ASSESSMENT OF THE ECOLOGICAL INTEGRITY OF LOWER SABAKI RIVER
USING MACRO-BENTHIC INVERTEBRATES AS BIOLOGICAL INDICATORS

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Fisheries of Pwani University

NOVEMBER, 2016
DECLARATION

Student’s declaration

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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Supervisors’ declaration

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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DEDICATION

I dedicate this thesis to my dear husband Salim Shehe and our children Noella, Matilda and Jabali.
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ABSTRACT

The present study was conducted at the lower reaches of the Athi-Galana-Sabaki River system that empties its water into the Indian Ocean. The objective of the study was to assess the ecological integrity of the lower Sabaki River using macro-benthic invertebrates as biological indicators. Macro-benthic invertebrate samples were collected monthly from December 2015 through February 2016 using a scoop net of 500μm mesh-size, at three selected sampling stations (St.-1 downstream station, St.-2 middle station and St.-3 uppermost station). Physicochemical parameters were measured in-situ using digital meter sensor probes and water samples collected at each sampling station for nutrients analysis. The nutrients; phosphorus and nitrogen were analysed using the APHA-2012 standard methods and procedures. Species diversity, richness and evenness were calculated using Shannon-Wiener diversity $H'$, Margalef’s $D'$ and Pielou’s $J$ Evenness indices, respectively. A total of 24,479 specimens belonging to 4 classes, 11 orders, 23 families and 23 species were sampled. Results showed higher species richness and evenness at St.-3 while St.-1 recorded the lowest richness and evenness. Shannon diversity index was <1 at all the sampling stations. Principal Component Analysis (PCA) results showed that two components; PC-1 and PC-2 explained 100% of the water quality variability in the sampled stations with pH, nitrites, nitrates and phosphates showing positive loadings in both PCs. Similar correlations between these parameters with species richness, diversity and evenness were also evident in the analysis with Pearson correlation. This study revealed that macro-benthic invertebrates could be used as potential indicators of the integrity of the lower Sabaki River, which was confirmed with the correlations with physico-chemical parameters.

Key words: Sabaki River, Ecological integrity, Biological indicators, Macro-benthic invertebrates
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<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>APHA</td>
<td>American Public Health Association</td>
</tr>
<tr>
<td>BE</td>
<td>Blue Economy</td>
</tr>
<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical Conductivity</td>
</tr>
<tr>
<td>EPT</td>
<td>Ephemeroptera, Plecoptera, Trichoptera</td>
</tr>
<tr>
<td>g/l</td>
<td>grams per litre</td>
</tr>
<tr>
<td>IBA</td>
<td>Important Bird Areas</td>
</tr>
<tr>
<td>KMFRI</td>
<td>Kenya Marine Fisheries and Research Institute</td>
</tr>
<tr>
<td>mL</td>
<td>Millilitre</td>
</tr>
<tr>
<td>µ/s</td>
<td>Micro Siemens</td>
</tr>
<tr>
<td>Nm</td>
<td>Nanometer</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Environmental Management Authority</td>
</tr>
<tr>
<td>Ppt</td>
<td>Parts per thousands</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SDF</td>
<td>State Department of Fisheries</td>
</tr>
<tr>
<td>TDS</td>
<td>Total Dissolved Solids</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environmental Program</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>US-EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>YSI</td>
<td>Yellow Springs Instrument (Ohio-USA)</td>
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CHAPTER 1: INTRODUCTION

1.1. Background

The integrity of freshwater resources is vital to human life and contributes towards the economic well-being of all nations. Sound management of this resource is of great importance for the life of a society and is a challenge that threatens the future generations (Benetti et al., 2012). Rivers present the most important freshwater resource for the society because they are the main sources of portable water, water for irrigation and industrial use, generation of hydro-electric power; recreational activities as well as being the most suitable media for cleaning, dispersing, transporting and disposal of various wastes (Chapman, 1996).

Although a lot of ecosystem goods and services are offered by these river systems, the quality of water that remains after the extractive uses, augmented by increasing pollution levels, cannot equally sustain the integrity of the ecosystems (Baronet et al., 2003). The ecosystem integrity of a river is costly and often irreplaceable once it has been degraded. Notwithstanding, many rivers around the world are being degraded by pollution at a higher rate than at any other time in human history, and at a faster rate than they can be restored (Baronet et al., 2003).

Establishing the integrity of streams and rivers is a comprehensive and multi-functional approach which involves highlighting the major threats to the sustainability of these freshwaters ecosystems. Biological assessment of river water bodies is a direct indicator of stresses to biodiversity in inland waters (Zalewski, 2000). Most drivers of water quality change arise from land-based activities and therefore each and every human activity impacts the biophysical environment in some way, often de-stabilizing the existing equilibrium or accelerating natural rates of change (Karanja, 2011).

In general, the effects of human activities on rivers and their ecosystem affect the key attributes of aquatic ecosystems including water quality, habitat structure, stream flow patterns, sources of energy and nutrients and biotic interactions (Karr, 1999). Altering these attributes in turn
upsets the ecosystem integrity of the entire river. A river whose ecosystem cannot sustain itself impacts the aquatic biota (Karr and Chu, 2000). Consequently, there is a need to conduct biological assessment in integration with physico-chemical assessment to ensure a comprehensive monitoring of the water quality of the river.

The Sabaki is a perennial river in the lower coastal area of Kenya. The river discharges its waters into the Indian Ocean on the shores of the Malindi Bay (Lambo and Ormond, 2006; Ongore et al., 2013). The River is part of the Athi-Galana-Sabaki River system that originates from the Aberdares mountains in the central highlands of Kenya. The river is a vital resource and offers numerous ecosystem goods and services to the community including water for domestic, municipal, irrigation and livestock. The river presents a major source of livelihood along the areas where it flows. The Sabaki estuary is listed among the most “important bird areas” (IBAs) along the Kenyan coast and is a globally important site under the “bird congregations” category of the IBA’s criteria (Bennun and Njoroge, 1999). The river discharge also enriches the fisheries of the Malindi Bay which supports the livelihoods of a diverse populace of the coastal fisher communities (KMFRI, 2013).

Although numerous ecosystem goods and services are derived from the river, increase in pollutants and degradation of the river system due to domestic, run-off wastes and non-point sources of pollutants remain the most critical challenges to the continued provision of these services from the river (Kitheka, 2002; 2013; Kithiia, 2007). There is considerable evidence from both field and laboratory studies indicating that pollution of lakes and streams may change the structure of the communities of organisms living in these environments (Smolders et al., 2003; Oller and Goitia, 2005).

Macro-invertebrates are among the fauna of rivers that are most affected by pollution and especially their ecology with regards to their diversity, spatial-temporal distribution and sizes (Shivoga, 1999). Major changes associated with water pollution include decline in the
abundance and taxa richness of key macro-invertebrates such as mayflies nymphs (Ephemeroptera), stone fly nymphs (Plecoptera) and Caddis fly larvae (Trichoptera), as well as an increase in abundance of chironomids (midges) and oligochaetes (earthworms) (Barbour et al., 1999). Macro-benthic invertebrate are animals without backbone inhabiting the bottom substrate of an aquatic environment and are large enough to be seen with unaided eye (Beauchene, 2005). They are the most frequently used bio-indicators of anthropogenic contaminations in surface waters as well as sediments; they have found wider application as bio-monitoring tools owing to their abundance, diversity and sedentary nature (Reece and Richardson, 2000; Dallas and Mosepele, 2007). The use of macro-benthic invertebrates as indicators of water quality in rivers is highly recommended since they integrate information for a very long time and signifies the responses of aquatic habitats (Ojija, 2016). Over the last few decades, macro-benthic invertebrates have been used as bio-indicators in assessing impacts of pollution in many developed countries such as Europe, Canada and United States and are included in the national and technical standards of water quality monitoring (Elias et al., 2014). However, their use in most of the developing countries including Kenya is still very limited, partly due to lack of a well-known and established bio-monitoring systems and biotic indices (Karanja, 2011).

However, for many rivers in Kenya including the Sabaki River, data and information on the composition, abundance, diversity and distribution of macro-benthic invertebrates in relation to degree of anthropogenic impacts is limited as a result making the management of this river an uphill.

1.2. Problem Statement

The Sabaki River is a source of water and livelihoods for many riparian communities and provides a habitat for fish, a bird sanctuary and a support system for the Malindi Bay fisheries. However, levels of anthropogenic input of pollutants into the river have increased over the years threatening the survival of aquatic organisms, productivity of the Malindi Bay, the
associated wetlands, birds and livelihoods for many coastal fisher-folks (Ongore et al., 2013). The increased pollution of the river system has been augmented by the increasing human settlements in the catchment area of the Athi-Galana-Sabaki River system as well as on the riparian areas (UNEP, 1998; Kimakwa, 2004; Kosgey, 2013). Additionally, the Sabaki River is under extreme anthropogenic pressure from land-use activities on the riparian areas and domestic wastes disposal (Kithiia, 1997; Kosgey, 2013). There has also been an increased abstraction of water from the river for agricultural, industrial and domestic uses, as well as for the development activities in the sub-urban areas of Malindi and Sabaki (Diop et al., 2016). These activities have not only reduced the quantity of water flowing in the river but also the water quality. It’s the deterioration of the water quality in the Sabaki River that poses highly deleterious effects on the river’s ability to support the wildlife populations, the associated wetland ecosystems, as well as the Malindi Bay fishery.

1.3. Justification of the Study
The Sabaki River is a vital resource for the community and aquatic organisms. It is a source of water and livelihood to the community and its estuary is gazetted as important bird areas (IBAs) along the Kenyan coast (Bennun and Njoroge, 1999). The river acts as a support system for the Malindi Bay fishery owing to the terrigenous sediment-rich waters that discharge into the bay enriching the fishing grounds in the bay (KMFRI, 2002). Consequently, the Malindi Bay, which is part of the wider Malindi-Ungwana complex, presents one of the richest and most productive fishing grounds along the Kenyan coast; it supports vast small-scale inshore fisheries which forms the main source of livelihood for many of the coastal communities (KMFRI, 2002; 2013).

Data and information on the influence of water quality on diversity, abundance and distribution of macro-benthic invertebrates in the sediments of Sabaki River is scanty, making the management of the resources an uphill task. If left unaddressed, the threats posed to Sabaki River have the potential for severe long-term impacts on the productivity of the Malindi Bay fishery and the livelihoods of the local communities.
Furthermore, the role played by the Sabaki River estuary as a bird sanctuary and biodiversity hotspot would face severer impacts if the ecosystem of the river is deleteriously impacted.

Therefore, the urgent need to assess the ecological integrity of the Sabaki River cannot be understated. Establishment of the use of macro-benthic invertebrates as biological indicators was aimed at providing a basis for the integration of rapid-assessment methods with conventional water quality studies for continual assessment and sustainable management of the Sabaki River system and surrounding ecosystems. The present study provides baseline data on the current composition, distribution and abundance of macro-benthic invertebrates and is a positive inquiry for the scientific community. Furthermore, the study provides an insight to the resource managers of the ecosystem as well as the local community resource-users.

1.4. Objectives of the Study

1.4.1. General Objective:

The general objective of this study was to assess the ecological integrity of the lower Sabaki River system using macro-benthic invertebrates as biological indicators.

The specific objectives of the study were to:-

1. Assess the water quality of the lower Sabaki River specifically the physico-chemical parameters.
2. Identify macro-benthic invertebrates species in the lower Sabaki River.
3. Determine the species richness and diversity of macro-benthic invertebrates in the lower Sabaki River.
4. Determine the factors that influence macro-benthic invertebrate species’ assemblages in the lower Sabaki River.

1.5. Research Questions

The study was aimed at addressing the following questions:-

1. What is the status of the water quality in the lower Sabaki River?
2. What species of macro-benthic invertebrates are found in the lower Sabaki River?
3. How is the species richness and diversity of macro-benthic invertebrates in the lower Sabaki River?

4. What are the factors influencing macro-benthic invertebrates species assemblages in the lower Sabaki River?

1.6. Hypotheses

- $H_0$-1: The physico-chemical parameters of the lower Sabaki River are the same.
- $H_0$-2: The species richness and diversity of macro-benthic invertebrates in the lower Sabaki River cannot be determined.
- $H_0$-3: The factors influencing macro-benthic invertebrates species assemblages in the lower Sabaki River cannot be determined.
- $H_0$-4: The ecological integrity of the lower Sabaki River cannot be assessed using macro-benthic invertebrates as bio-indicators.
CHAPTER 2: LITERATURE REVIEW

2.1. The Concept of Ecological Integrity

Ecological integrity is a concept that seeks to incorporate the biotic and abiotic components of an ecosystem with regard to how they relate in their functions, goods and services output and their regeneration rates (Maddock, 1999). Additionally, in freshwater ecosystems, all internal and external processes should interact with the environment in such a way that the biotic community corresponds to its natural type-specific aquatic habitats (Maddock, 1999). Floternersch et al. (2006) defined the ecological integrity of river ecosystems as "the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes".

For a long time ecological integrity assessments in flowing water systems have concentrated on the physico-chemical parameters with little emphasis on the biological attributed of these lotic systems. However, physico-chemical measurements alone are inadequate for assessing river health as the processes linking changes in physical and chemical conditions in rivers and their ecological status are poorly understood and/or, are too complex, hence the need to link both methods (Zalewski, 2000).

2.2. Biological Monitoring

Bio-monitoring assessments or bio-assays use biota as endpoint to represent environmental condition and assess environmental quality. According to Bonada et al. (2006), early uses of bio-assays date back to the saprobic system which established the conceptual basis for bio-monitoring methods and was based on the sensitivity of aquatic organisms to organic pollution. Kasangaki et al. (2006) noted that traditional means of assessing the impacts of pollution on water bodies were through the measurement of physical and chemical parameters. However such measurements could not provide ecological information because the synergistic effects of pollution on aquatic biotic community may not be fully and easily assessed through physical and chemical measurements. Furthermore, only physical and chemical measurements
cannot form the basis for biodiversity conservation. These shortcomings of physical and chemical water measurements necessitated the use of biological organisms to assess the impacts of anthropogenic activities on water in aquatic ecosystems and have given rise to a branch of ecology called biological monitoring (or bio-monitoring). Bio-monitoring is a product of the assumption that the response or “health” of biota is a reflection of the “health” of the environment in which they live (Rosenberg and Resh, 1993; Bonada et al., 2006). It uses biological indicators on the basis that biological diversity in terms of species and community structures are indicators of the water quality, hydrology and overall health of a river ecosystem. Nixon et al. (1996) used biological indicators to monitor toxicity levels and chemical content i.e. the chemical and physical parameters and the overall health of river systems. It is noted that, the presence or absence of biological indicator’s taxonomic groups, individual species, groups of species and or entire communities are used to reflect environmental conditions (Karr, 1981).

Niemi and McDonald (2004) defined biological indicators as species of organisms whose function, population, or status can be used to determine the integrity of an ecosystem. According to Chapman (1996), natural events and anthropogenic activities can impact on these organisms in different ways. For instance the response of these organisms from man-made substances added to the water, alteration of the flow regime and physico-chemical nature of the water may include death or migration to other habitats. Once the responses of particular aquatic organisms to any given changes have been known, they may be used to determine the quality of water with respect to its suitability for aquatic life. Biological indicators or bio-indicators are used to document and understand changes in fresh water ecosystems, especially changes associated with anthropogenic activities. Karr (1999) observed that maintenance of the integrity of fresh water ecosystems is essential in sustaining the goods and services the human society depends on and also the organisms inhabiting these aquatic systems.

According to Merritt et al. (2008) the common bio-indicators are freshwater macro-benthic invertebrates which include representatives of many insects’ orders as well as crustaceans,
gastropods, bivalves and oligochaetes. They contribute to various ecological functions including decomposition of organic matter and nutrient cycling, as well as being part of the food webs as both consumers and prey. Covich et al. (1999) and Merritt et al. (2008) reported that insects are often the dominant group among the macro-benthic invertebrates, in both absolute numbers and species diversity, since the juvenile stages of many insects are typically aquatic.

Studies have shown that macro-benthic invertebrates are important biological indicators of water quality because they inhabit the sediment or live on the bottom substrates and have relatively long life-cycles and therefore, they integrate the full range of environmental changes (Rosenberg and Resh, 1993; Karr and Chu, 2000). Moreover, Giller et al. (2004) noted that any modification of the aquatic ecosystems by pollutants, sedimentation and watershed degradation mostly impacts upon the macro-benthic community structure.

Therefore, by assessing the structure of the macro-benthic invertebrate communities, it is possible to determine the degree to pollution resulting inecological changes such as loss of the pollution-sensitive groups of organisms (Bae et al., 2005). Carlisle et al. (2007) noted that macro-benthic invertebrate populations in streams and rivers can assist in the assessment of the overall health of riversystems. Similar observations have also been given by Sharma and Chowdhary (2011) who concluded that live organisms offer valuable information regarding the habitats they inhabit and can be used to evaluate the physical, chemical and biological impact, as well as cumulative effects on the ecosystems. Additionally, assessment of species richness and composition, relative abundance, and feeding relationships between the inhabiting organisms can provide the most direct measure of water quality to determine if a water body meets the biological standards for aquatic life.

Realizing the immense importance of bio-monitoring as a tool for assessment of river water quality, several studies have been conducted globally. Macro-benthic invertebrates have been much used for biological monitoring of environmental quality in aquatic ecosystems
especially Canada, Europe and North America (Yap et al., 2003). In Africa, the use of biological tools for water quality assessment in water bodies is not familiar; it has been used in various countries such as South Africa, Zimbabwe, Ethiopia and Nigeria. In East Africa, it has been used in for the assessment of water quality of rivers in Tanzania and Uganda. For Kenya, the idea of bio-monitoring is still new with only a few studies. For example, Bonzemo (2013) assessed the water quality of Kibisi River in Mount Elgon using the Ephemeroptera, Plecoptera and Trichoptera (EPT) index; Karanja (2011) used various macro-benthic invertebrate metrics in the assessment of the ecological status of Tsavo River and Mzima Springs in the Tsavo West National Park; Masese et al. (2009) assessed water quality of Moiben River using macro-invertebrates assemblages while Raburu (2003) assessed the water quality of River Nyando, using both macro-invertebrates and ichthyofauna.

The limited use of this method in Kenya has been due to lack of a well-known and established bio-monitoring system and biotic index within the country and the fact that Kenyan environmental laws, acts, regulatory processes and bodies do not emphasize the use of aquatic macro-invertebrates as bio-indicators of water quality to evaluate the quality of aquatic ecosystems (Karanja, 2011). The use of biological indicators is long overdue, and hence this study aimed to address these gaps and develops the much needed tools for ecological assessment of the dwindling water resources which form the livelihoods of many riparian communities.
CHAPTER 3: MATERIALS AND METHODS

3.1. Study Area

The study was conducted in the lower Sabaki River, upstream of the Sabaki Bridge, 4 kilometers north of Malindi town (NEMA, 2009). The river is part of the Athi-Galana-Sabaki system which originates from the Aberdares mountain range in the central highlands of Kenya. The upper reaches of the system, the Athi River, runs through the Yatta plateau, and as the Galana River in the middle reaches in the Athi-Kapiti plains. The Sabaki River forms the lower reaches of the Athi-Galana-Sabaki system, which finally discharges its waters into the Indian Ocean within the Malindi Bay (Abuodha, 2004). It is the second longest river system in Kenya, after the Sagana-Tana River system which empties its waters at Kipini, north of the Ungwana Bay (Indian Ocean).

The study area is characterized by a tropical climate with Southeast Monsoon (SEM) winds prevailing from April to July and Northeast Monsoon (NEM) winds from October to March. The rainfall pattern is bi-modal, with long rains during March through May and short rains from October through December. The mean annual temperature is 24.0±7°C (Mean±SD) while the annual average rainfall is about 1,000mm (Abuodha, 2003).

The vegetation of the area is varied depending on proximity to fresh- and/or marine waters as well as the soil types which range from sand-dunes to riverbed sediments. The grasslands are seasonal, forming an expansive flat on the northern shores where the invasive Mexican thorn Prosopis juliflora thickets are well developed. The native bush has been severely denuded due to excessive fuel wood collection and charcoal burning (NEMA, 2009). The Sabaki river mouth area is characterized by poor soils, shallow depressions and a gently undulating terrain characterized by sandy to sandy loam soils with very high infiltration rates. Human activities within the area include sand harvesting, fishing, livestock keeping, drought resistant agriculture and small-holder horticultural irrigation (NEMA, 2009).
3.2. Sampling Stations

The Sabaki River is a perennial river and a source of water supply to hundreds of the households, institutions, urban centres, agriculture and animals along the coastal Kenya. Three sampling stations were established along a 2km stretch north of the Sabaki River Bridge (Figure 1). The sampling stations were established based on presence / absence of human activities, vegetation and ease of accessibility, as described below:

Station-I (St.-1) was located near Shaha village approximately 300m north of the Sabaki river bridge. In this station, there is some considerable intensity of human activities which included washing of motorbikes, water pumping, animal grazing, cultivation of crops, irrigation for fruits, vegetable and rice, watering domestic animals, drawing of water for domestic use, fishing, laundry, bathing and swimming. This site was deforested and free of aquatic emergent plants and the river bank had no visible vegetation.

The second station (St.-2) was located near the Maekani village, 700m north of St.-1. The area was characterized by lower intensity of human activities with a few activities including rice/vegetable farming and water extraction for irrigation. The vegetation in this site is sparse and patchy with P. juliflorashrubs being the dominant species in this area.

The last sampling station, St.-3 was located near Chuka-cha-wanawake village, some 1.0km north of St.-2. The station is rich in aquatic emergent vegetation and thick shrubs of P. juliflora and grasses dominated the riparian vegetation. There are no major human activities here except the presence of some few youthful fishers who harvest freshwatershrimp (Palaemon sp.) in the river waters.
Figure 1: Map of Kenya showing the Sabaki River and location of sampling stations
3.3. Sampling Procedures

3.3.1. Physico-chemical parameters

Sampling was conducted monthly beginning from December 2015 to February 2016. Selected physico-chemical parameters including water temperature, Dissolved Oxygen, pH, Total Dissolved Oxygen, Electrical Conductivity and Salinity were measured in situ using digital sensor probe meters (Ecosense®, YSI, USA) as shown in plate 1, 2 and 3. Water temperature and dissolved oxygen were measured using (Ecosense, YSI, DO 200A meter), pH was measured using (Ecosense, YSI, pH 100A meter) while electrical conductivity, total dissolved solids and salinity were measured using (Ecosense, YSI EC/TDS/Salinity 300A meter). The parameters were then recorded as temperature (°C); Dissolved Oxygen (mg/l); Electrical Conductivity in micro-siemens per centimeter (mS/cm), Total Dissolved Solids (g/l) and Salinity in parts per thousands (ppt).

3.3.2. Macro-benthic Invertebrates

Sampling for the macro-benthic invertebrates was conducted using rapid bio-assessment protocols for rivers and wadeable streams as described by Barbour et al. (1999). Three scoops of macro-benthic invertebrate samples were collected in each sampling station using a scoop net with mesh size of 500μm. The scoop net was dipped into the water with its position against the direction of water flow (plate 4). Disturbance removal sampling technique which involved defining a specific sampling area of 10-m distance was applied, and the selected site sampled by vigorously kicking, jabbing, dipping and sweeping the substrate with the scoop net for about 20 min to dislodge the invertebrates which were then trapped a few meters downstream into the scoop net. The process was repeated three times for each sampling station. The triplicates samples were then combined to make a composite sample representative of each sampling station.

The samples of macro-benthic invertebrates were then processed on site by sorting out any inorganic debris from the discrete collections (plate 5) in order to bring a cleaner composite
sample for analysis in laboratory. After sorting, they were preserved in 500-ml containers using 70% ethanol with appropriate labelling for station number (St.) and date (plate 6). The samples were transported to the laboratory for analysis at the Kenya Marine and Fisheries Research Institute in Mombasa.

In the laboratory, prior to identification, each composite sample was washed thoroughly with water to remove any traces of ethanol as shown in plate 7. The cleaned samples were emptied into a white tray and sorted out using forceps to separate the macro-benthic invertebrates and organic debris (plate 8). The debris was discarded and water added to macro-invertebrates which were then sorted to taxonomic groups. Owing to the lack of taxonomic keys specific for the Kenyan streams fauna, most specimens were assigned only to the lowest possible level. However, some specimens could be identified to species level using a stereo-dissecting microscope at x50 magnification (plate 9), guided by taxonomic keys in Pennak, 2001; Gerber and Gabriel, 2002; Gooderham and Tysrlin, 2002; Bouchard, 2004 and Danladi et al., 2013.

3.3.3. Nutrients

Sampling for nutrients involved collection of triplicate water samples from each station using 500-ml plastic bottles (plate 10). The samples were immediately fixed using mercury chloride on site and transported to the Kenya Marine and Fisheries Research Institute (KMFRI) in Mombasa for analysis. Prior to analysis, the water samples were filtered using 0.45 μm glass fiber filters and then placed in hydrochloric (HCL) acid-washed plastic bottles. Thereafter, nitrates (NO₃-N), nitrites (NO₂-N), phosphates (PO₄³⁻-P) and ammonia (NH₄-N), were determined using standard spectrophotometric methods in APHA, 2012, as described below:

Nitrates were determined using the cadmium reduction method which involved reduction of the nitrate to nitrite at pH 8 in a copperized cadmium reduction coil. The reduced nitrite reacted under acidic conditions with sulfanilamide to form a diazo-compound that couples with N-1-1-naphthylethylendiamine (NEDD) to form a highly coloured azo-dye. The concentration was then measured spectrophotometrically at 540-nm wavelength.
Phosphates were determined by colorimetric method which involved the reaction of phosphates with molybdate ion and antimony ion followed by reduction with ascorbic acid to form blue-coloured phosphor-molybdenum complex, which was then measured spectrophotometrically at 880-nm wavelength.

Lastly, ammonia was determined by the phenate method which involved the addition of phenol solution together with hypochlorite and nitroprusside catalyst to the water sample. The ammonia reacted to form a blue indophenol colour which was then measured spectrophotometrically at 640 nm wavelength.

3.4. Data Analysis

Data analysis was conducted as follows:

All data were entered in Ms Excel 2010 ®. Descriptive statistics was presented as means and their standard deviations were used to summarize the data characteristics. A One-Way Analysis of Variance (ANOVA) was used to test for statistical differences among the study sites. Kolmogorov-Smirnov test was used to check the normality of the distribution of data. All statistical analysis was conducted in Minitab® Ver. 17.0. All tests were considered significant at $p<0.05$. Relative abundance (%) of macro-benthic invertebrates was calculated as follows:

$$RA(\%) = \frac{\text{# Individuals of species "A"}}{\text{# Individuals of all species}} \times 100$$

3.4.1. Species Diversity Indices

3.4.1.1. Shannon-Wiener Index

Species diversity was analysed using Shannon-Wiener index (Magurran, 2004). Shannon index is an information statistic index, which means it assumed all species were represented in a sample and that they are randomly sampled. Shannon-Wiener index:

$$H' = \sum_{i=1}^{s} p_i \ln(p_i)$$

Where; $H'$=Shannon wiener diversity index; $p_i$ -proportion of total samples of $i^{th}$ species; $s$-number of species in a sample; and $i$=the number of individual species.
The Shannon-Wiener index was preferred because it takes into account the number of species as well as the proportion of individuals distributed among each species. The index $H'$ ranges 1.5 and 3.5. A value of less than 1 indicates very low diversity and would be characteristic of a highly polluted habitat, $H'=1$ to 3 characterises a moderately polluted habitat while $H'>4$ would be characteristic of fairly pristine environments with very low, if any, kinds of pollution (Gray, 2000). The implication of this index is that $H'$ has its foundations in information theory and represents the uncertainty about the identity of an unknown individual. In a highly diverse (and evenly distributed) system, an unknown individual could belong to any species, leading to a high uncertainty in predictions of its identity. In a less diverse system dominated by one or a few species, it is easier to predict the identity of unknown individuals and there is less uncertainty in the system.

### 3.4.1.2. Pielou $J'$ Index

Species evenness was calculated using Pielou's evenness index:

$$J' = \frac{H'}{H_{\text{max}}} = \frac{H'}{\ln S}$$

, where $H'$ = Shannon-Wiener index and $H_{\text{max}}$ = highest value scored in the Shannon-Wiener index (Rosenberg, 2005). The Pielou evenness index $J'$ ranges from 0' to 1; where '0' represents communities with very low evenness and '1' represents communities with a very high evenness index (Stirling and Wilsey, 2001). A low evenness indicates a species with very patchy distribution in the habitats under study whereas a high evenness indicates that the species exhibit a fairly equal or uniform distribution (Smith and Wilson, 1996)

### 3.4.1.3. Margalef’s $D'$ Index

Margalef’s index ($D'$): is a measure of species richness (Margalef, 1958; Gamito, 2010) and was expressed as:

$$D' = \frac{S-1}{\ln(n)}$$

Where; $S=$ the number of species in a sample and $n=$ the total number of individuals in the sample.
3.4.2. Principal Component Analysis

Principal Component Analysis (PCA) was used to identify physico-chemical parameters that characterised each of the sampling stations and that influenced the distribution of the macro-benthic invertebrates. The PCA was used to identify the compositional patterns and determine the major factors driving the association among the parameters (Raj and Azeez, 2009).

Further, a scree-plot was used to identify the number of Principal Components (PC’s) that explained or accounted for the variability in the physico-chemical parameter data. On the basis of the scree-plot test criterion, two PC’s were retained for interpretation; they were shown by a major slope change. All the PCA and Scree-plot analysis were conducted in Minitab® Ver. 17.0. The loadings of each PC were classified according to method adapted from Singh et al. (2004) which classifies a component factor loading matrix as strong (eigenvalue > 0.75), moderate (eigenvalue; 0.75-0.50) and weak (eigenvalue; 0.50-0.30). In this analysis, a negative loading value indicates that the parameter is inversely related to other parameters which have positive values in the PC analysis.

3.4.3. Correlation Analysis

Pearson product-moment correlation coefficient (r) was used to check the correlation between physico-chemical parameters and macro-benthic invertebrates. The Pearson product-moment correlation coefficient (Pearson's r) is a measure of the linear dependence between two variables; a positive correlation coefficient 'r' indicated that as the values of one variable increases, the values of the other variable also increased, whereas a negative correlation coefficient 'r' indicated that as the values of one variable increases, the values of the other variable decreased (Salkind, 2006)
CHAPTER 4: RESULTS

4.1. Physico-chemical Parameters

The results for physico-chemical parameters (Mean±SD) recorded at the three sampling stations of the Sabaki River during December 2015 and February 2016 are shown in Table 1. Water temperatures at the sampling stations ranged from 29.3°C to 33.7°C; St.-1 recorded the highest mean temperatures of 31.1±2.2; followed by St.-2 (30.9±1.5°C) while the lowest mean temperatures (29.4±0.7°C) were recorded at St.-3. The temperature did not differ significantly among the stations (One Way ANOVA, F(2, 24) = 0.1244, p>0.05). On the other hand, pH levels ranged from 7.6 to 8.3 with St.-1 also recording higher values (pH = 8.0±0.2) compared to St.-2 at 7.9±0.2 and St.-3 at 7.8±0.3. The pH values did not differ significantly among the stations (One Way ANOVA, F(2, 24) = 0.6317, p>0.05). Conductivity values showed significant differences among the stations (One Way ANOVA, F(2, 24) = 1.446, p<0.05) with lowest conductivity (362.4±38.7 µScm⁻¹) at St.-3, followed by St.-2 (398.2±52.6µScm⁻¹) and St.-1 (462.6±118.9µScm⁻¹). Similarly, there were significant differences among the study stations in D.O. levels (One Way ANOVA, F(2, 24) = 3.25, P<0.05). St.-3 recorded the highest levels of D.O (6.0±0.4 mgL⁻¹) and the lowest levels were at St.-1 (4.48±0.2 mgL⁻¹). Total dissolved solids (TDS) also differed significantly among the stations (One Way ANOVA, F(2, 24) = 3.257, p<0.05). TDS values ranged from 200.2 to 398.7 mgL⁻¹ and followed similar trends to temperature and pH with the lowest values recorded at St.-3 (234.6±33.9mgL⁻¹), followed by St.-2 (268.5±65.4mgL⁻¹) and the highest TDS levels were recorded at St.-1 (352.7±43.3mgL⁻¹). However, there were no significant differences among the stations in terms of salinity levels (One Way ANOVA, F(2, 24) = 1.091, p>0.05). Salinity ranged from 0.1 to 0.3 with the following values recorded in each station: St.-1 (0.2±0.1mgL⁻¹) followed by St.-2 (0.2±0.1mgL⁻¹) and St.-3 (0.1±0.1mgL⁻¹).
Table 1: Physico-chemical parameters (Mean±SD, Range) in the study area of lower Sabaki River, Kenya during December 2015 through February, 2016. One Way ANOVA test results for means comparison among the stations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>St.1</th>
<th>St.2</th>
<th>St.3</th>
<th>ANOVA Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water temperature (°C)</td>
<td>31.1±2.2</td>
<td>30.9±1.5</td>
<td>29.4±0.7</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>(29.6-33.7)</td>
<td>(29.4-33.3)</td>
<td>(29.3-33.3)</td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (mgL⁻¹)</td>
<td>4.5 ± 0.2</td>
<td>5.3±0.1</td>
<td>6.0±0.4</td>
<td>Significant</td>
</tr>
<tr>
<td></td>
<td>(4.3 - 4.7)</td>
<td>(5.2 - 5.4)</td>
<td>(5.7 - 6.5)</td>
<td></td>
</tr>
<tr>
<td>Salinity (mgL⁻¹)</td>
<td>0.2±0.1</td>
<td>0.2±0.1</td>
<td>0.2±0.1</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>(0.13-0.3)</td>
<td>(0.1-0.2)</td>
<td>(0.1-0.2)</td>
<td></td>
</tr>
<tr>
<td>Conductivity (µScm⁻¹)</td>
<td>462.6±118.9</td>
<td>398.2±52.5</td>
<td>362.4±38.7</td>
<td>Significant</td>
</tr>
<tr>
<td></td>
<td>(341.3-578.9)</td>
<td>(339.7-441.4)</td>
<td>(333.6-406.4)</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>8.0±0.2</td>
<td>7.9±0.24</td>
<td>7.7±0.3</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>(7.9-8.3)</td>
<td>(7.8-8.2)</td>
<td>(7.6-8.2)</td>
<td></td>
</tr>
<tr>
<td>TDS (mgL⁻¹)</td>
<td>352.7±43.7</td>
<td>268.5±65.4</td>
<td>234.6±33.9</td>
<td>Significant</td>
</tr>
<tr>
<td></td>
<td>(312.7-398.7)</td>
<td>(200.5-331.0)</td>
<td>(200.2-268.1)</td>
<td></td>
</tr>
</tbody>
</table>

4.2. Nutrients

The study analyzed Ammonium (NH₄-N), Nitrate (NO₃-N), Nitrite (NO₂-N), and phosphate (PO₄³⁻-P). The results for nutrients analysis are shown in Table 2. NH₄⁺ concentration did not differ significantly (One Way ANOVA, F (2, 24) = 0.8037, p>0.05). NH₄-N ranged from 0.05 to 0.18 mg L⁻¹ and was highest at St.-1 (0.15±0.04 mgL⁻¹) followed by St.-2 (0.07±0.02 mgL⁻¹) and St.-3 which recorded the lowest values (0.05±0.04 mgL⁻¹). Similarly, there was no significantly differences in NO₂ concentrations among the stations (One Way ANOVA, F (2, 24) = 1.532, p>0.05). NO₂ ranged from 0.03 to 1.39 mgL⁻¹. The highest values were recorded at St.-2 (0.97±0.31 mgL⁻¹) followed by St.-3 and St.-1 at 0.92±0.28 mgL⁻¹ and 0.70±0.43 mgL⁻¹, respectively. Furthermore, there was no significant differences in NO₃ among the stations (One Way ANOVA, F (2, 24) = 684.4, p>0.05). NO₃ ranged from 0.71 to 1.90 mgL⁻¹. St.-
1(1.45±0.32 mgL⁻¹), St. -2 (1.40±0.37 mgL⁻¹) and St. -3 (1.30±0.37 mgL⁻¹). Significant differences were evident among the study stations in PO₄³⁻ concentrations (One Way ANOVA, F(2, 24) = 6.623, p<0.05). PO₄³⁻ concentrations ranged from 2.54 mgL⁻¹ to 6.91 mgL⁻¹. St. -1 recorded the highest values (5.78±0.82 mgL⁻¹), followed by St. -2 (4.35±1.31 mgL⁻¹) with far much lower concentrations at St. -3 (2.90±0.31 mgL⁻¹).

**Table 2**: Nutrients concentrations (Mean±SD, Range) in the study area of lower Sabaki River, Kenya during December 2015 through February, 2016. One Way ANOVA test results for means comparison among the stations.

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>St. 1</th>
<th>St. 2</th>
<th>St. 3</th>
<th>ANOVA test</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₄-N (mgL⁻¹)</td>
<td>0.15±0.04 (0.05-0.18)</td>
<td>0.07±0.02 (0.05-0.10)</td>
<td>0.05±0.04 (0.00-0.13)</td>
<td>Not significant</td>
</tr>
<tr>
<td>NO₂-N (mgL⁻¹)</td>
<td>0.7±0.43 (0.43-1.13)</td>
<td>0.97±0.31 (0.62-1.38)</td>
<td>0.92±0.28 (0.32-1.24)</td>
<td>Not significant</td>
</tr>
<tr>
<td>NO₃-N (mgL⁻¹)</td>
<td>1.45±0.32 (1.02-1.90)</td>
<td>1.40±0.37 (0.71-1.73)</td>
<td>1.30±0.37 (0.78-1.65)</td>
<td>Not significant</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>5.78±0.82 (4.64-6.91)</td>
<td>4.35±1.31 (2.80-5.95)</td>
<td>2.90±0.31 (2.54-3.35)</td>
<td>Significant</td>
</tr>
</tbody>
</table>

### 4.3. Macro-benthic Invertebrates

#### 4.3.1. Species Composition and Abundance

A total of 24,479 specimens belonging to four (4) classes, 12 orders, 23 families and 23 species were sampled during the study period (Table 3). The four classes recorded were Insecta, Branchiopoda, Malacostraca and Gastropoda with Insecta represented by 6 orders (Plecoptera, Ephemeroptera, Odonata, Coleoptera, Hemiptera and Diptera) while Branchiopoda recording one (1) order– Cladocera, Malacostraca recorded two (2) orders: Decapoda and Aranea. Under Mollusca, the Gastropoda was represented by the orders Lymnaeacea and Neritoida.
Out of the 24,479 specimens sampled from the Sabaki River, Decapoda was the most abundant, with two families; Palaemonidae and Potamonautidae accounting for 24,357 of the specimens. Table 4 shows the relative abundance of macro-benthic invertebrates by species. *Palaemon* sp was dominant accounting for 99% of the relative macro-invertebrate abundance (24,310 specimens) followed by *Potamonauta* sp at 0.19%. The rest of the species including *Amphinemura sulcicollis, Diaphanosoma, Epicorduliasp, Physasp* and *Thiarasp* accounted for relative abundances of ≈0.01% each. Relative abundances as indicated in figure 2 showed lower relative abundance at St.-1 (19%), followed by St.-2 at 30% and St.-3 (51%).

Grouping of the macro-benthic invertebrates sampled from the Sabaki River based on tolerance to pollutants is as shown in Table 5. St.-1 recorded the highest numbers of Pollution-tolerant groups including Dipteran-midges (*Dixidasp*), blackflies (*Chironomus* sp.) and water boatmen (*Hesperocorixa* sp.). In St.-2, majority of macro-benthic invertebrates recorded belonged to the somewhat pollution-tolerant group. This category included the dragon flies (*Epicordulia* sp, *Aphylla* sp and *Aeshna elliot*), black flies (*Simulium* sp), diving beetles (*Dysticus* sp), carridean shrimps (*Palaemon* sp), crab (*Potamonautesp*) and waterspiders (*Cybaie* sp). In the final uppermost station, St.-3, the sampled macro-invertebrate species were found to belong to the highly pollutant-sensitive which included water penny beetles (*Psephunus* sp), mayflies: *Ephemerella* sp and *Centroptilum tuteolum*, and river flies: *Habrophlebiafusca* and *Amphinemura sulcicollis*. 
Table 3: Composition and abundance of macro-benthic invertebrates in the lower Sabaki River, Kenya during December 2015 through February, 2016

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Family</th>
<th>Species</th>
<th>English name</th>
<th>St. 1</th>
<th>St. 2</th>
<th>St. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insecta</td>
<td>Plecoptera</td>
<td>Nemourida</td>
<td><em>Amphinemura</em></td>
<td>Riverflies</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>sulcicollis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td>Leptophlebiidae</td>
<td><em>Habrophlebia fuscata</em></td>
<td>Riverflies</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Baetidae</td>
<td></td>
<td></td>
<td><em>Centroptilum tuteolum</em></td>
<td>Mayflies</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Ephemerellidae</td>
<td>Ephemerelidae</td>
<td><em>Ephemerella sp</em></td>
<td>Mayflies</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Odonata</td>
<td>Cordullidae</td>
<td>Epicordulia sp.</td>
<td>Dragonflies</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Gomphidae</td>
<td></td>
<td><em>Aphylla</em></td>
<td>Dragonflies</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Aeshnidae</td>
<td><em>Aeshna elliot</em></td>
<td>Dragonflies</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coleoptera</td>
<td>Dytiscidae</td>
<td>Dytiscus sp</td>
<td>Diving Beetles</td>
<td>1</td>
<td>1</td>
<td>6</td>
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</tr>
<tr>
<td></td>
<td>Psephenidae</td>
<td><em>Psephunus sp</em></td>
<td>Water penny Beetles</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td></td>
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<tr>
<td></td>
<td>Gyrinidae</td>
<td><em>Gyrinus sp</em></td>
<td>Whirligig Beetles</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td></td>
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<tr>
<td>Hemiptera</td>
<td>Corixidae</td>
<td>Hesperocorixia sp</td>
<td>Water boatman</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td></td>
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<tr>
<td>Diptera</td>
<td>Chironomidae</td>
<td>Chironomus sp</td>
<td>Midges</td>
<td>9</td>
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<td>0</td>
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</tr>
<tr>
<td></td>
<td>Simuliidae</td>
<td>Simulium sp</td>
<td>Black flies</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dixidae</td>
<td>Dixida sp</td>
<td>Midges</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Branchiopoda</td>
<td>Cladocera</td>
<td>Sididae</td>
<td>Diaphanosoma sp</td>
<td>Water fleas</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Malacostraca</td>
<td>Decapoda</td>
<td>Palaemonida</td>
<td>Palaemon sp</td>
<td>Caridean Shrimp</td>
<td>4520</td>
<td>7340</td>
<td>12450</td>
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<td></td>
<td>Potamonautidae</td>
<td>Potamonautae sp</td>
<td>Crab</td>
<td>13</td>
<td>19</td>
<td>15</td>
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</tr>
<tr>
<td>Gastropoda</td>
<td>Aranea</td>
<td>Cybaidae</td>
<td><em>Cybae sp</em></td>
<td>Water spider</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Lymnaeacea</td>
<td>lymnaeidae</td>
<td>lymnaea sp</td>
<td>Gastropods</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Lymnaeacea</td>
<td>Physidae</td>
<td>Physa sp</td>
<td>Gastropods</td>
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<td>0</td>
<td>2</td>
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<td></td>
<td>Lymnaeacea</td>
<td>Planorbidae</td>
<td>planorba sp</td>
<td>Gastropods</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Lymnaeacea</td>
<td>Thiaridae</td>
<td>Thiara sp</td>
<td>Gastropods</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Neritopsina</td>
<td>Neritidae</td>
<td>Vittina sp</td>
<td>Gastropods</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Total Number of Macro-benthic invertebrates for each sampling station 4568  7385  12526
**Table 4:** Relative abundances (%) of macro-benthic invertebrates by species in the study area of lower Sabaki River, Kenya during December 2015 through February, 2016.

<table>
<thead>
<tr>
<th>Macro-benthic invertebrates</th>
<th>Number of individuals</th>
<th>Relative abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Palaemon</em> sp</td>
<td>24310</td>
<td>99.39</td>
</tr>
<tr>
<td><em>Potamonautes</em> sp</td>
<td>46</td>
<td>0.19</td>
</tr>
<tr>
<td><em>Dixida</em> sp</td>
<td>13</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Hesperocorixasp</em></td>
<td>10</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Chironomus</em> sp</td>
<td>9</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Psephunus</em> sp</td>
<td>9</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Simulium</em> sp</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Cybaie</em> sp</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td><em>Epicordulia</em> sp</td>
<td>6</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Aeshna elliot</em></td>
<td>5</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Centroptilum tuteolum</em></td>
<td>5</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Ephemeraldia</em> sp</td>
<td>5</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Gyrinus</em> sp</td>
<td>5</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Diaphanosoma</em> sp</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Vitinaasp</em></td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Aphylla</em> sp</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td><em>Amphinemura sulcicollis</em></td>
<td>3</td>
<td>0.01</td>
</tr>
<tr>
<td><em>Thiara</em> sp</td>
<td>3</td>
<td>0.01</td>
</tr>
<tr>
<td><em>Lymnaea</em> sp</td>
<td>3</td>
<td>0.01</td>
</tr>
<tr>
<td><em>Physa</em> sp</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td><em>Planorba</em> sp</td>
<td>1</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Figure 2: Relative abundance (%) of Macro-benthic invertebrates by numbers in the sampling stations of the lower Sabaki River during the Sampling period.
Table 5: Grouping of macro-benthic invertebrates sampled from Sabaki based on their water pollution tolerance

<table>
<thead>
<tr>
<th>Pollution Sensitivity</th>
<th>Order</th>
<th>Species</th>
<th>English name</th>
<th>St. 1</th>
<th>St. 2</th>
<th>St. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollution intolerant</td>
<td>Plecoptera</td>
<td><em>Amphinemura sulcicollis</em></td>
<td>Riverflies</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pollution intolerant</td>
<td>Ephemeroptera</td>
<td><em>Habrophlebia fusca</em></td>
<td>Riverflies</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pollution intolerant</td>
<td>Ephemeroptera</td>
<td><em>Centroptilum tuteolum</em></td>
<td>Mayflies</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pollution intolerant</td>
<td>Ephemeroptera</td>
<td><em>Ephemera sp</em></td>
<td>Mayflies</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pollution intolerant</td>
<td>Coleoptera</td>
<td><em>Psephunus sp</em></td>
<td>Water penny Beetles</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Odonata</td>
<td><em>Epicordulia sp.</em></td>
<td>Dragonflies</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Odonata</td>
<td><em>Aphylla</em></td>
<td>Dragonflies</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Coleoptera</td>
<td><em>Gyrinus sps</em></td>
<td>Whirligig Beetles</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Odonata</td>
<td><em>Aeshna elliot</em></td>
<td>Dragonflies</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Coleoptera</td>
<td><em>Dytiscus sp</em></td>
<td>Diving Beetles</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Cladocera</td>
<td><em>Diaphanosoma</em></td>
<td>Water fleas</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Diptera</td>
<td><em>Simulium sp</em></td>
<td>Black fly</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Decapoda</td>
<td><em>Palaemon sp</em></td>
<td>Caridean Shrimp</td>
<td>12450</td>
<td>7340</td>
<td>4520</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Decapoda</td>
<td><em>Potamonautes sp</em></td>
<td>Crab</td>
<td>15</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Aranea</td>
<td><em>Cybaie sp</em></td>
<td>Water spider</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Lymnaeacea</td>
<td><em>lymnaea sp</em></td>
<td>Gastropods</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Lymnaeacea</td>
<td><em>Physa sp</em></td>
<td>Gastropods</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Lymnaeacea</td>
<td><em>planorba sp</em></td>
<td>Gastropods</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Neritopsina</td>
<td><em>Nerita sp</em></td>
<td>Gastropods</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Some what Pollution Tolerant</td>
<td>Lymnaeacea</td>
<td><em>Thiara sp</em></td>
<td>Gastropods</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pollution tolerant</td>
<td>Hemiptera</td>
<td><em>Hesperocorixa</em></td>
<td>Water Boatman</td>
<td>7</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Pollution tolerant</td>
<td>Diptera</td>
<td><em>Chironomus sp</em></td>
<td>Midge</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Pollution tolerant</td>
<td>Diptera</td>
<td><em>Dixida sp</em></td>
<td>Midge</td>
<td>8</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
4.3.2. Species Diversity Indices

From the species diversity indices results in Table 6, Margalef’s species richness index ($D'$) values were highest at St.-3 ($D'$=2.01), followed by St.-2 ($D'$=1.57), and St.-1($D'$=1.19). Species diversity based on the Shannon-Weiner Index followed a similar pattern, with highest diversity at St.-3($H'$= 0.07) followed by St.-2($H'$=0.05) and St.–1 ($H'$= 0.04). However, the species evenness based on Pielou index ($J'$) was highest in St.-3 ($J'$= 0.05), followed by St.-2 ($J'$=0.07) and lowest in St.-1 ($J'$= 0.09).

Table 6: Macro-benthic invertebrate species diversity in the Study area of lower Sabaki River, Kenya during December 2015 through February, 2016

<table>
<thead>
<tr>
<th>Diversity</th>
<th>St.-1</th>
<th>St.-2</th>
<th>St.-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Individuals (N)</td>
<td>4568</td>
<td>7385</td>
<td>12526</td>
</tr>
<tr>
<td>Number of Species (S)</td>
<td>11</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Species Richness using Margalef’s Index ($D'$)</td>
<td>1.19</td>
<td>1.57</td>
<td>2.01</td>
</tr>
<tr>
<td>Shannon’s -Wiener Diversity Index ($H'$)</td>
<td>0.04</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Pielou’s Species Evenness index($J'$)</td>
<td>0.05</td>
<td>0.07</td>
<td>0.09</td>
</tr>
</tbody>
</table>

4.3.3. Principal Component Analysis

The results of the Principal component Analysis (PCA) for the physico-chemical parameters are shown in Table 7 while the Eigen analysis of the correlation matrix (Eigenvalues and proportion for each significant PC) is shown in Table 8. From this analysis, two principal Components-PC-1 and 2 were identified based on the scree plot analysis (Figure 3). The two PCs 1 and 2 account for the parameters that explained the water quality in the three sampling stations and represent 100% of the total variation. The PC-1 explained 77% of the total variation between the sampling stations and comprised the parameters temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, pH and all the nutrients (NH$_4$-N, NO$_3$-N, NO$_2$-N, and PO$_4^{3-}$-P). The remaining 23% of the variation was explained by PC- 2 and included only the parameters DO, pH and three nutrients (NO$_3$-N, NO$_2$-N, and PO$_4^{3-}$-P). The
bi-plot of the first and second principal components as indicated by figure 4 showed that St.-1 was mainly characterized by TDS, E.C, PO$_4^{3-}$, NH$_4$, Salinity and Temperature. St.2 was attributed to NO$_3$-N, NO$_2$ and pH while St.-3 was mostly influenced by D.O.

Table 7: Principal Component loading matrix indicating loadings of Physico-chemical parameters on significant Principal Components (PCs)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PC-1</th>
<th>PC-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>0.323</td>
<td>-0.001</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>-0.323</td>
<td>0.062</td>
</tr>
<tr>
<td>Salinity</td>
<td>0.323</td>
<td>-0.001</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>0.318</td>
<td>-0.257</td>
</tr>
<tr>
<td>pH</td>
<td>0.305</td>
<td>0.513</td>
</tr>
<tr>
<td>TDS</td>
<td>0.313</td>
<td>-0.376</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.305</td>
<td>-0.515</td>
</tr>
<tr>
<td>Nitrites</td>
<td>0.310</td>
<td>0.434</td>
</tr>
<tr>
<td>Nitrates</td>
<td>0.318</td>
<td>0.267</td>
</tr>
<tr>
<td>Phosphates</td>
<td>0.323</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Table 8: Eigen analysis of the Correlation matrix for the significant Principal Components (PCs)

<table>
<thead>
<tr>
<th></th>
<th>PC-1</th>
<th>PC-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>7.7</td>
<td>2.3</td>
</tr>
<tr>
<td>% Proportion</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>% Cumulative</td>
<td>77</td>
<td>100</td>
</tr>
</tbody>
</table>
Figure 3: Scree-plot of Physico-chemical parameters in this study

Figure 4: A bi-plot of the Physico-chemical parameters influencing the distribution of macro-benthic invertebrates in the sampling stations of lower Sabaki River
4.3.4. Correlation between Physico-chemical parameters and Macro-benthic invertebrates

Pearson correlation analysis results as indicated in Table 9 showed that DO positively correlated with Margalef’s $D'$ species richness ($r=0.997; p<0.05$) but species richness was negatively correlated with phosphates $PO_4^{3-}$-$P$ ($r=-0.999; p<0.05$). Pielou evenness $J'$ was positively correlated with phosphates $PO_4^{3-}$-$P$ ($r=1.000; p<0.05$) but negatively correlated with DO ($r=-0.999; p<0.05$). Shannon-Wiener $H'$ species diversity was negatively correlated with nitrites ($r=-1.000; p<0.05$).
Table 9: Correlation of macro-benthic invertebrate diversity indices with Physico-chemical parameters. * Correlation is significant at $\alpha=0.05$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Temp.</th>
<th>D.O</th>
<th>Salinity</th>
<th>E.C</th>
<th>pH</th>
<th>TDS</th>
<th>NH$_4$-N</th>
<th>NO$_3$-N</th>
<th>NO$_2$-N</th>
<th>PO$_4$-3-N</th>
<th>Shannon</th>
<th>Pielou</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.O</td>
<td>-0.974</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>0.982</td>
<td>-0.999</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E.C</td>
<td>0.939</td>
<td>-0.993</td>
<td>0.987</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>0.990</td>
<td>-0.932</td>
<td>0.945</td>
<td>0.880</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDS</td>
<td>0.908</td>
<td>-0.980</td>
<td>0.971</td>
<td>0.997</td>
<td>0.839</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH$_4$-N</td>
<td>0.866</td>
<td>-0.957</td>
<td>0.945</td>
<td>0.985</td>
<td>0.786</td>
<td>0.996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_3$-N</td>
<td>1.000*</td>
<td>-0.978</td>
<td>0.985</td>
<td>0.945</td>
<td>0.987</td>
<td>0.916</td>
<td>0.875</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$-N</td>
<td>0.996</td>
<td>-0.949</td>
<td>0.961</td>
<td>0.904</td>
<td>0.999*</td>
<td>0.867</td>
<td>0.817</td>
<td>0.994</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO$_4$-3-N</td>
<td>0.983</td>
<td>-0.999*</td>
<td>1.000*</td>
<td>0.987</td>
<td>0.946</td>
<td>0.970</td>
<td>0.944</td>
<td>0.986</td>
<td>0.962</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shannon(H')</td>
<td>-1.000</td>
<td>0.974</td>
<td>-0.982</td>
<td>-0.939</td>
<td>-0.990</td>
<td>-0.908</td>
<td>-0.866</td>
<td>-1.000*</td>
<td>-0.996</td>
<td>-0.983</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pielou (J')</td>
<td>0.982</td>
<td>-0.999*</td>
<td>1.000</td>
<td>0.987</td>
<td>0.945</td>
<td>0.971</td>
<td>0.945</td>
<td>0.985</td>
<td>0.961</td>
<td>1.000*</td>
<td>-0.982</td>
<td></td>
</tr>
<tr>
<td>Margalef's $D'$</td>
<td>-0.989</td>
<td>0.997*</td>
<td>-0.999</td>
<td>-0.980</td>
<td>-0.185</td>
<td>-0.960</td>
<td>-0.930</td>
<td>-0.992</td>
<td>-0.972*</td>
<td>-0.999*</td>
<td>0.989</td>
<td>-0.999</td>
</tr>
</tbody>
</table>
CHAPTER 5: DISCUSSION

5.1. Physico-Chemical Parameters

The water temperature recorded in the three sampling stations during the study period was relatively high. The increased in water temperature could be attributed to the weather associated with the dry conditions running from November through February, reduced water current flow and minimal cloud cover which resulted to increased solar irradiation. The higher water temperature was consistent with similar results from Karanja (2011) who noted that high temperatures were normal during the hot and dry months of September to March which are associated with the Savannah and coastal ecosystems, the environment in which Sabaki River is found. In addition, the uppermost station (St.-3) generally recorded lower temperature and this could be attributed to the presence of vegetation cover that limited direct solar radiation reaching the water thus contributing to small fluctuations of temperature.

Dissolved oxygen concentrations of St.-3 were higher than the minimum amount needed for survival and functioning of biological communities, 5 mg/L as indicated by Chapman and Kimstach (1996) while those in St.-1 were lower. The decline in the D.O at the downstream site (St.-1) could be attributed to the high organic load from the anthropogenic activities including animal droppings from the animal watering and disposed household wastes which require oxygen during decomposition hence explaining the low D.O values at this site. In the lower Qua Iboe River, Okorafor (2011), explained that depletion of D.O was due to increase amounts of organic loads which required high levels of oxygen for chemical oxidation, decomposition or breakdown.

Higher electrical conductivity values at the downstream site (St.-1) may be associated with physical disturbances within the riparian area. Busulwa and Bailey (2004) noted that the watering of herds of livestock could also have contributed to some form of organic pollution due to excretory waste they deposit into the water. A study conducted by Dow and Zampella (2000) explained that organic loading increases river water ionic concentrations and
subsequently the levels of conductivity in addition the reduced river discharged volumes resulted to less dilution of solutes hence increasing the ionic concentrations. Total Dissolved Solid (TDS), which is a measurement of inorganic salts, organic matter and other dissolved materials in water and closely associated with EC also recorded higher values at St.-1 compared to St.-2 and St.-3. This suggests that St.-1 has higher increased deposition of ions and nutrients from the agricultural activities and river bank erosion caused by watering of animals along the river shores and deforestation on the river bank. Water pH is the measure of alkalinity or acidity and influences many chemical and biological processes in water (Vyas and Bhawsar, 2013). In this study, the pH ranged from 7.9 to 8.0 with very little variation among stations, and was within the permissible range for natural waters (USEPA, 2002; Mehari et al., 2014). This pH range is also good for aquatic organisms (Oso and Fagbuaoro, 2008) and falls within the EPA Redbook recommended range for fresh waters (6.5-9.0) as reported by Schmitz (1996).

Ammonia concentration in the sampled stations of the lower Sabaki River varied between 0.00 and 0.18 mgL⁻¹. St.-1 recorded higher values (0.15±0.04 mgL⁻¹) and this is attributed to increased livestock droppings and urine deposited into the River by the livestock that come to drink water, nutrient concentration owing to runoff from the disturbed stream bank. Karanja (2011) noted that nutrients concentrated in reduced quantity of water. The concentration of nitrates in the sampling sites was below the limit (5mgL⁻¹) above which nitrate pollution reported to cause adverse effects on aquatic ecosystem (Admasu, 2007). The records of all these sites were within the acceptable limits (EPA, 2003) standard of 10mgL⁻¹. Phosphates concentrations were higher at St.-1 and this could be attributed to the use of phosphate fertilizers in the nearby farms, phosphate-based detergents and soaps during washing and bathing (Davies et al., 2009) as well as the accumulation of livestock dung (Schmitz, 1996). However, nitrites levels were lower, ranging between 0.01 and 0.12 mgL⁻¹. These low levels of
nitrites maybe due to the fairly well oxygenated shallow waters resulting in oxidation of most of the nitrites to nitrates.

The results of the Principal Component loading matrix (Table 7) indicated that both PC-1 & PC-2 were mainly driven by pH, nitrites, nitrates and phosphates which indicated that the pollution was more likely of agricultural origin. Both components showed positive loadings in physico-chemical parameters which are related with agricultural pollutants and domestic activities. This is supported by Carpenter et al. (1998) who reported that nitrates, phosphates and nitrates are the common nutrients associated with sediments from agricultural fields and is easily discharged to the water through soil erosion.

The bi-plot analysis as indicated in Figure 8 associated St.-1 with TDS, E.C, ammonia, phosphates, temperature and salinity. This association can be explained by the numerous anthropogenic activities taking place in this station ranging from washing of motor bikes, clothes and bathing using phosphates related detergents which are a source of phosphates, Animal droppings and urine from the livestock that come to drink water are a source of ammonia and organic materials. On the other hand, St.-2 was associated with nitrates, nitrites, pH and, which suggests the influence of the agricultural activities taking place in this sampling station. The uppermost site; St.-3 was associated with dissolved oxygen because of the low level of anthropogenic influence at this site.

5.2. Macro-Benthic InvertebratesComposition, Abundance and Diversity

The higher abundance and species richness of macro-benthic invertebrates recorded at St.-3 may be attributed to the fact that the station is located in an area with a few human activities, well vegetated, reducing inputs of erosion-based pollution into the River. Additionally, the presence of vegetation at this station is also a good source of allochthonous material which is utilized as food and micro-habitats for a variety of macro-benthic invertebrates and may therefore account for the higher abundances of pollution sensitive organisms.
Such findings have been reported by Ogbeibu and Egborge 1995 that river ecosystems devoid of significant human disturbances have high biodiversity.

On the other hand, St.-1 recorded the lowest number of organisms with low species richness and diversity as evidenced from the findings (Table 5). This suggests that the site is more impacted by human activities and therefore can only support pollution–tolerant species of macro-benthic invertebrates. Bonzemo (2013) noted that lowland reaches of a river experiences intensive and extensive anthropogenic activities that include removal of riparian vegetation from the river watershed, river bank farming, and conversion to farming and pastureland as well as human settlements. These activities result in rise of river water pollution and increase in environmental stress downstream leading to a decrease in number of macro-invertebrate benthic assemblages making pollution tolerant species more dominant in these sites.

The *Palaemon* sp. was most abundant and was recorded in all the sampling stations with a relative abundance of 99.3%. Spatial distribution of species increased as their relative abundance increased. Therefore, the wider spatial distribution of *Palaemon* sp. in this study is probably due to their survival requirements which include variety of habitat types for feeding, reproduction and refuge throughout their lives (Richardson *et al.*, 2004; Price and Humphries, 2010). The spatial location of these habitats in the river system drives these species to migrate over considerable distances to find scarce or vital resources which are important for their survival and completion of their life cycles. Hence their migrations are also key indicators used in explaining the distribution of stream shrimp species (Covich *et al.*, 1996).

Grouping of macro-benthic invertebrates species according to their pollution sensitivity characteristics was done based on the principle that macro-benthic invertebrates are bio-indicators whose presence, absence provides information about environmental quality of aquatic systems. Pollution-sensitive macro-benthic invertebrates such as Ephemeroptera and Plecoptera were well represented at St.-3 but the numbers decreased at St.-2, and were virtually
absent in St.-1 suggesting highly impaired ecological condition at this site. The higher level of pollution at St.-1 is indicated by the lower D.O levels and higher levels of nutrients (nitrates and phosphates). Similar study findings by Allan (2004) noted that streams that receive inputs from agricultural runoff were likely to have elevated nutrients concentrations resulting in increased primary production which depletes D.O concentrations especially in the early morning hours, explaining the absence of pollutant sensitive Ephemeroptera, and Plecoptera species. Lack of aquatic vegetation in St.-1 which limits the availability of diverse microhabitats may also have contributed to the absence of these macro-benthic invertebrates at the site.

Pollutant-tolerant organisms such as dipteran *Chironomus* sp were abundantly represented in St.-1 but absent in the St.-2 and St.-3 confirming less pollution at these upstream sites. This observation concurs with study findings by Mehari et al. (2014) who noted that most dipteran larvae were able to survive lower oxygen conditions because of the presence of hemoglobin which enables them to survive and remain abundant in waters of relatively poor quality. The abundance of pollution-tolerant species such as *Dixida* sp. and *Simulium* sp. in St.-1 could also be attributed to the fact that most pollution tolerant organisms contain high glycogen content and exhibit limited migrations which adapts them to increased dissolved salts/ion levels in such habitats (Camargo et al., 2004). Additionally, the pollutant-tolerant family Corixidae was more abundant in St-1 suggesting that the species can survive in waters depleted of dissolved oxygen since they easily float to the surface of the water. According to Galbrand et al. (2007), Corixidae are not dependent on DO from the water column because they are able to breathe air from air bubbles under their wings on the surface of the water.

Shannon-Wiener diversity ($H'$) was highest at St.-3 decreasing through St.-2 to St.-1, a confirmation that the density of macro-benthic invertebrates decline as the level of pollution and nutrient enrichment increased.
This is supported by Raburu et al. (2014) who noted that a lower value of the diversity index is generally interpreted as a characteristic of polluted conditions in an area making a few tolerant organisms dominant. Consequently, the less polluted St.-3 reflected higher relative abundance, species richness and diversity which are closely linked to better habitats often characterised by higher DO levels, availability of food and lower nutrient concentrations (Bonzemo, 2013).

Pielou evenness index ($J'$) was higher in St.-3 and lower in St.-1 suggesting a more homogenous distribution of individuals in St.-3 compared to St.-1 and St.-2. In all the sites, the overall Pielou evenness index ($J'$) was <1.0, which was attributed to the fact that the benthic community was mainly dominated by only a single species; *Palaemon* sp. which was also widely distributed at all the sampled sites. This low evenness on the distribution of the macro-benthic invertebrates is a confirmation of the presence of stressors in this river system as reported (Mehari et al., 2014).

Margalef’s species richness index ($D'$) was higher at St.-3 and decreased towards St.-1 which was reflective of the trend in anthropogenic influence at these sampling sites. Similar findings by Barnes (2010) noted that human disturbances are determining key drivers of the level of species richness. Therefore, the low species richness at St.-1 was attributed to increased human activities at this site compared to St.-2 and St.-3 where there was little anthropogenic influence.

5.3. Correlation between Physico-chemical parameters and Species Diversity

Pearson correlation analysis indicated that dissolved oxygen, phosphates, nitrates, nitrites were the key parameters that influenced species richness, diversity and evenness of the macro-benthic invertebrates of the lower Sabaki River.
The weak correlation between the parameters and the macro-benthic indices especially at St.-1 were attributed to the physiological adaptations of the pollutant-tolerant species to the unfavorable environmental conditions in the lower reaches of the Sabaki River as was reported by Tyokumbor et al. (2002) in which weak relationships between diptera, odonata and Mollusca to water temperature was reported. This is an indication of the variable ability of the macro-benthic species to survive, adapt and/or migrate under favorable or unfavorable environmental conditions.
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The purpose of this study was to determine the ecological integrity of the lower Sabaki River using macro-benthic invertebrates. It is evident from this study that there is a linkage between the physico-chemical conditions and the macro–benthic community structure of the lower Sabaki River. Therefore, study concluded the following findings: those sites with degraded water quality conditions had higher values of TDS, E.C, phosphates and nitrates. Low water quality negatively impacted the distribution of macro-benthic invertebrates with pollutant-tolerant groups dominated sites with highly disturbed water quality. Macro-benthic invertebrate species composition and abundance was highest in study sites with minimally disturbed water quality. PCA analysis, PC1 & PC2 showed a positive loading for pH, nitrites, nitrates and phosphates indicating that they are the key drivers of water quality in the lower sabaki river. Similarly, these parameters had a significant influence on the species richness, diversity and distribution of the macro-benthic invertebrates based on Pearson correlation analysis. Hence the integrity of the Lower Sabaki River can be assessed using the macro-benthic invertebrates; correlated well with physico-chemical parameters.

6.2. Recommendations

1. This study was carried out during the dry season when the flow rates were low; there is a need for a similar study to be carried out during the rainy season when the flow rates have increased. This would assess seasonal variation as well as pollution effects with increased water flow.

2. Human activities along the river bank and disposal of wastes should be managed as possible
3. A buffer zone should be created through reforestation of the riverine areas of the lower Sabaki river to allow for the growth of riparian vegetation which can take up some of the water pollutants and hence reduce water quality degradation and restore its quality.

4. Public awareness forums should be organized in which the local community get awareness on the effects of pollution and the importance of conserving fresh water resources.
REFERENCES


APHA - (American Public Health Association) (2012), Standard methods for the examination of water and waste water. 22nd ed. APHA, Washington DC, USA.


APPENDICES: Measurement of Physico-Chemical Parameters, Sampling of Macro-Benthic Invertebrates and Laboratory Analysis

Plate 1: YSI Probe meter used for measuring physico-chemical parameters

Plate 2: Calibration of YSI probe meters in the Laboratory

Plate 3: Field recording of physico-chemical parameters at the Sabaki River

Plate 4: Sampling for macro-benthic invertebrates at the Sabaki River using a scoop net
Plate 5: Sorting of macro-benthic invertebrates samples in the field

Plate 6: Preservation of macro-benthic invertebrates samples in 70% ethanol

Plate 7: Washing of macro-benthic invertebrates to remove traces of ethanol

Plate 8: Sorting for macro-benthic invertebrates
Plate 9: Identification of macro-benthic invertebrates using a microscope

Plate 10: Collection and fixing of water samples using mercury chloride

Plate 11: Auto analyser machine used to analyse water samples for nutrients

Plate 12: Auto analyser machine in operation