macroinvertebrate comparison among the river zones

The population of *Melanoides* were found to increase downstream and the higher abundances were in the mature river zone and rejuvenated foothill which might be due to tidal influence and increase in conductivity since this zone is close to the ocean. The mature river zone is within 10 km from the ocean and due to the dam upstream the zone river flow is regulated and as the result the ocean water has a huge influence to high observed high conductivity in this zone. Similarly the studies of Giovanelli et al. (2005), Ferraira et al. (2010) have reported chloride being the most important criteria explaining the abundance of *Melanoides tuberculatus* in the lotic environment and the study of Barroso & Matthews-Cascon (2009) observed the occurrence of *Melanoides tuberculatus* in mangroves in the estuary (Brazil) where salinity can rise up to 30. The rejuvenated zone of Sigi river is dominated by the bedrock substratum and highly covered by algae which have also been pointed as the preference source of food for *Melanoides* (Giovanelli et al. 2005). Its high abundance in the wet season might be due to additional sampling in the mature river zone, as explained in the methodology section.

Potamonautes, *Ephemerythus*, *Neoperla* and *Cheumatopsyche* were observed to be dominant in the upper area of the river MS and UF zones. *Ephemerythus* and *Neoperla* are good indicators of the water quality (have highest score) thus they prefer the pristine conditions, running waters with high aeration especially in riffles. Sites in MS zones were located in the forest (Reserve area) thus pristine conditions are there due to less human activities and good water quality is reached. *Potamonautes* are predominantly shredders feeding on detritus inputs from the surrounding terrestrial vegetation (Pelmera et al. 1993, Dobson et al. 2007) thus observed to be abundant in forested areas similarly to the finding in our study. MS zone is located in the Eastern Arc Mountain (Usambara forest) and UF zones is out of the forest reserve but still there is pristine environment with natural forests therefore terrestrial vegetation and detritus materials are plenty providing a food for *Potamonautes*. Although *Potamonautes* are very tolerant and have lower score for water quality (Drickens & Graham 2002), but the habitat preference could be another reason for their abundant in the MS and UF zones.

Cheumatopsyche found to be distributed from the fast flowing upper foothill stream to the lower foothills. The genus contains species of different character. In Sigi River *Cheumatopsyche* were found to be highly abundant in the mountains streams (MS), however

were also found to be present in the upper foothill and Rejuvenated foothill. Similarly to the study on the higher altitude of Hogsbacks Mountains *Cheumatopsyche* were observed abundantly. Rejuvenated foothills are dominated with bedrock with large riffle (cascade) comparably the study of Heino et al. (2005) *Cheumatopsyche* were highly abundant in large river riffles.

Caenis and *Ceratogomphus* were abundant in the Lower foothill zone located in the middle reaches of the river where the substratum is dominated by sand and few gravel and pebbles. These areas lack coarse plant particulate compared to the mountain streams and upper foothills zones, thus organic matters such as periphyton and other fine plant particulate are present (Van note et al. 1980). *Caenis* has been mentioned by Edmunds & Waltz (1996) to feed on vegetated fine sediments, with the feeding habits as scraper of algae and fine organic matter collector (Palmer et al. 1993) as the results they prefer middle reaches of the river. Furthermore *Caenis* and *Ceratogomphus* have the burrowing habits and have elongated respiratory siphons that reach above the sand surface (Hora 1928) as the result the sand substratum is their habitat preference since it's easy to burrow compared to the stones or bedrock substratum.

4.2 Macroinvertebrate distribution in dry and wet periods.

In general temporal variation of macroinvertebrate assemblages was found to be small, which could also be linked to the variation in environmental and hydrological factors between the two samplings which showed a small range of change. However the two samplings were very different based on taxa composition and individual abundances of macroinvertebrates, the change of pattern can reflect habitat preference, life history characteristics and changes of abiotic factors example temperature, discharge, conductivity flow velocity. Mean abundance *Afronurus* showed a significant difference in abundance between the dry and wet seasons (Table 9) and not significantly among the river zone. Yanoviak & McCafferty (1996) reported that the variation in the taxonomic make up of macroinvertebrate assemblages may be due to the differences among insect life cycle while the seasonal variation in abundances and distribution often reflect the life history. The life history means at any given time a single species may be represented by eggs, larvae, pupae, nymph and/or adult. In this study higher abundances of *Afronurus* were recorded during the wet period. It is possible that by the time that the dry sampling was conducted, the emergence

had just taken place and individuals of the next generation were too small to be caught in the 1mm. Similarly the studies of King (1981), Dallas (2004b) have described the seasonal variation *Afromurus* to be related to their small sizes thus not caught during their emergence.

4.3 The influence of Hydrology and Environmental variables

Discharge was found to vary among the river zones and between times. The variation of discharge can lead to differences in wetted perimeter, hydraulic conditions and biotope availability (Chessman et al. 1997). Discharge has been reported to affect macroinvertebrate community by lowering their abundances (Masese et al. 2010). Also discharge can have a cascade impact by affecting water temperature (Dallas 2004b) and thus solubility of oxygen. Periods of low discharges are usually associated with higher temperatures and vice versa. Higher temperatures reduce the solubility of dissolved oxygen in water, decreasing its concentration and thus its availability to aquatic organisms. This scenario is important in explaining the spatial and temporal variation of macroinvertebrate assemblages. In our study discharge and temperature showed to have the same influence towards macroinvertebrate community (Figure 9). The variation in temperature occurs longitudinally down a river system with headwaters typically cooler than lowland areas (Vannote et al. 1980). In Sigi River the similar gradient was observed and also canopy cover which affects water temperature (Graynorth 1979) was an important factor to the variations of temperatures along the Sigi River. REJ zones located in lowland reaches were less exposed to direct heating from the sun as the results less temperatures were recorded. Macroinvertebrates as any living organism have a range of temperature at which optimal growth, reproduction and general fit occur. Ephemeropterans (Baetidae) are among the group of macroinvertebrates sensitive to temperature changes, and they tend to prefer low temperature waters which are associated with high levels of dissolved oxygen.

Conductivity was found to be an important variable determining the distribution of macroinvertebrates in the Sigi River. MS and UF zones featured with water of low conductivity as the result showed to contain different invertebrate communities compared to the zones in the lower reaches where conductivity showed to increase. The distribution of Thiaridae (*Melanoides*) and Atyidae (*Caridina*) were positively correlated to conductivity. The study of Giovanelli et al. 2005 reported the same findings for *Melanoides*. Also the study

of Chaves et al. (2005) in the Mondego River basin found the conductivity to be an important environmental factor in structuring the macroinvertebrate.

Mountains streams zone were dominated by boulders and few bedrock, upper foothill composed of cobbles and gravels, lower foothill and mature river zones were sand substrate and the rejuvenated foothill composed of bedrock with cascade. These different types of substrates where the results of different gradients exists which in turn determine the habitat quality and kind of species favourable. Most aquatic macroinvertebrate have specific substrate requirements and therefore influenced by the nature and quality of the habitat available at a site. For example presence of mud or silt in stones biotope may reduces the quality of the habitat for stones-dwelling organism (Dallas 2004a & 2007).

The characteristic of substratum *i.e.* boulders, cobbles, gravels, sand, bedrock were identified as important predictor towards the observed macroinvertebrate assemblages distribution. The river substrate changes from upland leaches to lowland reaches. In steep slope bedrock outcrops and course riverbed material dominates while low grain size riverbed material is connected with flat catchments with pool percentage and the presence of macrophytic vegetation and organic debris. These characteristics change along the river and therefore important in explaining the spatial macroinvertebrates assemblages.

Understanding the role of the distinct environmental variables to the distribution of macroinvertebrates along the River Sigi, is an important contribution to the knowledge of biodiversity in the area, established a baseline knowledge for future assessments of the consequences on changes in water quality and quantity to the macroinvertebrate assemblages.

5.0 ECOHYDROLOGY APPROACH IN SIGI RIVER.

The Ecohydrology concept (Zalewski 2000) aims to integrate the biota compartment with hydrological characteristics of the aquatic ecosystems based on finding and quantifying the relations between variables that can be used for tuning ecosystem functioning as a basis for enhancing the resilience of ecosystems to anthropogenic impacts. The concept utilizes the ***dual regulation*** between biological and hydrological processes in individual ecosystems that aiming in enhancement of a catchment resilience, leading to improvements in water resources (quality and quantity) and ecosystem status (biodiversity and environmental health) while meeting the needs of water users, is a fundamental goal of ecohydrological management.

The study in Sigi River was aiming in finding and quantifying hydrological, hydraulics and environmental variables that best regulate and distribute macroinvertebrate assemblages (biota) which is part of ecohydrology study. Among the hydrological and hydraulic variables measured, discharge was the one that better explained the variation in macroinvertebrate assemblages, other variables that arguably associated with discharge such as temperature and conductivity also added to the predictive power in explaining the distribution of macroinvertebrates assemblages which was discussed in detail.

The use of riparian forest to moderate water temperature along the Sigi river can be crucial. Along the river in particular lower reaches (LF and MR) it was clearly observed different human activities near and inside the river channel. Loss of riparian forest is among the major impact observed, according to Moore et al. 2005 the substantial loss of riparian forest can result increase of water temperature in a river channel as much as 7-8⁰C. Thus by encouraging this ecohydrology approach (the use of biota to regulate hydrology) and creating riparian buffer can substantially regulate the water temperature and ameliorate the effects which arise due to high temperature example decrease of oxygen solubility.

Several studies have explored the information on the influence of hydrology on macroinvertebrates but little is known in the ability of macroinvertebrates to fix or regulate hydrological processes for example improving the water quality. Based on the finding of our study several group of macroinvertebrates obtained can be used or tested their ability in regulating the water quality. For example *Melanoides tuberculatus* was very abundant in the lower zones (Sigi estuary), they have been highly studied and listed as good invaders due to their adaptability to a wide range of environmental condition and have high reproductive rate.

Barroso & Matthews-Cascon (2009) reported their abundant in mangroves area in an estuary north-eastern Brazil. Furthermore they are primarily grazers feeding on algae (Giovanelli et al. 2005) thus in future studies *Melanoides tuberculatus* is among the good species of macroinvertebrate which can be used in regulating the water quality by feeding on suspended materials and algae.

6.0 CONCLUSION

Macroinvertebrate assemblages varied along the Sigi River. The difference in slope existing among the zones showed to strongly influence their variations strongly in both sampling periods.

The Mature river zone showed the least number of taxa, species richness and diversity indices due to the harsh and extremely highly varied environment. The presence of dam along the river have clearly shown to have devastating impacts to downstream areas especially in the mature river zone by completely change of biodiversity due reducing the freshwater flow and enhance the domination of sea water

The mountain stream zone was dominated by taxa associated with pristine or unimpacted waters with a decrease in the diversity indices downstream. This response is the clear indication that macroinvertebrates are good candidates in assessing the water quality and stability of the environment.

Temporal variations were not strong, however the taxa composition and abundance between the two seasons was of interest showing the influence of the life history to some species like *Afronurus*.

Distance based linear Model showed substrate, conductivity, temperature, pH and discharge showed to influence the distribution of macroinvertebrate assemblages while the hydraulics variables (depth, velocity and Froude number) were found to have no influence in the distribution of macroinvertebrate assemblages along the river due to the scale of research being large (site and catchment level).

The study also highlights ecohydrology solution like increase of riparian forest to improve environmental variables which will further positively influence the macroinvertebrate community and other organisms.

This study opens a door more studies on the river discharge in order to come up with optimum amount of freshwater needed to be realised by the dam for improvement of the biotic community downstream.

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Appendix

Table 1: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Afronurus* between the two sampling periods (dry and wet periods)

Comparisons for factor: Time			
Comparison	Diff of Means	P	P<0.050
Wet vs. Dry	2.078	0.04	Yes

Table 2: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Potamonautes* among the river zones. Codes; MS= Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature river.

Comparisons for factor: River zones			
Comparison	Difference of Means	P	P<0.050
MS vs. REJ	5.833	<0.001	Yes
MS vs. LF	5.25	<0.001	Yes
MS vs. MR	5.167	0.001	Yes
MS vs. UF	2.167	0.07	No
UF vs. REJ	3.667	0.063	No
UF vs. LF	3.083	0.051	Do Not Test
UF vs. MR	3	0.042	Do Not Test
MR vs. REJ	0.667	0.906	Do Not Test
MR vs. LF	0.0833	0.954	Do Not Test
LF vs. REJ	0.583	0.686	Do Not Test

Table 3: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Amphipsyche* among the river zones. Codes; MS= Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature river.

Comparisons for factor: River zones within Dry period				Comparisons for factor: River zones within Wet period			
Comparison	Difference of Means	P	P<0.05	Comparison	Difference of Means	P	P<0.05
REJ vs. MS	13.667	<0.001	Yes	MS vs. LF	0.556	0.935	No
REJ vs. MR	13.667	<0.001	Yes	MS vs. MR	0.556	0.863	Do Not Test
REJ vs. LF	13.167	<0.001	Yes	MS vs. UF	0.556	0.717	Do Not Test
REJ vs. UF	13.167	<0.001	Yes	MS vs. REJ	0.222	0.756	Do Not Test
UF vs. MS	0.5	0.896	No	REJ vs. LF	0.333	0.974	Do Not Test
UF vs. MR	0.5	0.86	Do Not Test	REJ vs. MR	0.333	0.904	Do Not Test
UF vs. LF	1.11E-16	1	Do Not Test	REJ vs. UF	0.333	0.671	Do Not Test
LF vs. MS	0.5	0.763	Do Not Test	UF vs. LF	3.33E-16	1	Do Not Test
LF vs. MR	0.5	0.603	Do Not Test	UF vs. MR	2.78E-16	1	Do Not Test
MR vs. MS	4.44E-16	1	Do Not Test	MR vs. LF	5.55E-17	1	Do Not Test

Table 4: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Melanoides* among the river zones. Codes; MS= Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature river.

Comparisons for factor: River zone within Dry period				Comparisons for factor: River zones within Wet period			
Comparison	Difference of Means	P	P<0.05	Comparison	Difference of Means	P	P<0.05
REJ vs. MS	1.667	0.993	No	MR vs. MS	14.722	<0.001	Yes
REJ vs. MR	1.667	0.985	Do Not Test	MR vs. LF	13.833	<0.001	Yes
REJ vs. UF	1.5	0.929	Do Not Test	MR vs. UF	12	0.002	Yes
REJ vs. LF	1	0.808	Do Not Test	MR vs. REJ	8.333	0.016	Yes
LF vs. MS	0.667	0.996	Do Not Test	REJ vs. MS	6.389	0.168	No
LF vs. MR	0.667	0.986	Do Not Test	REJ vs. LF	5.5	0.235	Do Not Test
LF vs. UF	0.5	0.882	Do Not Test	REJ vs. UF	3.667	0.277	Do Not Test
UF vs. MS	0.167	0.998	Do Not Test	UF vs. MS	2.722	0.647	Do Not Test
UF vs. MR	0.167	0.968	Do Not Test	UF vs. LF	1.833	0.585	Do Not Test
MR vs. MS	3.55E-15	1	Do Not Test	LF vs. MS	0.889	0.772	Do Not Test

Table 5: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Ephemerythus* and *Neoperla* among the river zones. Codes; MS= Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature river.

<i>Ephemerythus</i>				<i>Neoperla</i>			
Comparisons for factor: River zones				Comparisons for factor: River zones			
Comparison	Difference of Means	P	P<0.050	Comparison	Difference of Means	P	P<0.050
MS vs. MR	5.139	0.017	Yes	UF vs. REJ	5.833	<0.001	Yes
MS vs. LF	4.889	0.005	Yes	UF vs. MR	5.833	<0.001	Yes
MS vs. REJ	4.722	0.012	Yes	UF vs. LF	5.75	<0.001	Yes
MS vs. UF	4.472	0.002	Yes	UF vs. MS	4.722	<0.001	Yes
UF vs. MR	0.667	0.979	No	MS vs. REJ	1.111	0.779	No
UF vs. LF	0.417	0.96	Do Not Test	MS vs. MR	1.111	0.612	Do Not Test
UF vs. REJ	0.25	0.884	Do Not Test	MS vs. LF	1.028	0.322	Do Not Test
REJ vs. MR	0.417	0.973	Do Not Test	LF vs. REJ	0.0833	0.998	Do Not Test
REJ vs. LF	0.167	0.922	Do Not Test	LF vs. MR	0.0833	0.948	Do Not Test
LF vs. MR	0.25	0.884	Do Not Test	MR vs. REJ	2.22E-16	1	Do Not Test

Table 6: Pairwise multiple comparison (Student- Newman- Keuls Method) for *Caenis* and *Cleopatra* among the river zones. Codes; MS= Mountains streams, UF = Upper foothill, LF = Lower foothill, REJ = Rejuvenated foothill and MR = Mature river.

<i>Caenis</i>				<i>Cleopatra</i>			
Comparisons for factor: River zones				Comparisons for factor: River zones			
Comparison	Difference of Means	P	P<0.050	Comparison	Difference of Means	P	P<0.050
LF vs. MR	3.75	<0.001	Yes	LF vs. MR	4.75	0.013	Yes
LF vs. UF	3.5	<0.001	Yes	LF vs. MS	3.417	0.025	Yes
LF vs. MS	3.472	<0.001	Yes	LF vs. REJ	3.167	0.076	No
LF vs. REJ	3	<0.001	Yes	LF vs. UF	1.833	0.156	Do Not Test
REJ vs. MR	0.75	0.67	No	UF vs. MR	2.917	0.183	No
REJ vs. UF	0.5	0.687	Do Not Test	UF vs. MS	1.583	0.367	Do Not Test
REJ vs. MS	0.472	0.405	Do Not Test	UF vs. REJ	1.333	0.353	Do Not Test
MS vs. MR	0.278	0.874	Do Not Test	REJ vs. MR	1.583	0.57	Do Not Test
MS vs. UF	0.0278	0.955	Do Not Test	REJ vs. MS	0.25	0.851	Do Not Test
UF vs. MR	0.25	0.681	Do Not Test	MS vs. MR	1.333	0.319	Do Not Test