POLLUTION STATUS OF GBALEGBE RIVER, DELTA STATE, NIGERIA

BY

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ABSTRACT

Pollution of inland waters, limits their contributions to fish food supply. Regular monitoring of water quality in Nigeria is germane to aquatic pollution management. However, information on pollution dynamics, of highly anthropogenic impacted Gbalegbe River is limited. Therefore, the pollution status and its impact on physical, chemical, and biological parameters of Gbalegbe River, Nigeria were investigated.

Gbalegbe River (12.5 km)was spatially stratified into eight stations (S1 – low human activities; S2 – glass production factory; S3 – power plant; S4 – rubber processing mill; S5 – Oil farm tanks; S6 – Automechanic shops; S7 – Cassava processing mill and S8 – Sand mining) based on proximity to key anthropogenic activities. In each station, three sampling points were randomly selected. Temporal stratification covered wet (March - October) and dry (November – February) seasons. Water, sediments, Phytoplankton, Zooplankton and Benthic Invertebrates (BI) samples were collected from each station forth-nightly for 24, months following standard methods. Fish samples were collected from local fishers. Water samples were analysed for Dissolved Oxygen (DO, mg/L), Temperature (^{o}C) and Biological Oxygen Demand (BOD, mg/L) using standard procedures. Phytoplankton, Zooplankton, BI and fish samples collected were counted and identified to species level. Diversity indices such as Shannon-Weiner (H) and Evenness (E) were calculated. Heavy Metals (HM) - Copper, Chromium and Lead in water (mg/L) and sediment (mg/Kg) were assessed using standard procedures. Pollution indices: Modified degree of Contamination in sediment (mCd): < 1.5 (very low) to ≥ 32 (very high) and Geo-accumulation index (I-geo): 0 (unpolluted) to ≥ 5 (extremely polluted) were determined to assess HM contamination level. Data were analysed by using descriptive statistics and ANOVA at $\alpha_{0.05.}$

The highest (4.52±0.56) and least (3.13±0.67) DO were obtained in S1 and S2, respectively. Temperature and BOD ranged from 24.28±5.84, 28.45±2.06 (S3 and S2) to 0.65±0.03, 1.59±0.69 (S1 and S2), respectively. Temperature values were 27.55±1.60, 26.94±1.97; DO (5.75±0.73, 4.00±0.66) and BOD (1.10±0.67, 1.38±0.71) in dry and wet seasons, respectively. Individual number and species of phytoplankton recorded were 928, 25; Zooplankton (5,545; 23); BI (14,675; 22) and fish (14,308; 32), respectively. Highest and least dominant Phytoplankton were *Pseudo – Nitzschia autralis* (6.9%), *Tchophyton ajelloi* (0.1%); Zooplankton: *Diaptomus* species, (3.1%), *Harpacticoid copepods* (0.4%); BI: *Hesperocorixa castanea* (4.1%), *Gyrinus* species (0.3%) and fish: *Clarias anguillaris* (9.6%),

Malapterurus electricus (0.3%), respectively. Diversity indices were: for phytoplankton H=3.61, 2.07; E=0.83, 0.17; zooplankton (H=3.81, 2.27; E=0.72, 0.41); BI (H=3.74, 1.99; E=0.73, 0.29) and fish (H=3.10, 1.99; E=0.71, 0.35) in wet and dry seasons, respectively. Highest and least significant levels of Copper (0.19±0.03, 0.11±0.02); Chromium (0.78±0.13, 0.03±0.01) and Lead (0.25±0.12, 0.10±0.01) in water were recorded in S2 and S1, respectively. Copper in sediment ranged from 0.07±0.02 to 0.19±0.04; Chromium (0.06±0.02 to 0.34±0.01) and Lead (0.03±0.01 to 0.08±0.02) in S2 and S1, respectively. The mCd was 0.15 while I-geo for Copper, Chromium and Lead were (0.02, 0.04); (0.03, 0.06) and (0.97; 0.02) in dry and wet seasons, respectively.

Gbalegbe River is fairly polluted with Lead, however, heavy metal contamination is generally low, thus its rich biodiversity could be threatened.

Keywords: Inland water, Gbalegbe River, Aquatic sediment, Biodiversity, Aquatic pollution.
Word count: 493.

CERTIFICATION

This is to certify that, this research work was carried out under my supervision, by Mr Jacob Somorhire EWUTANURE in the Department of Aquaculture and Fisheries Management, University of Ibadan, Nigeria.

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DEDICATION

This Thesis is dedicated to Jesus Christ, the one who watches over me in His mercy and in whom there is no impossibility; my wife, Mrs Victoria K. Ewutanure and my children: Master Winner Oghenekparobor and Miss PraiseGod Dorcas Ejiroghene, whose actions always remind me of hard-work. Also my parents for bringing me into this world to fulfill God's plans.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Aquatic Pollution

Pollution is the undesirable alteration of the environmental quality, due to anthropogenic activities and nature (Adeyemi *et al.,* 2011). Water constitutes 75% of the earth (Joseph and Raj, 2011). It has been reported that, the presence of pollutants in surface water negatively impact aquatic biota. Hamed(2011) reported that streams and rivers help in themovement and distribution of eroded materials along their courses. These substances could be harmful to the environment, man's health, aquatic organisms as well as serve as distortion to the activities of fishers. Increased urbanization and agricultural activities have adverse effects on surface waterand their biological production (Olowu *et al.*, 2012).

Aquatic habitats are used as channels of waste disposal (Adebayo *et al.,* 2007). Pollution of water is a global phenomenon and a worldwide reason of death and diseases (Adewolu *et al.,* 2009). The stress (as a result of the presence of aquatic contaminants) exerted on water courses, is borne by the biological communities within them, such as fish, macro-invertebrates, plankton and other aquaticbiota.

1.1.1 Aquatic ecosystems in Nigeria

Nigeria has total terrestrial and aquatic areas of 923,787sq/km; 918,869sq/km and 12999.87sq/km respectively (Udo, 1978).It has a coastline of 847.87 km into the Atlantic Ocean. It is located between latitudes 4°14' and 13°8'N and longitudes 2°21' to 14°31'E (Ince *et al.,* 2005). Its land size in the coastal area is 27899.78sq/km. From East to West, it has a length of 1,199.68 km, but between North and South, its distance is 999.97 km (Taiwo *et al.*, 2012). Nigeria coastal region is made up of lagoons, tidal channels, mangrove swamp forest and freshwater swamps forest (Balogun and Ajani, 2015).

1.2 Global oil pollution problems

1.2.1 Catastrophic oil spill in the Gulf of Mexico

British Petroleum (BP) spill took place on 20 April, 2010 (Jervis and Levin, 2010). This explosion killed eleven people (Robertson and Krauss, 2010). It was rated as the highest aquatic oil pollution since the beginning of the petroleum extraction companies. It was reported that, the spill was about 31% greater than that of the Ixtoc I spill. A total of about 4.9 million barrels were reported to have been spilled (BP, 2010). The well was eventually sealed on 19 September, 2010. But some leakages from the well were reported in 2012 (Jahasz, 2012).

Due to the explosion and leakages, adequate control response was adopted to keep the keep the surrounding wetlands, estuaries and beaches from the spreading oil by using skimmer ships, floating booms, controlled burns and 1.84 million gallons of oil dispersant (Plate 1.1) – (Viegas, 2010). Moreover, due to the long periods of spillage and burns, damages to the aquatic environment and its biota were reported (Plate 1.2) – (Juhasz, 2012). It was observed that, dolphins and other aquatic organisms die in very high numbers. It was also reported that, young dolphins were dying six times over the projected rate for 2013, while Tuna and Amberjack in contact with the oil spill developed deformities of the hearts (Wines, 2014).

1.2.2 Collision of Iranian oil tanker with Hong – Kong cargo ship

The Iranian Oil Tanker (IOT) and the Hong – Kong Cargo Ship (HKCS) collided on January 6, 2018 (The Telegraph, 2018). It was reported that the IOT was transporting about 960,000 barrels of fuel to South Korea (BBC News, 2018). Shortly after the collision, the IOT caught fire and drifted for a week but latter sank on 14 January, 2018 (Shih, 2018). The 32 crew members on-board were reported to have died (Xiang, 2018).

1.2.3 Burning of the Iranian Oil Tanker

Efforts were made to combat the fire by the South Korea Maritime Police Agency and the United States Naval Authorities (Plate 1.4) (World Maritime News, 2018). The South Korea Mnistry of Ocean and Fisheries (SKMO) reported that, it could take about 4 weeks for the fire to stop burning (Crystal, 2018). The burning IOT drifted to the Exclusive Economic Zone – (EEZ) of Japan 12 January, 2018 (World Maritime News, 2018). It was reported that the IOT drifted about 300km to the Island of Oshima 11 January, 2018 (Samma TV, 2018).

Two dead bodies were reportedly recovered by the life saving crew from a life boat on 13 January, 2018 (Reuters, 2018). The toxic smoke from the burning IOT prevented the rescue team from effectively doing their job (Bland, 2018). It was reported by the China Ministry of Transport (CMT) that the wreck IOT was found at a depth of 115m in January, 2018 (Tang, 2018). A heavy sleek was reportedly formed on the surface water (Hernandez, 2018). The sleek threatened the lives of the aquatic organisms.

The environmental impact of the exploded IOT was assessed in one of the New York Times, stating that, the place where the explosion took place, was a breeding (spawning) ground for fish at that particular time, as well as the migrating rout of whales (Xiang, 2018). It was equally reported that, the impacts of the aquatic pollution originating from this incident could extend, because, the wreck was closed to the location of the terrific Kuroshio Current which could enhance speedy and adequate spreading (The Telegrapph, 2018).

1.3 Genesis of petroleum industrial activities in Nigeria

A German company in Araromi, Ondo State started oil exploration in Nigeria in 1908, but could not continue due to the outbreak of World War I (Abowei and Sikoki, 2005). In 1937, Shell D' Arcy (now Shell Petroleum) continued (Abu and Egenonu, 2008). The first crude oil deposit was discovered in Rivers State (Oloibiri) in 1956. It was immediately followed by other oil wells at Afam in 1957, Bomu (in Ogoni land) in 1958 (Abowei *et al*., 2012).

Shell – BP had been operating for about twenty six years, as the only oil company in Nigeria until 1965 when Chevron (formerly Gulf Oil) emerged and started production at Okan (Adati, 2012) while in 1966, ElF and Agip started at Ahaoda, Rivers State. Other multinational companies in Nigeria are: Allied energy; Ashland; Texaco; Exxon – Mobil; Dubril/Philips; Statoil; Pam Ocean; Canoxy and Tenneco (Abowei and Hart, 2009).

Plate 1.1. Gulf of Mexico oil spill and controlled burning
Source: Viegas (2010).

Plate 1.2. Fish mortality due to Gulf of Mexico oil spill
Source: The Telegraph, (2010).

Plate 1.3.The burning Iranian oil tanker (IOT) after collision with the Hong Kong Cargo Ship.

Source: BBC News online, (2018).

Plate1.4. Fire fighting ship extinguishing the fire after Iranian oil tanker collided with the Hong Kong Ship CF Crystal

Source: BBC News online, (2018).

In 1977, the Nigerian National Petroleum Company Corporation was created. As at 1958, Nigeria oil export earning was put at 1% and from 1970 till date, it accounted for about 80% of the total Federal Government Revenue. From the mid-sixties, the petroleum sector became the main stay of the Nigerian economy. In 1958, a commercial quantity of oil was discovered along the Niger Delta vicinity. This greatly increased the output from 100,000 – 200, 000 barrels per day (b/d) in the early – sixties, to a peak of 2.3 – million p/d in 1979 (Abowei and Hart, 2009). As a result of the loss of markets from the Organisation of Exporting Countries (OPEC) and the North Sea competition for Nigerian oil, the production and earnings from oil fell drastically from 1981. The Niger Delta, Eastern and Midwestern parts of the country host the largest oil fields both on – shore and off – shore (Abowei and Sikoki, 2005).

1.4 Niger Delta Region's (NDR) industrial pollution

The 6th oil producing country in the world is Nigeria (Olowu *et al.*, 2012). Her economy relies mainly on the oil sector, while most of the petroleum companies are situated in the Niger Delta Region (NDR). Fishing activities within the communities of the NDR are seriously hampered by petroleum production operations (Majolagbe *et al.*, 2011). It has been reported that,about ten million tonnes of crude oil enter the environment each year from accidental spills, as a result of routine petroleum operation within the NDR. Abowei and Sikoki (2005) observed that crude oil also reduce growth, tissue, and organ damage, in fish and other aquatic organisms. All fish, sediment macro-invertebrates and plankton bioaccumulate pollutants either directly or indirectly from contaminated water and sediments, which may results in massive deterioration, impairment and death of aquatic flora and fauna (Adewuyi and Olowu, 2012).

1.5 Sustainable development goals (SDG)

A total of 194 countries of the UN members met on 25September, 2015 andapproved the 2030 Agenda for Sustainable Development (United Nations Security Council, UNSC, 2015). There were 17 Sustainable Development Goals (SDG) in the Agenda, out of which 3, 6 and 14 arevery keyed to this study. Goal 3 – Good health. Its primary concern is to promote quality life for everyone. The key tool is increased access to clean water and sanitation (UN-SDG, 2015). Goal 6 – Clean Water and sanitation. Its key objective is to ensure availabilityandsustainable management of water for all (UNDP, 2017).

Goal 14 – Life below water.It ensures conservation and sustainable uses of the aquatic resources for sustainable development. This goal, specifically aims at preventing, reducing aquatic pollution by 2025; sustainably manage, protect aquatic coastal ecosystems and regulate overfishing in 2020, respectively (Rao, 2015; United Nations Sustainable Development Goal,UNSDG, 2015). It has been estimated that, 65 million people in Nigerians do not have access to clean water (Majuru *et al.*, 2011). The reason for the shortage was attributed to increased urbanization and anthropogenic activities (Lawal and Basorun, 2015).

1.6 Justification

It has been reported that pollution of inland water bodies due to anthropogenic activities alterstheir quality and ability to support aquatic biota (Adeyemi *et al.,* 2011). However, rivers and streams are used as channels of waste disposal, help in the transportation and distribution of eroded materials along their courses. The presence of pollutants in surface water negatively impacts the flora and fauna community (Hamed 2011). Water pollution is a major global problem and a leading cause of death and diseases (Adewolu *et al.,* 2009).

Consistent water quality monitoring is necessary for the management of surface water pollution so as to safe guard the life of the aquatic resources and the health of man. The assessment of anthropogenic effluents and environmental quality of rivers, streams and lakes had shown elevated levels of pollution stress on aquatic organisms (WHO, 2008). Rivers in Nigeria such as Gbalegbe River are important aspects of the aquatic ecosystem, helping in flood control, storm water drainage and as habitats to aquatic organism, yet they are being destructively exploited in recent times due to the effluents from industrial activities that have rendered the surface water quality unsupportive of its aquatic biota (Nwankwo, 2004a).

Gbalegbe River is the main River flowing through the Ughelli Town, Delta State, Nigeria, in addition to its ecological importance to the inhabitants of Ughelli Town, receives effluents from petroleum industries, glass factory, power plant, sand mining, auto-mechanic workshops, rubber and cassava mills located within and around it, earlier studies carried out on it focused majorly on its socio – economic benefits to the immediate communities, domestic utilization of the water and impacts of sand dredging on government and private infrastructures (roads, bridges and buildings) constructed very closed to it (Ochuko *et al*., 2008).

Regrettably, the people from this area are mainly fishers and crop farmers whose water and lands are being destroyed as a results of anthropogenic effluents. Studies conducted in some inland water bodies around Gbalegbe River were centred on the physico – chemical characteristics of Warri River (Okoye and Iteyere, 2014), Phytoplankton species diversity of Ologbo River (Suleman *et al*., 2015), Zooplankton compositions and abundance of Ekpan River (Iloba and Ruejoma, 2013), Benthic invertebrate species diversity of Ekpan Creek (Olomukoro and Azubuike, 2009), Fish species compositions, abundance and diversity of Warri and Ubeji Rivers (Egborge, 1992; Ogaga *et al*., 2015; Akintoju *et al*., 2013); heavy metal and total petroleum hydrocarbon concentrations in Esi River (Samuel *et al*., 2015).

Others were Flora, fauna and pollution status of: River Niger (Arazu and Ogbeibu, 2017); Imo River (Dike and Adedolapo, 2012); River Ogbese (Olawusi-Peters *et al*., 2014); Great Kwa River (Ada *et al*., 2012) and Bonny Estuary (Ajuonu *et al.,* 2011), but information on the pollution dynamics of highly anthropogenic impacted Gbalegbe River is limited. Therefore, the pollution status and its impacts on physical, chemical and biological parameters of Gbalegbe River, Nigeria were investigated.

1.7 Research questions

Research questions to be answered are as follow:

- What are the spatial and temporal variations in the physico-chemical parameters of Gbalegbe River?
- What are the abundance, diversity of flora and fauna of the Gbalegbe River?
- What are the levels of pollutants (TPH, Ni, Cu, Fe, Cd, Cr, Mn, Zn and Pb) in water, sediments and fauna of Gbalegbe River?

1.8 Objective

The specific objectives were to:

1 Assess the spatial and temporal variations in the physico-chemical parameters of Gbalegbe River;

2 Evaluate the abundance and distribution of flora and fauna composition of Gbalegbe River;

3 Determine the levels of pollutants (TPH, Ni, Cu, Fe, Cd, Cr, Mn, Zn andPb) in water, sediment and fauna of Gbalegbe River;

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Characteristics of inland waterquality

Inland waters are very unstable ecosystem, because they are affected by anthropogenic andnatural activities, as well as wind and water movement (Olaifa, 2004). The monitoring of anthropogenic effluents and environmental adjustment in rivers, streams and lakes had shown elevated levels of pollution stress on aquatic organisms (WHO, 2008). Rivers are important aspects of the aquatic ecosystem, helping in flood control, storm water drainage and as habitats to aquatic organism, yet they are being destructively exploited in recent times Nwankwo, (2004a).

Discharge of domestic and industrial effluents are actions by man which undermine the ecological integrity of river ecosystems (Boyd, 1998). Water quality criteria are developed by experts, and provide basic scientific informationabout the effects of water pollutants on a specific water use (Ogbuagu, 2013). They describe water quality requirements for protecting and maintaining and sustaining aquatic organisms and man.

Water quality criteria are based on indicators that distinguish the quality of the suspended particulate matter, bottom sediment and the biota Nwankwo, (2004b). Maximum acceptable limits are set as criteria which will not be harmful, when thespecific medium is used continuously for a single and specific purpose. For dissolved oxygen, temperature, pH, Alkalinity, and so on,water quality criteria are set at theminimum acceptable concentration to ensure the maintenance of biological functions (Boyd, 1979).

Most industrial processes render the quality of surface water unattractive. Hence, criteria are usually developed for raw water in relation to its useas a source of water for drinking, agriculture, recreation, and a habitatfor biological communities (Adefemi and Awokunmi, 2010). Criteria may also be developed in relation to the functioningof aquatic ecosystems in general (Abowei *et al*., 2012). The protection and maintenance of these water usesusually impose different requirements on water quality and, therefore, the associatedwater quality criteria are often different for each use (Nigeria Industrial Standards, NIS, 2007).

2.1.1 Water quality criteria for Nigeria

The Government of Nigeria promogated a decree to:control, restore and preserve its aquatic environment in 1988. Thisdecree gave the various agencies concerned the right to establish water quality standards to enhance the quality of water for the survival of aquatic resources (NIS, 2007). As a result of paucity of scientific data, FEPA handled this assignment through the reviewing of water quality guidelines and standards of other countries (developed and developing) as well as those of international organisations which were later compared with data available on physico-chemical parameters from Nigeria's waters. Australia, Brazil, Canada, India, Tanzania, United States and those of the World Health Organization (WHO) recorded as standards.

These data were modified and used to produce the short term standards for Nigeria. They were concerned with drinking water, use of water for recreational activities, aquatic lives and anthropogenic effluents disposal (Federal Environmental Protection Agency, FEPA, 1991). According to Gupta (2001), the three basic reasons for water quality analyses were to determine its suitability for drinking (public health);irrigation (agriculture) and for the environment (pollution).

2.1.2 Water quality assessment and monitoring

Biological and chemical methods are used in the assessment of rivers receiving anthropogenic effluents. The most popular biological method is the use of sediment macro-invertebrates. Evidenceshad been established on indicators that are of good relationships between water quality and the presence or absence of certain sediment macro-invertebrates depending on their sensitivities.

For instance, the nymph of Plecoptera (stone fly) – insect family is the most sensitive to organic wastes followed by nymphs of the Ephemeroptera (may fly) (Wu *et al*., 2007). *Tubifex* species survives in an anaerobic condition for weeks. Tubificids have myoglobin, high affinity respiratory pigment used for respiration in oxygen deficient environment. Chironomus larvae have blood gills in addition to myoglobin(Edet and Worden, 2009).

The rat-tail maggot *Eristalis* speciesis found in the most polluted water body, containing organic matter. It extends its air breathing long tail to the surface of the water. *Psychoda* and *Telmatoscopus* larvae are found in fouling drainages and rotting vegetations. Rivers that are polluted tend to lack or have very low numbers of nymphs of Plecoptera and Ephemeroptera, while other benthic groups are present. In moderately polluted rivers, larvae of Trichoptera (caddis fly) and amphipods such as *Gamarus* species are absent or fewer, such as the plecoptera and Ephemeroptera, while heavily organically polluted water, only *Eristalis* sp may be present in abundance.

2.2 Primary productivity

Primary production in rivers is mostly carried out by phytoplankton, phytobenthos and macroalgae in the water column (Balogun and Ajani, 2015). Primary production depends on the process of photosynthesis which involves the utilization of sunlight energy by flora cells in conjuction with water and carbon to produce carbohydrates, thereby releasing oxygen into the atmosphere that is needed at higher trophic levels (Ajibola *et al.,* 2005).

Photosynthesis mainly comprises two reaction processes as: (1) light reaction. This reaction depends on light. It is the processing of sunlight energy to chemical energy and (2) dark reaction. This reaction occurs in the dark and results in the formation of complex compounds. The equation of photosynthesis is stated as:

$$6CO_2 + 6H_2O \xrightarrow[\text{Catalyst}]{\text{Solar radiation}} C_6H_{12}O_6 + 6O_2$$

The chemical conversion of energy is aided by photosynthetic pigments which absorb radiation in the range of 400 – 700nm. The most vital pigments found in the chloroplasts are the chlorophylls, while other pigments associated with the utilization of solar energy are carotenoid, phycobilins and xanthophylls (Alain and Francisco, 2000). The common photosynthetic pigment found in the phytoplankton groups is known as Chlorophyll a.

2.2.1Factors influencing primary production

The most essential factors that determine and limit primary productivity are sunlight energy and nutrients. The quantity and quality of solar energyis vital in the determination of the photosynthetic process in the aquatic ecosystem. Sun light energy fluctuates within the depthof rivers (Bannerjee and Chattopadhyay, 2008).The vital limiting nutrients in any riverecosystem are silicon, phosphorus, iron and nitrogen.

It is generally believed that, if their concentrations decrease, photosynthetic activity will be low, while phytoplankton biomass will also decrease. But when there is a rise in these nutrient levels as a result of upwelling effects, flooding, agricultural runoff from coastal areas and total photosynthesis, phytoplankton biomass usually increase (Balogun and Ajani, 2015).

2.2.2Chlorophylla (Chll a)

Alain and Francisco (2000) observed that, Chll a has four pyrrole groups with which it forms a porphyrin ring with its centre containg magnesium atom. Phytoplankton photosynthesis isrecorded as gross or net. Gross primary production is known as the total rate of CO_2 fixation without considering that, some are dessipated during respiration, while net primary production is the difference between total rate of photosynthetic CO_2 fixation and the rate of loss of CO_2 in respiration.

2.2.3Phytoplankton and their significance to the aquatic environment

Phytoplankton – (phyto – plant; planktos – made to wander) are single celled organism,with some that can moveusing the flagella, while others are drifted by water current. Their sizes are between 1/1000 mm and 2 mm, found in the upper 100m depth of the aquatic ecosystem and make use of sunlight energy during photosynthesis. They are also in needof inorganic chemical nutrients – (phosphate and nitrate) as well as carbon (carbon dioxide).

Phytoplankton generates the neccessary energy for consumer that goes to human. Phytoplankton are 2% of the total biomass globally, produce between 30 and 60% of the yearly fixation of carbon on earth (Wondie *et al.*, 2007) and reduces global warming in river via carbon sequesteration in sediments. Phytoplanktons help in: regulating atmospheric carbon dioxide adequately; serves, as a basis for aquatic food web (Littler, 1973) and,produces aquatic biotoxins which are released into the environment. The species diversityofphytoplankton are used to assess (bio – monitoring) the biological integrity of aquatic ecosystem(Davies *et al.,* 2009).

2.3 Zooplankton

Zooplanktonaremicrposcopic, floating and drifting aquatic organisms with restricted moving ability (Emoyan, 2009). Most of them exist as either unicellular or multicellular forms with different size ranges. Zooplankton species differ in morphological attributes and taxonomic arrangement. Zooplankton play an important role in the study of the fauna species diversity

of aquatic ecosystems. They represent almost all taxa in the animal kingdom which occur in the pelagic environment. Due to the abundance of holoplankton and meroplankton larvae at different depths, zooplankton are used to explain energy transportin secondary trophic level; feed on phytoplankton (Mayon *et al.*, 2006).

Zooplankton occurrence and distribution play a major role in pelagic fishery potentials. Fishes breed mostly in water body that have high abundance of planktonic organisms to be sure of adequate food supply to their young ones for survival and growth (Tamuno, 2005). Zooplanktons are more diverse than phytoplankton in river ecosystems and this is caused mainly by patchiness, diurnal vertical migration and seasons.

2.3.1 Characteristics of zooplankton

Zooplanktons are taxonomically classified into three groups (Jeje and Fernando, 1986) which include: rotifers. It is the smallest of all the zooplankton, has very soft body, grouped with size range of 100 – 200µm, possess cilia for movement, have the shortest life cycle among the zooplankton, e.g *Brachionus calyciflorus* serve as a vital feed for starter diet in fish larvae rearing; cladocera. Are generally referred to as water fleas, size range from 0.2 – 3.0mm (200 – 3000µm), peak reproductive period range from 14 – 15 days, eg *Moina* sp and *Daphnia* sp are used in the feeding of fish larvae and in bioassay research (Ovie and Ovie 2014) and copepoda. They are divided into three suborders which are (1) Calonoida, (2) Cyclopoida and (3) Harpacticoida. They reach sexual maturity in 18 days, have 24 days of peak reproductive period, lifespan is about 50 days, distinguished by the general structure of the first antennae, urosome and fift leg. Three suborders of the rotifer, cladocera and copepoda were identified.

2.4 Sediment macroinvertebrates

Sediment macro-invertebrates are organisms which are seen with unaided eyes (Xiaodong *et al.,* 2010). They are found in all aquatic ecosystems such as: river, ponds, lakes, streams and so on (Benson e*t al.* 2007). Some of them live most of their life cycles attached to substrates. Benthic organisms exist either as bacteria, phytobenthos or zoobenthos at various stages of the food web. Benthic invertebratesare classified according to size viz: microbenthos–has size of <0.063 mm; meiobenthos – with size range of 0.063–1.0 (or 0.5) mm; macrobenthos – has a size of >1.0 mm (Sediment macro-invertebrates) and megabenthos – with of > 10.0 mm (Water ECOscience, 2003).

Sediment macro-invertebrates can be distinguished due to the position they are locatedin or on sediments as: infauna - livesinside bottomsediments (examples, polychates and bivalves) and finally and epifauna – resides on sediments' surface (examples, crabs and gastropods).According to Water Framework Directive (2010), the most studied fauna speciesin surface water include: fish; planktons and macro-invertebrates.They are studied because, the levels of pollution tolerance differs among them. Therefore, if more pollution tolerant species are found in a river, it is and indication of an aquatic pollution,as most sensitive species disappeared (Australian and New Zealand Conservation Council, ANZECC, 2000).

Essentially, sediment macro-invertebrates are good indicators of river quality (Freund and Petty, 2007). This is because they: easily respond to the effects of the physical, chemical and biological changes;are seriously affected by the impacts of contaminants; are used to detect level of pollutant in surface water; they are used to found out the extent of pollution which physic-chemical parameters could not detect; act as very an essential components of river's ecosystem; are of ease to sampling and identification and many are sessile.

2.4.1 Sediment macro-invertebrate variables

Species diversity isan important factor, because it determines how sediment macro-invertebrates respond to decline in water quality. Significantly, increasedvariations in the individualnumber of taxa diversity, abundance, percentage contribution of Ephemeroptera, Trichoptera and Odonata (ETO taxa) are useful indicators of biological significance and sensitivity, in the study, detection and management of aquatic pollution (Rawson*et al.* 2010).

2.4.2 Usefulness of sediment macroinvertebrates in a water body

Utah State Water Plan(2010) reported that, the endangered wetland ecosystems in Nigeria are gradually being tended, due to the recent awareness of the usefulness of sediment macroinvertebrates which have been proven to be very essential in the determination of current state of aquatic systems. The orders – Emphemeroteran, Plecopteran and Trichopteran were generally found to be highly present in healthy surface water.

Arimoro, (2008), reported that, sediment macroinvertebrate species are made up of various sensitive apparatus to pollutants, and are widely accepted for the assessment of ecological effects of TPH and heavy metal contamination of rivers, lakes and streams.Metal

contamination reduces sediment macroinvertebrate species richness, density, growth and production (Gray and Delaney, 2008).

2.5 Bio – survey

Bio-survey shows clearly how river ecosystem quality has been impaired. It is also concerned with how habitats are loss, due to pollution (Popoola and Otalekor, 2011). The disadvantage of bio-survey is that, it cannot reveal the true evidence, why certain species of organisms are present or absent (Ǿyvin and Harper, 2001). The major habitats for macro-invertebrates in a river are as follow: bed sediments; rocks at the bottom of the river; aquatic macrophytes wthin the river; litter of leaves and submerged logs of woods (Popoola and Otalekor, 2011).

2.6 Bio-monitoring

The study of macro-invertebrates in a river's sediments and their responses is known as biological monitoring (Jiang *et al.,* 2008). It is applied in theevaluation of the integrity of ecosystems of river(Water ECOscience, 2003). One type of bio-monitoring is the biological survey (bio-survey). Bio-monitoring is a process of continous observation, measurement and evaluation of indicators of environmental degradation, according to pre-arranged schedules in space and time for the purpose of environmental management. Bio-monitoring involves the collection, processing and analyses of aquatic flora and fauna to evaluate the intergrity of aquatic ecosystems (Environtech Monitoring Pty Ltd, 2012). Monitoring could be done daily, monthly, annually or periodically. It provides information on trends and changes of the environmental behaviour, due to anthropogenic and industrial sources of effluents discharge, thereby providing early warning signs so that, protective measures can be taken (Valbo – Jorgensen *et al*., 2009).

2.6.1 Uses of bio-monitoring and habitat assessment

According to Environtech Monitoring Pty Ltd (2011), bio-monitoring and habitat assessment can be used in: indicatingpolluted stations along the stretch of rivers. It enhances the determination of the causes of habitat degradation; assess the impacts of pollution. Macro-invertebrates move very slowly and are sensitive to different levels of pollutants. Hence, any change in their abundance, clearly indicates the pollution effects of the river; examine the extent of pollution and grades ofstations along river course; enhance the sustainability of aquatic biota. Most countries established specific standards of identifying the concentrations of pollutants allowable limits and evaluation of water quality changes over many years.

2.7 Bio-criteria

Bio-criteria are identifying biological indicators for examining build – up of pollutants from different origin. The quality criteria for the preservation of aquatic biota are based on qualittative indices (Popoola and Otalekor, 2011), while in other countries, sensitive key species are utilized. It has been reported that, sensitive, short-lived and predatory species should be involved (Hollman and Miserendino, 2008).Aquatic fauna serving as contaminant indicators should be: widely spreadwithinthe aquatic environment;collected without difficulty and biomass;able to reproduce itself;able to response to anthropogenic pollutants in identifiable and quantifiable terms;adaptable to laboratory conditions and so on.

2.8 Indicator species

The most suitable species for aquatic bio-monitoring are the benthic macro-invertebrates because their continued absence is an indication of environmental damage to water bodies. Fishes are sensitive, but are highly mobile (Jiang *et al*., 2008). Therefore, biological assessment of the quality of freshwater courses, using benthic invertebrates provides useful advantages. Sediment macroinvertebrates are ubiquitous, inhabit different microhabitats within the river and are affected by all forms of environmental degradation. Basically, sedentary benthic invertebrates are affected by quantitative re-sampling in space and time.

2.9 Nigeria fishery industries

History has it that fishing is a source of food, employment and income in Nigeria, particularly in – the coastal areas (Olaifa, 2015). Despite its significant contribution to the national economic development, fishing has been neglected to the background. The first and second national development plans of Nigeria focussed on increasing domestic fish production for self – reliance, while the third plan aimed at self sufficiency in fish production and the generation of foreign exchange. Nigeria government first attempted to develop her fisheries sub – sector in 1942 but the artisanal fisheries sector had been in existence before then.

2.9.1 Inland freshwater fish species diversity of Nigeria

River Ase is an inland water body in Delta State, Nigeria (Idodo-Umeh, 2003). There are about 511 fish families in Nigeria (Ita, 1993). About 34% of these species are restricted to exclusive economic zone (EEZ) while approximately 44% are freshwater fisheries inhabiting water of very

low salinity (< 1‰). Banks *et al.* (1967) identified about 139 species of fish in River Niger, within the then proposed Kainji Reservoir Basin.

About 160 fish species were recorded in Northen Nigeria (Reed *et al*. 1967). About 181 species of fishwere identified from major rivers, lakes, estuarine and marine ecosystems, in Nigeria (Welman, 1984; Obasohan and Oronsaye 2006). In Lake Chad and the inflowing rivers, 80 species of fish were recorded (Hopson, 1967).A survey conducted in 1985 on the Yobe River, revealed a total of 19 species (Bukar and Gubio, 1985).White, (1965) provided a checklist of about 145 species which covered the upper Niger within the then proposed Kainji Lake Basin. Species of fish identified in Sokoto – Rima, Kaduna and Anambra, as major tributaries of the Niger were low diversity which were22, 28 and 23, species respectively compared with White (1965).

Checklists of 39, 23 and 23 species were identified in Cross River, Ogun and Oshun Rivers respectively. In most cases, the identification of species was limited to genus. A total of 101 and 52 fish species were identified in Kainji and Jebba Lakes respectively. The few number of species recorded in Jebba Lake was ascribed to the post impoundment that brought about slow water current that favoured the behaviour of most cyprinids and cyprinodonts. 108 fish species have been documentedwithin the inland water of Nigeria(Ita, 1993).

2.9.2 Inland fisheries in Nigeria

Fish represents an estimated 40% of the total protein in – take of Nigerians. Nigeria estimated inland water bodies is put at over 14 million hectares (Omorinkoba *et al.*, 2011), and has the capacity to produce over 297,836 million tonnes per annum (Olaifa, 2015). Inland fisheries are the main sources of freshwater fish diversity and serve as sources of protein, essential micronutrients, minerals and fatty acids to man. Unfortunately, some fish species within the Nigeria's freshwater bodies have listed as been endangered due to the negative impacts of aquatic pollution (Table 2.1), (Egborge, 1992; Asiwaju, 2011).

Globally, inland water such as, rivers, lakes, streams, reservoir and ponds contribute significantly to ensuring food security (Youn *et al*., 2014). The inland fisheries resource consists of approximately 40% of all fish species out of which 20% are vertebrate species (FAO, 2015).Generally, out of over 230 countries, 156 highlighted the inland capture fisheries production to FAO in 2010 (Youn *et al*., 2014; Olaifa, 2015). Based on this report, it was observed that, fish compositon and abundance were depleting due to pollution, over fishing and habitat degradation (Raby *et al*., 2011).

Table 2.1. Endangered fish species in Nigeria inland water bodies.

Serial number	Families	Genus/species	Water body
1	Albulidae	*Albula vulpes*	Warri River
2	Amphillidae	*Phractura clauseni*	Ogun River
3	Carangidae	*Trachinotus goreensis*	Niger/Benue River
4	Latidae	*Lates niloticus*	Widespread
5	Cromerridae	*Cromeria nilotica*	Niger/Benue
6	Gymnaichidae	*Gymnarchus niloticus*	Widespread
7	Hepsetidae	*Hepsetus odoe*	Widespread
8	Lepidosirenidae	*Protopterus annectens*	Fair distribution
9	Lutjanidae	*Lutjanus* sp.	River Cross
10	Mastacembelidae	M*astacembelus loennbergii*	Fair distribution
11	Malapteruridae	*Malapterurus electricus*	Widespread
12	Polycentridae	*Polycentropsis abbreviate*	Fair distribution
13	Ophiocephalidae	*Paraophiocephalus Africana*	Oguta Lake
14	Arapamidae	*Heterotis niloticus*	Widespread
15	Pantodoltidae	*Pabtodon butcholzi*	Fair distribution
16	Phracholaemidae	*Phratoleamus ansorgei*	Fair Distribution
17	Synbranchidae	*Synbranchus afer*	Ethiope River
18	Trigonidae	*Trigon margrarita*	Epe Lagoon, Lagos
19	Pristidae	*Pristis perrottetis*	Niger/Benue River
20	Trigonidae	*Potamotrygon garouensis*	Niger/Benue River
21	Monodactylidae	M*onodactylus sebae*	Niger/Benue

Source: Egborge, (1992); Asiwaju, (2011).

Inland fisheries generated about 10 – 12% of the total annual fish production globally (FAO, 2012), while global inland fish production was estimated at 11.9 million tons, out of which Nigeria contributed 354,466 tonnes (Olaifa, 2015). It was estimated that 56 million individuals directly participated in inland fisheries production in 2009 in the developing world (BNP, 2009) out of which 54% were women involved in processing and marketing (Welcomme *et al*., 2010). The Nigeria fisheries sector is divided into three major fishing industries namely: industrial, artisanal and aquaculture sub – sectors.

2.9.3 Artisanal fishery sector in Nigeria

The artisanal sector in Nigeria is the most neglected and under developed sector (Olaifa, 2015). It is characterised by low operative cost, poor application of technology, high labour intensity, low productivity, poor fish distribution network, poor processing methods, high post harvest loss and low revenue generation. In spite of these obstacles, the artisanal sector still serves as the backbone of fish production and supply in Nigeria (Welcomme *et al*., 2010).

2.9.4 Aquaculture sector in Nigeria

Aquaculture growth in Nigeria has been relatively steady in the last three decades. It increased from 16, 119 in 1995 to 313,200 tonnes in 2014 (Olaifa, 2015; FAO, 2016). Aquaculture has the potentials for speedy expansion to filling the the space created by decline in capture fisheries (Williams *et al*., 2007). Irrespective of the fact that there are over 300 indigenous cultivable fish species in the inland water of Nigeria, the predominantly culture fish species is *Clarias gariepinus* (Olaosebikan and Raji, 2013). The development and improvement in aquaculture could only be adequately achieved in a sustainable manner in the culturing of other endemic species.

2.9.5 Industrial fisheries of Nigeria

This sector in Nigeria requires high amount of capital on vessels, nets, cold storage facilities, efficient and effective marketing network, high operational maintenance cost, use of highly trained and skilled man power, advanced technology and foreign exchange. It is both local and international market oriented. Its annual contribution increased from 3.7% in 1990 to 4.71% in 2012 (Olaifa, 2015).

2.9.6 Fisheries resources of Delta State, Nigeria

According to Moses (1986); Olaifa, (2003) the fisheries resources of Delta State can be divided into four major groups, namely: the coastal pelagic fishery. The catches include *Ethmalosa fimbriata* (bonga), *Ilisha africana* (shad), *Sardinella eba*; freshwater fishery. Fish production from the freshwater capture fishery is of a high economic value to the people in the riverine and non – riverine areas, within the the hinterland and outside the state. Some of the main catches include,*Clarias gariepinus, C. anguillaris, Parachanna africana, P. obscura, Oreochromis niloticus, Hemichromis fasciatus, Papyrocranus afer, Xenomystus nigri, Tilapia guineensis, Synodontis clarias, Hemisynodontis membranaceous, Malapterurus electricus, Mastacembelus loennbergii, Phractolaemus ansorgei, Siluranodon auritus, Hepsetus odoe* and *Schilbe uronoscopus*; coastal demersal fishery Some of the catches are *Pseudolithus typpus* and *P. brachygnathus* (croakers); *Chrysichthys nigrodigitatus*; *Arius* sp.; *Cyanoglossus goreensis* (sole); *Luthjanus*sp. (snappers); *Polydactylus quadrifilis* (shiny nose) and the; cray fish fishery. Artisanal fishers harvest large size penaeids and Palaemonids shrimps but the largest crustaceans caught are the tiny *Carideid* shrimps (Palaemonidae) and the juveniles of *Penaeus notialis* that breeds in the sediment rich estuarine and brackish mangrove swamps (Garcia and Roserberg, 2010).

2.9.7 Problems of fishery resources in Nigeria

Globally, surface water bodies are considered the most endangered ecosystem (Eme *et al*., 2014). Therefore, the problems of sustainable inland fisheries resources in Nigeria can be viewed as human and natural. The human angle of inland fisheries sustainability can be considered from the aspect of policy implementation, auditing and sampling, analysis, taxonomy, management, pollution and land reclamation (Asiwaju, 2011). The study of inland fisheries in Nigeria includes wetlands which are under the mandate of the Nigerian Institute for Freshwater Fisheries Research (NIFFR). The laws and regulations governing the exploitation of the inland fisheries resources of Nigeria is very weak. Sometimes, where such laws and regulations (registration and licensing of fishermen, mesh size regulation, gear size regulation, prohibition of the use of poison and explosives, fishing with electricity as well as closed season and area) exist, they are not often enforced (Asiwaju, 2011).

In Nigeria, the management of inland waters is regarded as the exclusive responsibility of the States to which such water bodies belong. Whereas there is a Sea Fisheries Decrees Act of 1971, as well as the relevant Fishery Regulations and the Exclusive Economic Zone (EEZ) Decree of 1978, which enable the Federal Government to control, regulate and protect the sea fisheries resources(Fregene and Olanusi, 2012). Although it could be argued that, these waters are within State boundaries and should therefore be subjected to State Legislation, the waters usually traverse more than one state(Eme *et al*., 2014).

Besides the fact that fish do not recognise state boundaries, migratory fish often enter channels which pass through more than one state. Consequently, action or lack of action by one state can have a profound effect on the fishery resources, and fishing in another State. Moreso, migrant fishermen often cross state boundaries by using unlawful methods to capture fish, and the dumping of poisonous products or industrial wastes in one state, which does not give priority to fisheries, can lead to mass destruction of valuable fishery resources downstream in another State, where fishing may be of high priority.

Drought and predation are two major natural problems. Bukar and Gubio, (1985) reported ichthyofauna biodiversity changes as a result of drought in Lake Chad, Nigeria and inferred that, the decrease in the Lake water level led to an increased temperature, nutrient, pH, decreased dissolved oxygen, competition, fish mortality and decomposition.

2.10 The coastal environment

The coastal areas are referred to as the interface between three habitable media, namely: the earth, air and sea. All coastalareas conatin at least two habitats, namely: the maritime zone (contain terrestrial animals and plants) and the sea it self (Olaifa, 2003). The materials eroded along the coastline are transported in water and are determined by the particle sizes. Water movement plays a major role in coastal topography. The five main water currents associated with water movement are: wave, tide, seiches, current and aerial transport of spray influence of the coastal environment. There is also movement of water through evaporation, precipitation, run – off and drainage.

2.11 Environmental pollution in Nigeria

Polluted water bodies serve as media for the transportation of microorganisms and parasites which when consumed by man could lead to disease outbreak, organs failure, physical deformities and death (Atunbi, 2011). Anthropogenic effluents are major sources of aquatic contamination (Ekiye and Zejiao, 2010). Discharged of untreated industrial effluents into the aquatic environment can change water quality parameters abnormally.

Studies have shown that,the industries that treat their wastes in Nigeria are in the downward trend of 10 % before they are emptied into surface waters (Taiwo, 2010). The impacts of aquatic pollution on its biota include reduction in abundance and diversity of fish, phytoplankton, zooplankton,sediment macroinvertebrate, water quality impairment and low aesthetic values in water usage for recreational, industrial and domestic purposes (Wang and Fingas, 2003).

Oil pollution affects the wholesomeness of inland water quality leading to the problems of inadequate good water supply and instability of socio-economic activities around the oil producing areas. Most of the rivers within the Niger Delta Region–(NDR) Nigeria cannot be treated for drinking and aquaculture purposes because of excessive pollution from crude oil (Plate 2.1) (Olatunji *et al.,* 2011).

2.12 Crude oil production in Nigeria

The current crude oil production in Nigeria is about 2.5 million barrels per day, thereby making it the largest producer of oil in Africa and 6th largest producer in the world. This large quantity of crude oil is produced from just 7.5% of the total area of the (NDR)–(Nigerria Natural Resources, NNR, 2014). This 7.5% of the area that produces this huge quantity of crude oil is called NDR, while the states from which the oil is produced are called the oil producing States in Nigeria (figure 2.1). At present, there are eight crude oil producing States in Nigeria, namely: Akwa Ibom, Delta, Rivers, Bayelsa, Ondo, Edo, Imo and Abia out of which Akwa Ibom, Delta, Rivers and Bayelsa account for about 80% of the total crude oil produced(Figures 2.1). The annual oil production in Nigeria from 1980 to 2015 is shown in Figure 2.2.

Plate 2.1. Impact of oil spillage (near Burutu) in the Niger Delta Region of Nigeria
Source: Anon, (2016).

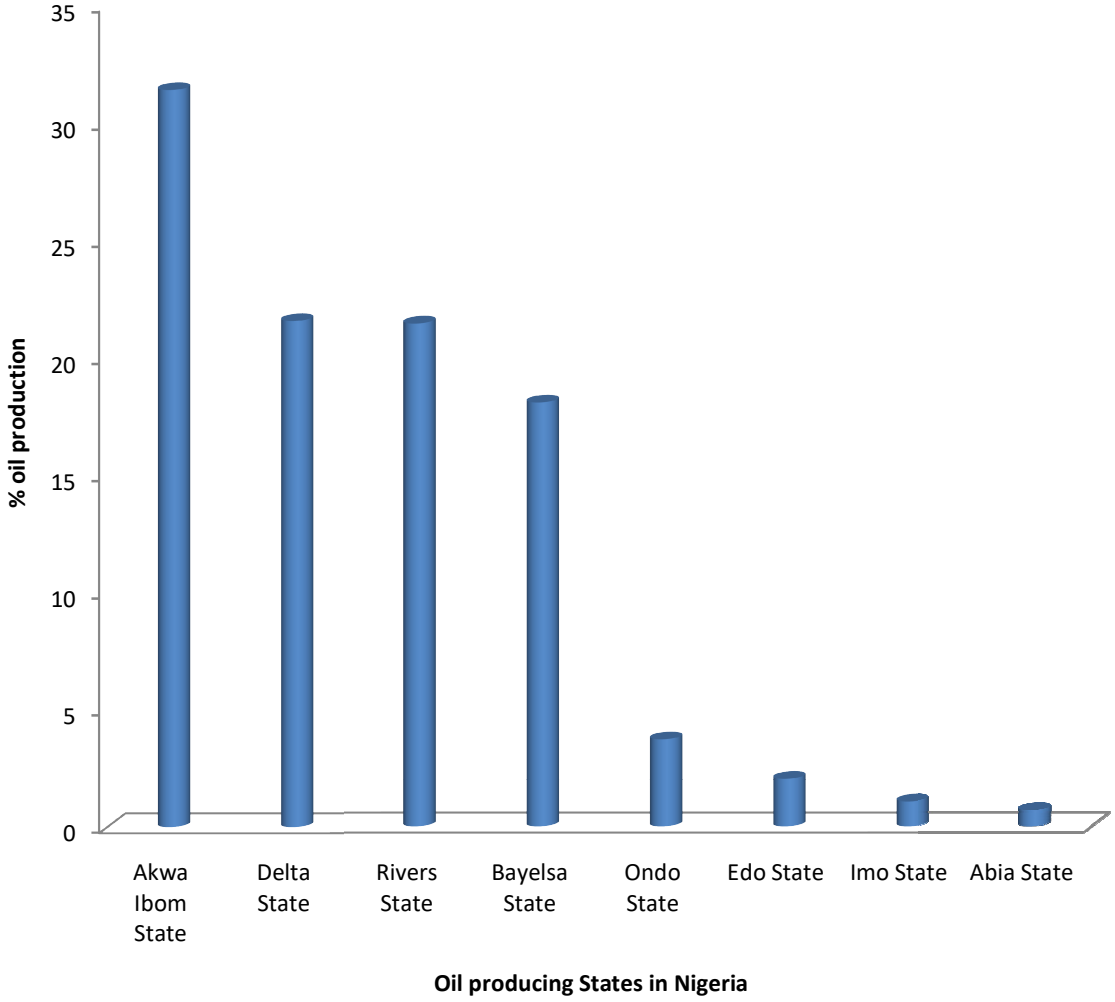

Figure 2.1. Percentage of oil production in Nigeria by state

Source: Adapted and modified from Nigeria Natural Resource (NNR), (2014).

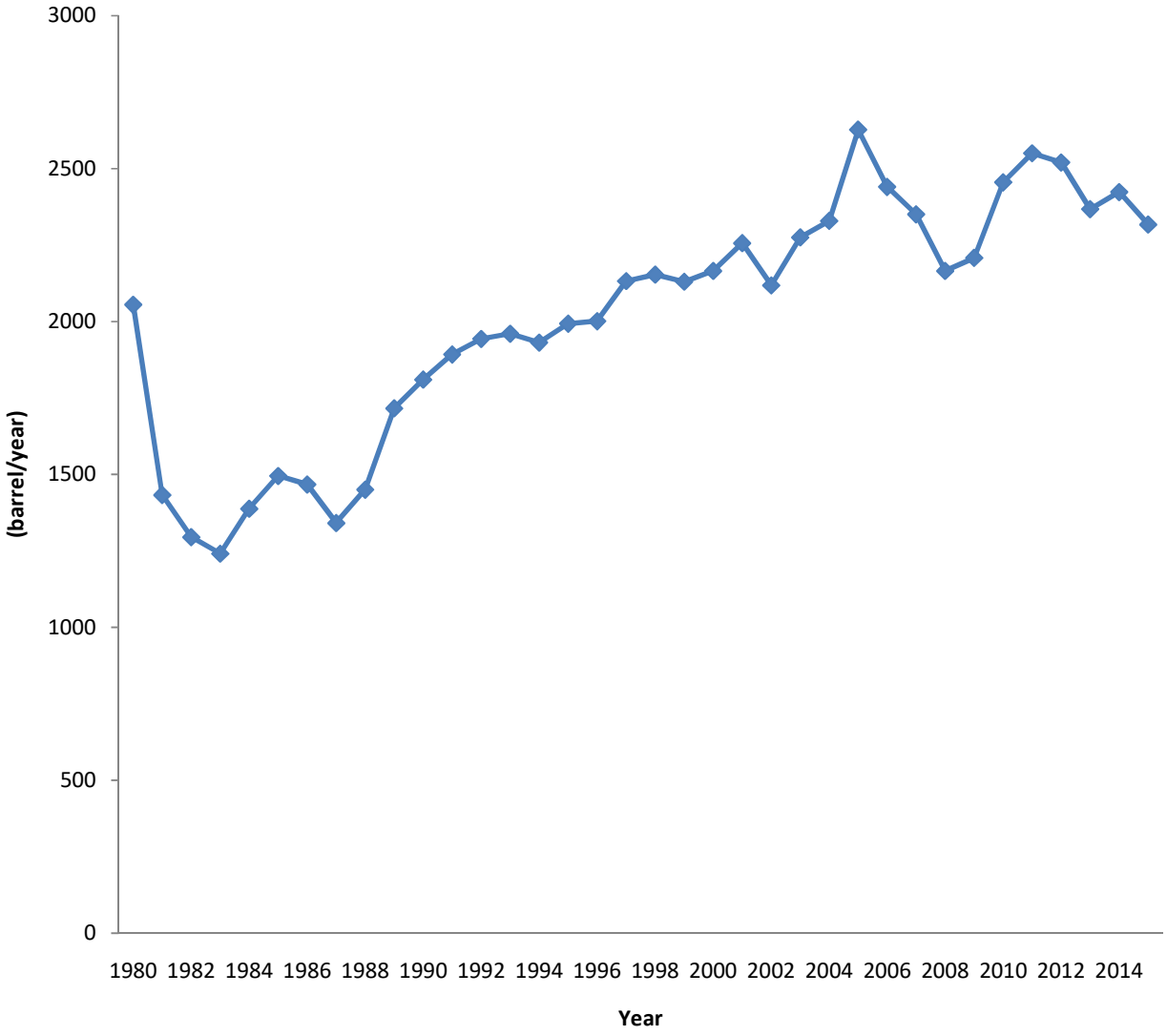

Figure 2.2. Annual oil production in Nigeria (1980 – 2015)

Source: Adapted and modified from United States Indexmundi, (2016).

Akwa Ibom produces 31.4% of the daily total crude oil, thereby making it the largest oil producing State in Nigeria. The second largest oil producing State is Delta, accounting for about 21.56%. It has a petrochemical plant and Refinery in Warri. At present, Rivers State refines the bulk of the crude oil in Nigeria. Rivers State produces 21.43% of the total oil production,thereby occupying the third position. Commercially, crude oil was initially found Bayelsa State (Oloibiri)–Nigeria in 1959. Bayelsa State produces about 18.07% of oil in Nigeria and it is fourth oil producing State. The historical Bonny Island is located in this state.

Ondo State, 3.74% (5th position) while other natural resources found in Ondo state are bitumen, tar and sands. Edo State contributes about 2.06% of the total crude oil output in the country, making it to occupy the sixth position. Imo State (7th position), produces about 1.06% of the total oil produced in Nigeria. This State also has other natural resources such as, lead, zinc, fine sand, clay and limestone. Abia State stands at the eightieth position among the oil producing State in Nigeria. It produces 0.68% of daily oil production in Nigeria.

2.13 Oil export terminals in Nigeria

There are six oil export terminals in Nigeria which are: Escravos and Pennington operated by Chevron; Forcados and Bonny operated by Shell; Qua lboe operated by ExxonMobi and Brass operated by Agip. The major foreign producers in Nigeria are Chevron, ExxonMobil, Total, Eniagip, Addax Petroleum, Conoco Phillips, Petrobras and Statoilhydro. Nigeria is the 5th largest foreign supplier to the United States and also supplies Europe, Brazil, India and South Africa. Presently, the proven gas reserve is put at 185 trillion cubic feet (Celestine, 2003). Nigeria is the eighth largest natural gas reserve holder worldwide and the largest in Africa. Nigeria flares most of its natural gas due to lack of infrastructure to produce and market (Federal Ministry of Environment, 2006).

2.14 The Niger Delta Region (NDR)

The NDR is one of the 10thmost essential marine and wetland ecosystem world-wide (Anifowose, 2008) but it is one of the five most severely petroleum destroyed ecosystems in the world and has an area of 20,000sq/km (NNR, 2014). It has been reported that 25% of the Nigeria populace lives within the NDR with it a steady growing population of approximately 30 million people, accounting for more than 23% of the total population of Nigeria (National Population Commission, 2006).

2.15 Industrial pollution around Gbalegbe River, Delta State

2.15.1 Characteristics of rubber effluents

Hydrocarbon can also be derived as a polymer of rubber obtainedfrom*Hevea brasiliensis*latex (Ahmad and Yazid, 2008). The purified form of rubber,which can be produced synthetically, is known as chemical polyisoprene. Natural rubber is widely used invarious applications and products (Tekasakul and Tekasakul, 2006). Increased rate, in the production of chemical polyisoprene from rubber, has led to the production of large volume of effluent which negatively alters surface water quality.

2.15.2 Glass manufacturing industries

The chemicals used in the colouration of glasses are mainly metallic oxides (Nigeria Industrial Standard, 2007). Dissolved heavy metals during the clean-up process of equipment and the floor of the factory, go into the aquatic environment, and change the quality of the surface water, thereby making it unfit for human utilization, and the survival of the aquatic life. Surface water is said to be polluted, ifthe levels of heavy metals it contains are greater than the acceptable standards (Olowu *et al*., 2012). The waste generated by the glass manufacturers contains many of the heavy metals used to colour the glass.

2.15.3 Characteristics of sand mining activities

Department of Irrigation and Drainage (DID, 2009) reported that for the construction of roads, bridges, dams and buildings, gravel and sand are used. In Ugelli Town, Delta State, the primary site of sand extraction is in river mining. In – river sand mining is a common practice, as these mining sites areseen along major roads in the study area. Sand mining along a water course can inducedeleterious effects onthe aquatic biota, private and public property (Japan International Cooperation Agency, JICA, 2009). Uncontrolled extraction of sand can seriously obstruct natural formation and stability of rivers channels. Sand mining, affects sediment transport within the aquatic environment and equilibrium of sediment of river downstream. The dimension of the effect depends on the extraction level in relation to bed load sediment supply as well as transport via the water column (Sarkula *et al.*, 2014).

DID, (2009) outlined the impacts of sand extraction as: sand mining could cause floodplain aquifer to draininto river, thereby lowering groundwater levels; reduction in the water table, can negatively affects natural vegetation because of water inducement stress; flooding is reduced as bed elevation decreases, which also causes decrease in flood heights leading to the

reduction in the hazard to man occupying foodplains areas; bed degradation undermines bridge supports, pipe lines and nearby houses; degradation through sand extraction changes the morphology of the river bed; sand mining depletes the depth of bed materials; reduction in overbank sediments to floodplains as flood heights reduces; it can induce bank collapse and erosion leading to high turbidity rate and sand mining upstream, causes river bed to decrease upstream and downstream;

Northern Carolina Chapter of the America Fisheries Society, NCAFS (2002) reported that, the implications of sand miningin a river as: Increased rate of sedimentation;High level of turbidity and bankfull; increased water temperatures; decrease in dissolved oxygen;reduced adjacent water table;increased water stress in plants and rivers' depth may increase at the point of extraction,but reduce downstream.

2.15.4 Oil and other industrial activities

The industrial activities around Gbalegbe River include oil, rubber, glass and sand mining. Oil spillage and petroleum products are the major anthropogenic sources of total petroleum hydrocarbon in the aquatic environment(Majolagbe *et al.*, 2011). Oil spill is a regular occurrence within and around Gbalegbe River, Delta State, Nigeria (Uzoekwe and Oghasanine, 2011).

2.16 Causes of oil spill

It has been reported that natural and anthropogenic factors are the major causes of oil spill in Nigeria (Ajayi, 2018).

- Anthropogenic causes: This is a major cause attributed to human activities such as terrorism, oil bunkering, accident during production and transportation, oil siphoning and sabotage.
- Natural causes: It could occure due to natural seepage, shifting of tectonic plates, natural disaster and insufficient trap systems,

2.16.1 Types of oil spillage

Egbe and Thompson, (2010); Ajayi, (2018) reported that oil spill can be classified into four major categories:

- Minor spill: This is said to happen when the quantity of the oil spilled is less than 25 barrrels in surface water or less than 250 barrels on land;
- Medium spill: It occurs when the volume of the spill is less than or equal to 250 barrels in inland water or ranges from 250 to 2500 barrels on off shoreshore and coastal water;
- Major spill: This happens when the quantity of oil discharged into inland water is in excess of 250 barrels in offshore or coastal waters and
- Catastrophic spill: It is known as any uncontrolled oil well blowout, pipeline explosion, failure of storage tanks which posses threat to the environment and the normal health status of man.

2.17 Sources of aquatic pollutants

Two major sources of aquatic pollutants exist which include:

- Point Source: These are pollutants or contaminants that entered the aquatic environments through specific and identifiable locations, e.g pipes, surface run – off or direct discharge of effluents.
- Non – Point Source: Pollutants from this source originate from different discrete points which cannot be traced to any single site of discharge (Subhend, 2006).

2.18 Aquatic pollutants classification

Aquatic pollutants can be classified into two groups: biodegradable and non-biodegradable (Ezemonye *et al.,* 2009). The biodegradable pollutants are from anthropogenic sources which which either be naturally be degraded or by the application of engineered processes (Adewolu *et al.,* 2009). The non–degradable pollutants–(conservative pollutants) include; nickel, mercury, aluminium and so on. They accumulate in aquatic biota and are subsequently bio–magnified within the aquatic food chains (Adeyemi *et al.,* 2011).

Pollutants can also be classified as toxic or inhibitor. These two categories of pollutants produce lethal or sub-lethal effects on the physiology, behaviour, nutrition, reproduction, metamorphosis, loss of pollution sensitive species of flora and fauna(Ajayi, 2018). River discharges contain high levels of pollutants and eroded nutrients (Boyd, 1979). Indirect effects of suspended solids are: reduction in light penetration and blanketing of bottom substrates – modification of the aquatic environment (NIS, 2007).

2.19 Total Petroleum Hydrocarbons (TPH)

The petrochemical industries are some of the major sources of total petroleum hydrocarbon pollution (TPH) in both lotic and lentic water bodies (Akporido, 2008). TPH is the quantity of hydrocarbon that can be determined in an aquatic system. The TPH is a family of large chemical compounds which are of crude oil origin. The TPH is a combination of various chemicals. They are derived absolutely from hydrogen and carbon.

The quantity of TPH contained in an aquatic sample is an indication of the petroleum pollution within such aquatic ecosystem. Waste waters released by oil processing, rubber, glass and sand mining industries are characterized by large volume of oilly products, polycyclic aromatic hydrocarbons, phenols, surface-active substances (FAO, 2011).The aquatic ecosystems act as a major sink for pollutants. Hydrocarbons are predominant pollutants in sediments of river ecosystems.

Riccardi *et al.*, (2008) reported that, TPH released into the water move through the water columns to the sediment. Individual compounds then separate from the mixture, depending on the chemical properties of the compound (Otokunefor and Obiukwu, 2005). Some of these compounds evaporate into the air while others dissolve into the water and sediment as well as flow away from the released area (Adewuyi *et al.* 2011).

2.20 How TPH gets in and out of aquatic organisms

TPH compounds are gradually distributed in the blood stream to different parts of the body (Manahan, 2003). When an organism gets in contact with TPH compounds, they are absorbed more slowly. Plate 1 showed the impact of oil spillage on fish. It was as a result of the incidence of pipelines bombing by the Niger Delta militants. The incidence occurred near Burutu, a community near Warri, Delta State, along the Forcados River.

2.21 Background and descriptions of heavy metals

Heavy metals are metals with relative densities greater exceeding $5gcm^{-3}$, while light metals have densities less than $5gcm^{-3}$ (Olaifa, 2004). They are also known as large class of inorganic chemicals which are toxic to aquatic health (Authman, 2008a).Heavy metal pollution has been observed as one of the major factors causing low primary productivity and fish mortality in aquaculture (Conservation Currents, North Virginia Soil and Water Conservation District, 2005). Ajao and Anurigwo, (2002) reported that, the knowledge of their toxicity to aquatic biota cannot be overemphasised. Rivers, lakes and coastal areas of

Nigeria are polluted by heavy metals. For most trace metals, anthropogenic sources contribute the more or equal to natural sources (Egbe and Thompson, 2010).

Metals can be grouped into two: the essential metals (iron, copper, nickel, zinc, manganese, chromium and so on)and non-essential metals (lead, cadmium and mercury). Cobalt, Cu, Ni, Znand so on are called trace metals (Udosen and Benson, 2006). The distribution of metals in the aquatic ecosystem is determined by: areas of metal introduction in the surface waters and the points of uptake by aquatic biota and demineralization. Mostheavy metals accummulate insediment because; sediment possesses high binding strength (Ibeto and Okoye, 2010). Bound metals in dust dissolved during precipitation or washed off the road to the receiving water bodies (Authman, 2008b).

2.22 General characteristics of heavy metals

Copper

Copper is a metal that belongs to group 1in the periodic table. It has an atomic weight and specific gravity of 64.37g and 9.47 $gcm^{-3}$with +2 and +1 as its oxidation states, respectively. It forms an important portion of the enzyme: metalloenzymes in aquatic organisms which is used in the production of haemoglobin. Elevated levels of copper could results in increased rate of free radical production and chromosomal mutilation.

Lead

Lead is found in the 14^{th} group of the periodic table. Its atomic mass and specific gravity are 206.78 and 10.75, respectively. It has 0, +2 and +4 oxidation states, respectively. Anthropogenic activitiesare its major sources.The European Union acceptable limitof Pb in fish farming is 0.3µg/g. Herros *et al.,* (2008), reported that, high concentrations of Pb distorts quality miltproduction in fish.

Nickel

Nickel is a group eightelement in the periodic table. Its atomic mass and specific gravity are 59.41g and 9.2gcm^{-3}, respectively. It is found in sediment. Its oxidation states are 0 and +2. Nickel is used in the production of steel, batteries, medical equipment, computer components and so on (Sivaperumal *et al.,* 2007).

Cadmium

Cadmium is a group 2metals in the periodic table, possessing an atomic mass and specific gravity of 111.78g and 9.35gcm^{-3}, respectively. Rported had it that, cadmium waste may get

to the aquatic environment from ore mining locations and waste products discharged into the water by industries. The European Union acceptable standard of Cd for fish culture is 0.1 - 0.3 μg/g (Herros *et al.*, 2008).

Zinc

Zinc is found in the group 2 of the periodic table(Chandrasekera *et al.*, 2008). It has an atom mass and specific density of 64.78g and 7.05g/Cm^3, respectively. Its oxidation state is +2. Its can be obtained in zinc sulphide–ZnS; zincite–ZnO and smithsonite–$ZnCO_3$. It is utilizedin batteries production. Anthropogenic activities are the main sources of Zn pollution in the aquatic community. The Znhelps in the production of protein while higher levels could cause kidney and liver breakdown(Duruibe *et al.*, 2007).

Manganese

The Mn is an element located in the group 7in the periodic table, with an atomic weight and a specific gravity of 55.34g and 6.83 gcm^{-3}, respectively. It has six oxidation states which include: +1, +2, +3, +4, +6 and +7, respectively. It is utilized in themanufacturing of steels, batteries, wood preservatives and so on. Manganese pollution disrupts the central nervous system and the normal functioning principles of the liver and kidney of fish.

2.23 Sources of heavy metal pollution

The sources of heavy metals contamination is anthropogenic activities. Pollution of the aquatic systems by heavy metals-(HM) is a major ecotoxicological concern because, they are toxic in high concentrations and persist in the aquatic environment even after removing the source of the pollutants (Cole *et al.*, 2009).

2.24 Bottom sediments

Sediments are fragmented materials, originally formed by weathering processes which can equally be found at the bottom of aquatic environments (Golovanova, 2008). They are made up of particulate matter of different sizes, forms and mineralogical components. Their three categories of sediments are:

- Lithogenic sediment–obtained from detrital products of disintegration of rocks;
- Biogenic sediment–obtained from the remains of flora and fauna.

- Hydrogenic sediment –obtained from precipitates in river and sea water or from interstitial water.

Biogenic sediment – composed of the highly preserved andwell degraded remains of plants and animals. They are divided into two, namely: (1) Carbonaceous sediments–(lacking hard skeletal parts) and (2)Fossiliferous sediments. They are made up of the benthic calcareous shelled organisms having over 50% of the total sediment. Sediments in which the most abundant component is woody plants, consist of fine-grained and unconsolidated microfossilsare described as oozes or hashes.

According to DID, (2009), sediment particles that possess variability in grain-size with fraction larger than sand (0.02 and 0.20 mm) is known as gravel, while sizeslesser than sand (silt and clay) are called mud (plate 2.2)–(Langer, 2003). This size differential explains the repartitioning of the particles within a river flow and the variation in their compositions.

2.24.1 Sediment pollution

Sediments act as a sink for pollutants, because, anthropogenic effluents are inevitably discharged into water bodies (Plate 2.2)(JICA, 2008). The TPH, heavy metals and pesticides are potential threat to surface water and sediment.

2.24.2 Sources of sediment

According to World Health Organisation, WHO, (2008) the three major sediment supplies are:

- Erosion of upland and areas used for farming;
- Collarpse of river banks and dams systems –Head cut and final,
- Natural siltation and sediment storage (remobilization) along flood plains or other storage sites as well as, channel migration, bank widening and avulsion.

2.24.3 Sediment transport

Sarkula *et al.*, (2010), reported that, sediment transport elucidates the mechanics of river system, because its checkmates the flow rate and the channel boundary. Erosion isconcerned with the removal and transportation of sediment – mainly from the boundary, while deposition involves the transportation and placement of the sediment on the boundary. Erosion and deposition form the channel of any alluvial river, as well as the floodplain

Plate 2.2. A local sand mining site along Gbalegbe River, Delta State, Nigeria
Source: Field report, (2015).
Note: A = Dredging pipe and B = Point of discharge

through which it moves.The quantity and size of sediment moving through a river channel are determined by three major factors viz: Competence; Capacity and Sediment supply. Competenceis concerned with the largest size with respect to the sediment particle size which the flowing current can cause to migrate along the river bed.

If the current of a river is flowing slowly, it might not be able to mobilize and transport sediment of certain sizeseven when such sedimentsare available for transportation.So a river can be competent or incompetent with respect to a given grain size. If it is incompetent, it will not transport sediment of a given size. If it is competent, it willmove sediment of that size if available (Flood Control District of Maricopa County, FCDMC, 2004).Capacityrefers to the highestquantity of sediment of a given size that a river can transport in traction as bed-load.

The supply of sedimentsdepend on the capacity of the channel gradient, discharge and the weight of the load because the presence of fines grains may increase fluid density andincrease capacity, while the presence of large particles can obstruct the flow and reduce its capacity.Capacitytransportis the competence-limited sediment transport (mass per unit time) and itoccurs when sediment supply is abundant (Arimoro *et al.*, 2007).

Sedimentsupplyrefers to the amount and size of sediment available for sediment transport. Capacity transport for a given grain size is only achieved if the supply of that weight of sediment is not limiting. Due to potential constraints of hydraulics and sediment supply, distinction is made between supply-limitedand capacity-limitedtransport. Mojorrivers operate as sediment-supply limited system.

It has been reported that, most of the materials supplied to a river are silt and clay which it carries in suspension (WHO, 2008). Though, an upper limit must be achieved for the capacity of the river to transport silt and clay, often, it is unachieved because natural channels and the quantity silt and clay moved are limited in supply. Whereas, transport of heavier or larger materials than fine sand aremajorly capacity limited (Wolanski, 2005).

2.24.4 Sediment deposition

Sediment can also be defined with reference to particle size and mineralogical compositions. The chemical compositions of the sediment at its point of deposition is can be determined by the original constituents of its source, size of the source material, sorting in the process of migration and the physical characteristics at the location of disposal (Arimoro *et al.*, 2007b). The patterns of sediment transport inrivers are relatively similar in relation to water velocity. The pattern of water movement in lake is oscillatory but linear in rivers of flow of waves produced by wind.

2.24.5 Adsorption of heavy metals in sediment particles

The adsorption of heavy metals in sediment particles depend on the sediment; composition, physical, chemical, forms of the heavy metals, environmental variableswithin the surface water system. The factors determing sediment adsorption are: pH, oxido-reduction potential, temperature, ionic capacity, adsorbent concentration and particle size. Temperature is an important factorrevealing how sediment affects adsorption of metal (Arimoro and Ikomi, 2008). Since physical adsorption and chemical adsorption are exothermic reactions, adsorptive capacity generally drops when the temperature rises. The speed of chemical adsorption is low and a rise in temperature speeds up the adsorption process.

The pH value is one of the most important factors in the adsorption variable of metal. The effect relates to the solubility of metal, the surface adsorptive features of sediment, and the sorption reaction of metal on the surface of sediment. The adsorptive capacity of heavy metal in sediment increases with the increasing pH concentration (Wyatt and Baird, 2007).

2.24.6 Particlesize fractions of sediments and grain-size influence

The size differentials between sand, silt and clay is essential if the infilling of a river is to be established or if the sediment quality is to be ascertained. Sand settles at the bottom immediately sediment migrates into rivers and the velocity increased, but silt and clay stay in suspension for a longer period and migratesmore within the river (Ziv *et al.*, 2012). The particle size of≤62 μm of suspended sediment is responsible for the transportation of adsorbed particles. The size of transported sediment particles range from clay-sized material notationally defined as (<0.004 mm).

This fraction consists mostly of clay minerals such as, montmorillonite and kaolinite but may also include some other fine minerals andorganic debris. The silt size range from 0.004 – 0.062, sand (0.062 – 2mm) while gravel is >2 mm. The adsorptive ability of sediment is determined by the surface area. Therefore, the finest particles sizes are majorly the richest in heavy metals. This is essentially visible when separate chemical analyses are made on different size fractions.

2.24.8 Sediment quality

Increased migration of fine sediment grains of silt and clay are the major yearly carrier of heavy metals, nutrients and other related aquatic pollutants (Baran and Guerin, 2012). Among the 128 major pollutants enumerated by the USEPA, 65% of them are mainly found sediment. The yearly 95% of phosphorus load in surface water migrates in conjuction sediment in suspension. Wondie *et al*., (2007), reported that, nutrient enrichment in aquatic ecosystems are increasingly becoming more useful as a result of sediment quality evaluation. Unfortunately, agencies saddled with the responsibility of ensuring the that water quality criteria are adhere, are failing in their capacity in giving attention to the study of suspended sediment because of:

- Paucity of information on current analytical procedures in sediment study;
- Inconsistent objectives applied in the monitoring of sediment research programmes;
- Undue attention on already established fact such as, faecal contamination and final,
- Inadequate finance, expertise and equipment.

2.25 Exchangeable cations and cation exchange capacity

Sediment contains electrostatic charges due to atomic replacement in the lattices of sediment minerals (Baran and Guerin, 2012). These charges attract counter–(exchangeable) ions and form the exchange complex. Cations held by sediments can be replaced by exchangeable cations. For example, Ca^{++} can be exchanged for H^{+} or K^{+} and vice versa. The strength of a cation's positive charges differ, thereby enabling one cation to replace another on negatively charged sediment (Ibeto and Okoye, 2010).

2.25.1 Cation exchange capacity (CEC)

According to DID, (2009), the total number of exchangeable cations, a sediment can hold is called its cation exchange capacity. The higher a sediment CEC, the more cations it can retain. The CEC of sediment depends on the quantity, clay type and the levels of the organic matter within the environment. The large the clay quantity, the higher the exchangeable cations it can hold. The CEC contents of sediment increases as its organic matter increases(Canadian Council of Ministry of Environment, CCME, 2008).

The CEC of sediment is expressed in terms milliequivalents per 100 gram of sediment (me/100g) or in centimoles of positive charge per kilogram of sediment (C mol^{+}/kg) which numerically translates to me/100g. While the CEC values of clay minerals are in the ranges of 10 to 150 C mol^{+}/kg, the CEC of organic material ranges from 199.99 to 400.01 C mol^{+}/kg (JICA, 2009).

2.25.2 Cation exchange

Cations are the positively charged nutrient ions and molecules (Baran and Guerin, 2012). The dominant residual charge on most sediment colloids is negative. These negatively charged sites attract positively charged ions in the sediment water (Yi *et al.*, 2008). Sediment acts as cations exchanger. Negatively charged colloids, attract cations and hold them tight. This characteristic explains why nitrate – nitrogen is more easily leached from the sediment than ammonium – nitrogen. Nitrate has a negative charge and as such, it is not held by the sediment but remains as a free ion in sediment. The amount of cations in the sediment solution are closely related to the exchangeable ions, while any change in the concentration of a cation in the solution forces a change in the proportions of all exchangeable ions.

2.25.3 Importance of cation exchange

Gupta, (2001) andCCME (2008) reported that, cation exchange essential feature in sediment nutrient enrichment and plays the following significant roles:

- It causes and corrects sediment acidity and basicity;
- It alters sediment phsico-chemical properties;
- Acts as a purifier of percolating water;
- It supplies calcium, magnesium and potassium to aquaticmacrophytes from exchangeable forms;

- Cation exchange locations keep the ions of Ca, Mg, K, Na and NH_4 so as to avoid being leached away;
- Cation exchange sites adsorb metals such as Cd, Zn, Ni and Pb that are present in wastewaters. Adsorption removes them from the percolating water, thereby cleansing the water that drains into the ground waters or surface waters and
- The cations exchange locations immobilized cations, but keep the exchangeable thereby making them available to the roots of aquatic macrophytes.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

Gbalegbe River which traverse up to 12.5 km is located within latitudes 5°10'N and 5°17'N of the Equator and Longitudes 5°56'E and 5°13'E of the Greenwich meridian. It emanates from a tributary of Asaba - Ase River, Delta State.Itshighest and mean depthswere 10.45m and 4.31m respectively, (Town Planning Authority, Ughelli, Delta State, 2014). Its basin is long, narrow and it is sectioned into two main partshaving the widest as 97.13m and narrowest part, slightly over 27.09m (Town Planning Authority, Ughelli, Delta State, 2014).

The study area lies between 0 – 100 meters above sea level (Kottek, *et al.,* 2006). Gbalegbe River is the major River flowing through Ughelli Town, Delta State Nigeria. The town was initially an agro – based but has been highly urbanized leading to the location oil and construction companies (SHELL, NNPC, SETRACO, Rubber Factory, Beta glass, sand miners).

In 1958, petroleum deposits were discovered in the vicinity, but exploration started in 1965. Since then, crude oil from the Ughelli fields has been shipped via the 225Km Trans-Niger Pipeline south – eastward to the port of Bonny for export (Ochuko *et al*., 2008). The location was chosen because it is one of the major areas where oil exploitation and exploration, glass and rubber production, gas flaring and sand mining activities were taking place in Delta State.

3.2 Climate and vegetation of the study area

The study area has humid climate, with wet season occurring from March – October, but a shorter dry season (November – February). The climate is influenced by two prevailing winds, namely: South – West monsoon wind from the Atlantic Ocean and the North – East trade wind from the Sahara Desert. The South – West monsoon wind causes wet season,while the North – East wind type, is responsible for dry season (Aweto, 2002). The mean annual rainfall of the study area was 2700mm. Rainfall peaks in June/July and September, with a short break period in August, while the mean yearly temperature was 27 °C(Ochuko *et al*., 2008). The vegetation of thestudy area is rain forestwith swamp forest occurring in flat-floored valleys and adjoining low-lying which are seasonally or permanently waterlogged (Ogaga *et al.*, 2015).

3.3 Experimental Procedures

Gbalegbe River was spatially stratified into eight stations (S1 – low human activities; S2 – glass production factory; S3 – power plant; S4 – rubber processing mill; S5 – Oil farm tanks; S6 – Automechanic shops; S7 – Cassava processing mill and S8 – Sand mining) based on proximity to key anthropogenic activities (ISO, 2006; Mohammed *et al.,* 2008), while the mean of the distance among each station was 1.56 km (Figure 3.1). In each station, three sampling points were randomly selected. Temporal stratification covered wet (March – October) and dry (November – February) (Ochuko *et al*., 2008) seasons. The study was carried out for 24 months (January, 2015 – December, 2016).

3.4 Sampling Techniques

The background weather data (rainfall, temperature and relative humidity) of the study area were collected from the Metereological Station of Ughelli North Local Government Area, Delta State, Nigeria, while bi-weekly field trips were madeto collect water, sediment, flora and fauna samples. Fish samples were purchased from the local fishers randomly to avoid being bias to certain size groups.

Physico – chemical parameters monitored were Total Dissolved Solids, Total Suspended Solids, Electrical Conductivity, pH, Dissolved Oxygen, Biological Oxygen Demand, Transparency, Alkalinity, Nitrate, Nitrite, Ammonia, Sulphate, Phosphate-Phosphorus, Calcium, Magnesium, Primary productivity (Chlorophyll a, Gross Primary Productivity, Net Primary Productivity), heavy metals (Nickel, Copper, Iron, Cadmium, Chromium, Manganese, Zinc, Lead) and Total Petroleum Hydrocarbon (TPH). Meteorological data such as; rainfall, relative humidity and air temperature were collected from the Meteorological Department, Ughelli North L.G.A., Delta State, Nigeria. Sampling was done using dug out canoe. Samples of Water, sediments, Phytoplankton, Zooplankton and Benthic invertebrates (BI) were collected per station following the methods described by Balogun and Ajani (2015); Popoola and Otalekor, (2011). The exact locations of all sampling stations were determined using Garmin GPSMAP eTrex 10 type sensors (Table 3.1).

Figure 3.1. Gbalegbe River, Delta State, Nigeria

Source: Department of Town Planning, Ughelli North LGA., Delta State, Nigeria, (2016)

Table 3.1. Site descriptions of sampling points

Stations	Latitudes (N)	Longitudes (E)	Altitude (m)
S1	5°30′40.21″	6°0′24.49″	207
S1	5°30′40.24″	6°0′24.49″	202
S1	5°30′40.34″	6°0′24.49″	183
S2	5°31′42.45″	5°5′43.87″	208
S2	5°31′46.95″	5°5′43.87″	219
S2	5°31′45.92″	5°5′43.87″	204
S3	5°31′27.67″	5°56′5.0″	183
S3	5°31′27.69″	5°56′5.04″	213
S3	5°31′25.60″	5°56′5. 04″	228
S4	5°29′47.82″	5°54′36. 33″	185
S4	5°29′45.80″	5°54′36. 53″	220
S4	5°29′47.83″	5°54′36. 34″	202
S5	5°30′0.42″	5°53′54.90″	194
S5	5°30′0.32″	5°53′53.95″	196
S5	5°30′0.40″	5°53′53.96″	183
S6	5°27′17.51″	5°27′13.87″	189
S6	5°27′17.55″	5°27′13.84″	225
S6	5°27′13.89″	5°27′13.89″	203
S7	5°28′12.04″	5°54′12.52″	216
S7	5°28′12.10″	5°53′12.52″	220
S7	5°28′12.54″	5°53′12.52″	209
S8	5°27′20.79″	5°54′13.44″	179
S8	5°27′21.80″	5°54′12.47″	198
S8	5°27′20.81″	5°54′13.49″	219

3.4.1 Pre – treatment of sampling equipment and storage containers

Before sampling, all samplers, polypropylene and glass bottles were washed using detergent and rinsed in destilled water. Later, polypropylene and glass bottles were rinsed with 1N nitric acid but 95% Acetone was used to rinse glass wares (APHA, 1998). Prior to collection of water samples, polypropylene and glass bottles were rinsed twice with the environmental sample.

3.5 Analytical techniques

3.5.1 Physico-chemical parametersof Gbalegbe River, Delta State

Dissolved Oxygen (DO)

Samples of water were collected bi – weekly between 0700 and 0900 hours from each point by dipping the sample bottles to a depth of 10 – 50 cm through inversion to avoid trapping air bubbles. Samples for BOD and DO analyses were collected in 300 mL and 250 mL glass bottles, stoppered and fixed immediately at the points of collection with Winkler A and B solutions respectively. Samples were preserved as recommended by AOAC, (1990).

The DO was evaluatedex-*situ* by titration – Winkler's method (Gupta, 2001). Water samples were fixed with Winkler A (manganous sulphate) and Winkler B (alkaline potassium iodide). This was done to trap and retain the DO in the water sample. In the laboratory, 2 mL of 10% H_2SO_4 was added to the water samples to dissolve the trapped oxygen. 4 drops of starch were introduced into 100 ml of water sampled (indicator) which turned the mixture blue-black. Sodium thiosulphate was then titrated against the resultant blue-black solution until a colourless solution was obtained while titre value was read off.

The DO was calculated using the formula;

DO (mg/L) $=\frac{V1 \times N \times 8 \times 1000}{V2-V3}$(Gupta, 2001).

Where:

V_1 = Volume of titrant (ml)

N = Normality of titrant (0.025N)

V_2 = Volume of Sampling bottle after placing the stopper (ml)

V_3 = Volume of manganous sulphate + potassium iodide solutions added (ml)

Biological Oxygen Demand (BOD_5)

Samples for biochemical oxygen demand (BOD_5) were incubatedfor five days in the laboratory at 20°C (Trivedy and Goel, 1984) and determined by Winkler method (APHA, 1998). Sulphate was analyzed according to standard method (USEPA, 1978a). BOD_5 was calculated by using the formula stated below:

$BOD_5 = (D1 - D2)\ X\ \frac{\text{Volume of BOD bottle}}{\text{ml of sample used}}$(Gupta, 2001). Where: D1 = Initial dissolved oxygen in sample and D2 = Sample dissolved oxygen after 5 days of incubation

Determination of Total Suspended Solids (TSS)

Measurement of TSS was through filteration method followed by oven drying method as described in (AOAC, 1990). Three filter papers were rinsed with deionised water to remove any solid that may remain during the manufacturing process. Thereafter, they were placed in separate labelled aluminium weight pans and oven dried at a temperature of 104°C for 30 minutes after which they were removed and placed in a desiccator to obtain a constant weight. 100 ml of the sample were filtered through the pre-weighed filter papers while each of the filter paper was placed in its weight pan in the oven for 1 hour at a temperature of 104°C. After which they were transferred into a desiccator and allowed to cool and a constant weight was obtained by repeating the drying and desiccating steps three times.

Calculation:

TSS (mg/L) $= \frac{A-B}{C}\ X\ 1000{,}000$ (AOAC, 1990)

Where:

A = Dry weight of residue + filter paper

B = Dry weight of filter paper alone

C = Total ml of water filtered

$$\text{Transparency (cm)} = \frac{(Point\ of\ disappearance + point\ of\ appearance)}{2}$$

Transparency

Water transparency was determined using secchi disc according to the method described by Boyd (1998). The secchi disc was painted black and white alternating each other. A graduated twine was attached at the centre. The disc was then gradually lowered into the water until the white part could no longer be seen (point of disappearance) and the retrieved gently until the part painted white became visible (point of appearance). The average of these two values gave the level of transparency of Gbalegbe River.

Water temperature was measured using mercury in glass thermometer (^{o}C), pH with digital pH meter (Hanna model: HI – 98107, USA).Turbidity was measured by using a turbidometer in accordance with USEPA, (1993) standards. Salinity, EC and TDS were evaluated bya Salinometer (Thermo Electron Corporation, model: Orion 150A+, USA).

Velocity

Velocity is the total distance travelled with time. It is also the rate of water flow of a river (JICA, 2008). The velocity of Gbalegbe River was determined during the study as decribed by Annon, (2005) by dropping a floater at point A, and allowing the water current to move it to point B, while the distance (meter) between points A and B, and the time (seconds) required for the floater to floats from point A to B were measured using a measuring tape and a stop clock, respectively.The velocity of flow was then calculated using:

$$\text{Velocity (m/s)} = \frac{Distance}{Time}$$

Alkalinity

Alkalinity was measured by titrimetric method using 0.01N HCl and methyl orange as indicator (APHA, 1998). About 25ml of the sample was diluted to 50ml with distilled water, 2ml of buffer solution and 0.10g Erichrome black-T-dye were added, while the resultant reddish solution was titrated with EDTA-titrant drop by drop until the colour changed from blue to colourless which was recorded as the end point.

$$\text{Alkalinity}CO_3^{-}\text{(g/L)} = \frac{Vol.of\ \mathrm{H2SO4}\ (titrant\ used)\times N \times Eq.wt\ of\ CO3-(30)}{Ml\ of\ water\ sample}$$ Lind, (2009).

Where: N = Normality of H_2SO_4 and Eq. wt = Equivalent weight of CO_3^{--}

Chloride

Chloride was analysed using N, N - Dimethyl-p-phenylenediamine (DPD) titration method (Boyd and Craig, 1992).A mixture of 5mL buffer solution and 5 mL of DPD was pipetted into a 250 mL beaker and swirled. A 100 mL of the water sample was measured with a graduated cylinder and transferred into the beaker. The sample and the reagents were allowed to mix thoroughly. Later, 1g of potassium iodide crystals was added and allowed to dissolve. The solution was titrated with standard ferrous ammonium sulphates until the red colour disappeared.

$$Chloride\ (mg/L) = \frac{(mL\ of\ titrant)x(N)x\ (35.45)x\ (1000)}{Volume\ of\ sample}$$ (Boyd and Craig, 1992).

Silicate

To 50 mL of the water sample in Erlenmeyer flask was added 1 mL HCl and 2 mL of ammonium molybdate solution. The solution was left for 10 minutes before adding 1.5 mL oxalic acid solution. The solution was thoroughly mixed while the absorbance was recorded using a spectrophotometer at 410 nm. The experiment was repeated by running blank using distilled water. The concentration of silica in sample was achieved from the standard curve and expressed in SiO_3 – Si/L.

3.5.2 Determination of water nutrients of Gbalegbe River, Delta State

Nitrate

Nitrate concentration was determined according to the Phenol disulphonic acid method (Gupta, 2001). 25 ml of sample collected was emptied into a porcelain dish of 50mLcapacity and evaporated to dryness at temperature of 105^{o}C using hot plate. Thereafter, 3mL of phenol disulphonic acid was added to the residue and dissolved the later by rotating the dish. After 10 minutes, 15mL of distilled water was added and stirred adequately using a glass rod. After cooling, the contentswere washed down into a 100mL volumetric flask and ammonia was slowly added (1:1) until the solution turned yellow as a result of the presence of nitrate. Another 2ml of ammonia was added and the volume made up to 100 ml with distilled water. The level of the yellow colour was determined using a colorimeter set at a wave length of 420 nm.

Calculation:

$$NO_3^- \text{ (mg/L - N)} = \frac{Concentration\ of \text{ Nitrate from standard curve}}{Volume\ of\ sample\ (mL)}$$

Nitrite

The concentration of nitrite was determined using sulphanilamide method (Gollenman *et al.,* 1978) as: 50 mL of the water sample filtered into an Erlenmeyer flask while 1 mL each of EDTA, Sulphanilic acid and naphthylamine hydrochloride solutions were added. A wine red colour was observed which indicated the presence of nitrite. The absorbance of this solution was measured using a spectrophotometer at 520 nm. The experiment was repeated by running using distilled water (blank). The difference between the two results gave concentration of nitrite present in the sample.

Ammonium

Ammonium concentration in the water sample was determined by volumetric method as described by Gollenman *et al.,* (1978). About 50 mL of water sample was transferred into a Micro – Kjeldhal distillation flask and 1 mL of borax buffer solution was added. About 5 mL boric acid was added as indicator into a conical flask. Heat (100^{o}C) was then applied to the Kjeldhal containing the water sample.

The distillation continued until about 40 mL of the distillate was collected in the conical flask. The conical flask whose content turned blue (indicating dissolution of ammonia) was removed. The distillate was titrated against 0.01 N hydrochloric acid. The blue colour turned into brown indicating the end point. The experiment was repeated by running a blank with distilled water. The concentration of ammonium was expressed in the formula:

$$NH_4 \text{ (mg/L - N)} = \frac{(T-B)x\ N\ x\ 14\ x\ 1000}{Volume\ of\ sample\ (mL)}$$

Where T = volume of titrant used against sample (mL), B = volume of titrant used against blank (mL); N = normality of titrant (0.01). The equivalent weight of NH_4 – N is 14.

Sulphate

The Ca^{2+} and Mg^{2+} contents of the sample were obtained by direct titration with EDTA. In another aliquot, CO_3^{2-} and HCO_3^{-} was determined by titration with standard HCl (0.02N), while in the third aliquot, about 2mL standard HCl equivalent to total alkalinity (CO_3^{2-} and HCO_3^{-}) was added and boiled at a temperature of 100^{o}Cto remove carbonate and CO_2. Then 25mL of $BaCl_2$ was ran into the mixture and boiled at a temperature of 100^{o}C using hot plate for 180 seconds. On cooling, 10mL of buffer solution and 5 drops of eriochrome black-T indicator were added and titrated with the standard EDTA solution. The experiment was repeated for a second time using 25mL $MgCl_2$ solution to obtained Ca and Mg.

Observation:Reading of Ca^{2+} and Mg^{2+} titration = B

Reading of Ca^{2+} and Mg^{2+} titration after the addition of Ba and Mg = T

Calculation:

Sulphate (mg/L) = B + Ba + Mg – T.

Where B is blank (milliequivalent, meq of Ca^{2+} and Mg^{2+}) in the original sample, Ba is the meq barium added, Mg is the meq of magnesium added while T is the meq of versenate (EDTA) of the total titration of the sample after adding Ba and Mg. 1mL of 1 N $BaCl_2$ = 1 meq Ba (1 mL of normal solution equals 1 meq/L; 1 meq of 0.02 N $BaCl_2$ = 0.02 meq Ba; 1 meq of 0.02 N Mg Cl_2 = 0.02 meq Mg).

Phosphate – phosphorus

The concentration of phosphorus in water sample was determined using colorimetric method as described by Gupta (2001). About 25 mL of the water sample was transferred into an Erlenmeyer flask and evaporated to dryness at a temperature of 105^{o}C. The residue was cooled in a desiccator and dissolved in 1 mL of Perchloric acid. Heat (75^{o}C) was gently applied to the flask until the content became colourless. The fask was allowed to cool.

Thereafter, 10 mL of distilled water and 2 drops of phenolphthalein indicator were added. The solution was then titrated against sodium hydroxide solution until a light pink colour appeared. The volume was made up to 25 mL by adding distilled water and transferred into 50 mL volumetric flask where 10 mL of reagent B (Ascorbic acid) dissolved in reagent A (ammonium molybdate + potassium antimony tartrate) was added. The solution was made up to 50 mL with distilled water to allow the blue colour develops. The solution was left for 30 minutes and absorbance was recorded using a spectrophotometer at 660nm.Phosphate – phosphorus concentration was expressed using the the formula:

$$Phosphate - phosphorus\ (mg/L) = \frac{mgP(in\ 50\ mL)}{Volume\ of\ sample}$$

3.5.3 Determination of primary productivityof Gbalegbe River, Delta State

Chlorophylla

Chlorophyll a was determined according the method described by Vellenweider (1969). Water samples were filtered through a Millipore (Pore size 0.45µm). All steps were carried out in the dark room to avoid breakdown of pigment. The filter papers containing the samples were placed in 90% acetone in plastic vials covered with aluminium foil, shaken properly and gently ground with a homogeniser to ensure that the filter (Millipore) dissolved very well before storage for 24 hours in the refrigerator at temperature of 4^{o}C.

One millitre (1 mL) of 1% Magnesium carbonate suspension was added to the filter paper to form a thin bed which served as a precaution against the development of any acidity and subsequent degradation of pigment in the extract. After 24 hours of extraction in the cold and dark, the plastic vial containing the filter paper was brought to room temperature (25^{o}C) and the volume brought up to the original level by addition of 90% acetone in a graduated centrifuge tube.

The solution was centrifuged for 20 minutes at 5000 rpm and the supernatant solution taken for the determination of optical density (transmission percentage) with the aid of a spectrophotometer (Model: HITACHI U - 1900). Chlorophyll$_{-a}$ (Chll$_{-a}$) was calculated using:

$Chll_{-a} = 11.9\ (A_{665} - A_{750})\ X\ \frac{V}{L}\ X\ \frac{1000}{S}$ (Vollenweider, 1969).

Where: A_{665} = Absorbance at 665 nm, A_{750} = Absorbance at 750nm, V = Acetone extract (ml), L = Length of light path in spectrophotometer (cm), S = Volume of acetone filtered

Gross and Net primary production

The oxygen light – dark bottle method was used (Boyd and Craig, 1992). This method uses dissolved oxygen concentrations in water samples incubated in clear water (2 light bottles), opaque (2 dark bottles) and 2 initial bottles to estimate phytoplankton productivity. The transparency was first measured using secchi disc. The Transparency value obtained was multiplied by 2 to determine the photic zone (Gupta, 2001). The photic zone is the maximum depth of light penetration in river.

Within the photic zone, depth intervals of 1/5 distance apart between the light and dark bottles were determined during the incubation period of 2 hours in the water (Gupta, 2001). From each depth, two initial, two light and two dark bottles were used to collect water samples. The dark bottles were wrapped in a layer of aluminium foil to avoid light leaks. The two light and two dark bottles were suspended at the depth where the samples were collected. After the incubation period of 2 hours, the sample bottles were retrieved and fixed. The dissolved oxygen contained in the initial, light and dark bottles were determined by winkler method APHA, (1998).The formulae stated below were used for Net Primary Production (NPP), Gross Primary Production (GPP) and respiration (R) (Boyd and Craig, 1992):

NPP = LB – IB

GPP = LB – DB

R = IB – DB

Where IB, LB and DB are initial, light and dark bottles, respectively.

3.5.4 Sampling, preservation and identification of phytoplankton

Direct enumeration method was used for the identification of phytoplankton as described by Boyd and Craig (1992). Phytoplanktonwas sampled by horizontal towing for 3 minutes using a net of mesh size of 25µm at a depth of 0 – 15 cm (Littler, 1973).Collected phytoplankton was immediately fixed and preserved in 10% formalin(Hoffman and Dawes, 1980). The samples were properly labelled, dated and transported to the laboratory for further analysis

and identification. In the laboratory, 50 mL of the water sample containing the phytoplankton samples was into a plastic conical centrifuge tube.

The mixture was allowed to sit undisturbed in a dark cupboard for four days. Thereafter, 40 mL of the supernatant was carefully decanted leaving 10 mL of the concentrated sample. About 1 mL of the concentrated sample was pipetted into the Sedgwick – Rafter counting chamber of the Microscope and the glass cover was gently positioned over the chamber without forming air bubbles. Later, the counting chamber was placed in its position in the microscope. A magnification of X400 was chosen. Counting and identification of plankton seen within the ocular micrometer grid were done.Phytoplankton were identified using standard keys such as Okusami and Odu (1992); Gupta (2001); Verlencar and Somshekar (2004).

Calculation was done using this formula:

$$Number\ of\ plankters\ per\ mL\ = (T)\frac{1000\ x\ volume\ of\ concentrate\ (mL)}{A\ x\ N\ x\ volume\ of\ sample\ (mL)}$$

Where:
T = total number of plankters; A = area of grid in square millimeters; Number of grids used and 1000 = area of counting chamber in square millimeters

3.5.5 Sampling, preservationand identification of zooplankton

Direct enumeration method was used for the identification zooplankton as described by Boyd (Gupta, 2001). Zooplankton samples were collected by horizontal hauling for 3 minutes (Nwoji *et al.,* 2010) using a net of mesh size of 0.2mm at a depth of 0 – 15 cm (Margalef, 1968). Collected samples were fixed and preserved in 5% formalin within the recommended time of 5 minutes to avoid damage to animal tissue by microbial action and autolysis. Samples were labelled, dated and taken to the laboratory for further analysis and identification.

In the laboratory, 50 mL of the water sample containing the zooplankton samples was introduced into a plastic conical centrifuge tube. The mixture was allowed to sit undisturbed in a dark cupboard for four days. Thereafter, 40 mL of the supernatant was carefully decanted leaving 10 mL of the concentrated sample. About 1 mL of the concentrated sample was pipetted into the Sedgwick – Rafter counting chamber of the Microscope and the glass cover was gently positioned over the chamber without forming air bubbles. Later, the counting chamber was placed in its position in the microscope. A magnification of X400 was chosen.

Counting and identification of zooplankton seen within the ocular micrometer grid were done. Zooplankters were identified to species level using standard keys such as Jeje and Fernando, (1986); Lynne, (2004) and Bouchard, (2004).

Calculation was done using this formula:

$$Number\ of\ zooplankton\ per\ mL\ = (T)\frac{1{,}000{,}000\ x\ volume\ of\ concentrate\ (mL)}{A\ x\ N\ x\ volume\ of\ sample\ (mL)}$$

Where:
T = total number of plankters; A = area of grid in square millimeters; Number of grids used and 1000 = area of counting chamber in square millimeters

This mesh size net was used because it is suitable for qualitative and quantitative studies of zooplankton.The recommended towing time and speed of 5 to 10 minutes was observed. If the towing speed is more, a static cone of water develops thereby diverting water outside the net and consequently reducing the effective filtration. For better quantitative and qualitative zooplankton collections, the recommended suitable time for horizontal sampling of 6:30am-7:30am (Ogbuagu, 2013) was observed. This was done because zooplankton migrates in response to light (Nwankwo, 2004a).

3.5.6 Collection, preservation and identification of sediment macro – invertebrates

A Van Veen bottom grab (Van Veen, 1933) sampler was used for sediment collection. The van Veen bottom grab can dig a depth range of 5 – 10cm (Eleftheriou and Holme, 1984). The grab sampler which was lowered vertically from a stationary canoe to capture the slow – moving and sedentary members of the epifauna and infauna to the depth excavated.

The sediments for macro – invertebrates analysis were emptied into a stainless steel bucket containing water. Thereafter, the sediments were filtered thoroughly through a sieve of mesh size of 0.5 mm. Organisms found were sorted from the detritus and stored in 10% formalin solution. The collected sediment macro-invertebrates were identified with the aid of a compound microscope (x 100), aquatic arthropod taxonomic keys and pictures to species levels (Macan, 1999;Lynne, 2004).

3.5.7 Sampling, preservation and identification of fish species

Fish samples purchased for total petroleum hydrocarbons (TPHs) were wrapped in aluminium foil, labelled, dated and kept in coolers of ice chips at a temperature of 4^{o}C. In the laboratory, the samples were transferred into a deep freezer for preservation. Fish samples were identified to species level using standard keys such as Idodo – Umeh, (2003) and Olaosebikan and Raji, (2004).

3.6 Characteristics of the different diversity indices used for the study

Javaid and Ashok, (2013) reported that the most commonly used diversity indices applied in ecological studies are the Shannon (1948). Simpson index assesses the dominance but fails to provide information on species richness (Pielou, 1966b), while Shannon-Wiener index determine both diversity characteristics such as evenness and richness but does not provide any information on the rare species which are very important in the studies of biodiversitySimpson (1949). This signifies that diversity cannot be estimated just by one index. Therefore, to overcome theselimitations, different diversity matrices were used (Pielou, 1966a).

Diversity indices such as Margalef, Simpson, Shannon – Wiener and Dominance were used to determine the level of pollution, dominance, eveness and distribution of flora and fauna species sampled.

$$\text{Margalef index (Ri)} = \frac{S-1}{In\,(N)} \qquad \text{Margalef (1958)}$$

Where: S = total number of species and
N = total density of species.

$$Simpson\ index\ (1 - Dominance) = \frac{D}{Dmax} \qquad \text{Simpson (1949)}$$

Where: D = species diversity while, Dmax = maximum amount of the species diversity index

Simpson index measures the evenness (E) in species distribution within the community and its ranges from 0 (No evenness in distribution) – 1 (distribution is even).

$$Shannon - Wiener\ index\ (H') = -\sum_{i=1}^{n} Pi\ log2Pi \qquad \text{Shannon and Weaver (1949).}$$

Where: n = total number of species i, Pi = ratio of the species i.

The H' takes into account the number of individuals and number of taxa. It ranges from 0 (community with only a single taxa to > 1 (community with many taxa).

$$\text{Dominance } (1 - \text{Simpson index}), \mathrm{D} = S\left(\frac{ni}{n}\right)2 \qquad \text{Simpson (1949)}$$

Where:ni = number of individual taxon per station, n = total number of individual

The D ranges from 0 (taxa not equally present) to 1 (a taxon is dominating).

3.7 Collection of water sample for Total Petroleum Hydrocarbonanalysis

All equipment used for sample collection, storage, analysis of Total Petroleum Hydrocarbon (TPH)were pre-cleaned using high-purity nitric acid (GFS Chemicals Inc.). Such cleaning and storage procedures ensured that there were no detectable TPH contaminants in the sampling equipment (Ogendi *et al.* 2014).The TPH concentration in the water sample was determined using volumetric method described by Etim (2009). Five hundred millitres (500 mL) of water samples from each station for TPH was collected in glass bottle and fixed in 2ml concentrated H_2SO_4 per litre of sample (Odiete, 1999).

After mixing the sample, the pH was checked by touching pH-sensitive paper to the cap to ensure that the pH was ≤ 2. The sample was poured into a separatory funnel, 30ml n-hexane was added to the sample bottle and rotated to rinse the sides. The solvent was transferred into a separatory funnel and extraction done by vigorous shaking of the bottle for two minutes while the layers were allowed to separate.

The solvent layer was filtered through a funnel containing solvent-moistened filter paper into a 100 mL conical flask. The steps were repeated twice with 30ml portion of fresh solvent, combining all solvent into the conical flask. The tip of the separatory funnel, filter paper and the funnel were rinsed with 5 – 10ml solvent and the rinsings collected in the flask. The extract was diluted to 100ml. Thereafter, the extract was filtered through a filter paper into a tarred flask and the weight of the hydrocarbon content of the solution was determined.

$$TPH\ (mg/L)\ = \frac{weigh\ \ of\ TPH\ from\ tarred\ bottle\ x\ extract\ dilution\ factor}{volume\ of\ sample\ (L)} \qquad \text{Etim (2009)}$$

3.8 Determination of Total Petroleum Hydrocarbon in most widely distributed fish and macro - invertebratesamples

Twenty grammes (20g) of fish and two grammes (2g) of macro-invertebratesamples were separately macerated in methanol after oven drying at a temperature of 105^{o}C for 2 hours. Thereafter, they were separately introduced into round bottom flasks containing 200 mL methanol and 8g of KOH and refluxed for 2 hours each. After cooling, the mixtures were separately filtered into two separatory funnels.

Thirty millitres (30 mL) of n-hexane was added to each round bottom flask and well rotated to rinse the sides. The solvents were introduced to the separatory funnels. Extraction by shaking vigorously for 120 seconds was done. The layers were allowed to separate. The n-hexane layers were then filtered through a funnel containing n-hexane moisture filter paper into thetwo 250 mLbeakers.

The steps were repeated twicemore with 30mL portion of fresh n-hexane directly added to the separatory funnels, thereby conveying all n-hexane into the two separate beakers. The tips of the separatory funnels, filter papers and the funnels were rinsed with 5 – 10 mL n-hexane and the rinsing collected in the beaker. The extracts were reduced to 10 mL using a rotary evaporator.Two columns were respectively, packed with gel, while 10mL of the concentrated extracts were eluted through the columns and elutes collected using a tarred flask and n-hexane was thereafter,recoveredwith the aid of rotary evaporators.
Calculation was done using this formula:

$$TPH\ (\mu g/Kg)\ = \frac{weigh\ \ of\ TPH\ in\ tarred\ flask\ x\ 1000}{weight\ of\ specimen\ sample(kg)}$$ Etim (2009).

3.9 Sampling of sediment for Total Petroleum Hydrocarbon analyses

Bottom sediment samples were collected from each station using a pre-cleaned van Veen bottom grab (van Veen, 1933) sampler. Sediment samples collected were air-dried at room temperature(25^{o}C) for seven (7) days in the laboratory and stored in clean polythene bag and aluminium foil for heavy metal and TPH, properly labelled and dated. The samples were ground into powdery form before being used for their respective analyses.

3.10 Determination of Total Petroleum Hydrocarbonfrom sediment

Fifty grammes (50g) of the sample was introduced into a round bottom flask carrying 200 mL methanol and 8g of potassium hydroxide (KOH) and refluxed for 120 minutes. After cooling, the mixture was then filtered into a separatory funnel while 30 mL of n-hexane was introduced into the round bottom flask and rotated to rinse its sides. The solvent was transferred into the separatory funnel. Extraction by shaking vigorously for 120 seconds was carried out and the layers were allowed to separate. The n-hexane layer was filtered through a funnel containing n-hexane moisture filter paper into a 250 mL beaker.

The above steps were repeated two times more with about 30 mLof fresh n-hexane directly introducedinto the separatory funnel which helped in combining all n-hexane into the beaker. The tip of the separatory funnel, filter paper and the funnel were rinsed with 5-10 mL n-hexane and the rinsings collected in the beaker. The extract was reduced to 10 mL using a rotary evaporator. A column was packed with gel, 10mL of the concentrated extract was eluted through the column and elute collected using a tarred flask and n-hexane subsequently recovered using rotary evaporator.The concentration of in sediment was calculated using the formula:

$$TPH\ (\mu g/Kg) = \frac{weig \quad of\ TPH\ in\ tarred\ flask\ x\ 1000}{weight\ of\ sample\ (g)}$$ Etim (2009)

3.11 Collection of water samples for heavy metals analysis

All equipment used for sample collection, storage, analysis of heavy metalswere pre-cleaned using high-purity nitric acid (GFS Chemicals Inc.). Such cleaning and storage procedures ensured that there were no detectable metalcontaminants in the sampling equipment (Ogendi *et al.* 2014).The samples were collected in polypropylene bottles and filtered immediately through 0.45 μm and acidified with ultra-pure HNO_3 at a concentration of 1 mL per litre of sample to pH< 2 and stored prior to heavy metal analyses. In the laboratory, the water samples were transferred into the refrigeratorat a temperature of 4^{o}C until needed for analyses (Olaifa, 2003). Thereafter, heavy metals in the water samples were analysed using Atomic Asorption Spectrophometer (AAS) based on the method described by APHA (1998).

3.12 Digestion of fish, macro-invertebrates samples and determination of heavy metals

Five grammes (5g) of fish and 2g ofmacro-invertebrates samples were oven-dried at 105℃ in a Gallenkamp oven to a constant weight. The samples were each ground into powdery form with the aid of a pestle and mortar. The powdered samples were further dried to constant weights while 0.5g of each sample was collected for digestion with the aid of an electric sensitive weighing balance. About 0.5g of each sample was placed in a 50 mL conical flask and 20mL of HNO_3, 2 mL of H_2SO_4 and 4 ml of perchloric acid (a catalyst) were added. The samples were each transferred to hot plates in a fume cupboard and heated for one hour at 200℃ after which the temperature was reduced to 70℃ and digestion allowed to continue.

The samples which showed black fumes were further acidified with 10 mL of HNO_3 and the digestion was allowed to continue until the white fumes of per chloric acid disappeared leaving a clear yellowish solution. The resultant yellowish solutions were allowed to cool and then filtered. The filtrate in the standard volumetric flask was made up to 50 mL mark with distilled water as described by Gupta, (2001). Thereafter, heavy metals in *C. gariepinus and H. castanea* samples were determined using Atomic Absorption Spectrophotometer (AAS) based on American Public Health Association (APHA), (1992) and American Society for Testing of Materials, (2006).

3.13 Digestion of sediment samples for heavy metals determination

One gramme (1g) of air – dried sediment sample was ground in a mortar and heated to reddish brown in a furnance and moistened using de – ionised water. 1 mL of 60% perchloric acid and 20 ml of 40% hydrofluoric acid were added. The content was heated to dryness in a sand bath at 180^{o}C. It was cooled and 15 mL of 10% hydrochloric acid added. The mixture was heated in a crucible to dryness (APHA, 1992). The concentrations of the metals in the sediment were determined using AAS. Sediment pH was determined by dissolving 5g of the sediment sample in distilled water and the pH level measured using a digital pH meter(Hanna model: HI – 98107, USA).

3.14 Determination of sediment particle sizes

Sediment particle sizes were determined using mechanical method described by Anon (2000). The sediment samples were emptied into sieves placed on each other with different mesh sizes of 0.50mm (coarse sand), 0.063mm (fine sand), 0.004 mm (silt) and 0.00024mm (clay). The sieves were then agitated by using an agitating machine (Model: OQ-1, USA). Sediment

particle meant for the respective sizes were retained in each of the mesh sizes. The percentage particle sizes were calculated by using the the formula stated below:

$$\% \text{ Particle size} = \frac{weigh\ \ of\ sediment\ retained\ in\ sieve}{To\ \ \ \ weigh\ \ of\ sediment\ filtered}\ x\ 100$$ APHA, (1998)

3.15 Determination of organic carbon, total nitrogen, phosphorus and cation exchange capacity in sediment

Determination of organic carbon in sediment of Gbalegbe River

The organic carbon content in the sediment of Gbalegbe River was determined using Walkley and Black rapid titration method (Gupta, 2001). 1g of the sediment sample was introduced into a dry 500 mL conical flask and 10 mL of 1N $K_2Cr2O_7$was pipetted into it and the mixture was properly swirled for 1 minute. Later, 20 mL of H_2SO_4 (containing AgSO4) was added and swirled again for 2 minutes. The flask was allowed to stand for 30 minutes before 200 mL of distilled water was added followed by the addition of 10 mL of phosphoric acid and 1 mL of diphenylamine as indicator. The content was then titrated with 0.5N ferrous ammonium sulphate solution until the colour changed from blue – violet to green. The experiment was repeated using a blank.

The organic carbon content in the sediment sample was then calculated using:

$$\% \text{ Organic carbon in sediment} = \text{N}\frac{B - C}{Weight\ of\ sediment\ sample\ (g)}\ x\ 0.003\ x\ 100$$

Where: N = normality of ferrous ammonium sulphate, B (mL) = volume of 0.5N ferrous ammonium sulphate required to neutralized 10 mL of 1N K_2Cr2O_7, C = volume of 0.5N ferrous ammonium sulphate needed for titration of soil sample.

Determination of sediment available nitrogen

The available nitrogen in the sediment of Gbalegbe River was determined using the Alkaline permanganate method described by Subbiah and Asija, (1956); Gupta, 2001. 20g of Gbalegbe River sediment were introduced into 800 mL dry Kjeldahl flask, 20 mL of distilled water was added and then swirled. One millitre (1 mL) of liquid paraffin and 5 glass beads were added to prevent frothing bumping, respectively during distillation.

Thereafter, 100 mL of 0.32% $KMnO_4$ solution was added followed by the addition of 20 mL of boric acid and mixed indicator solution in a conical flak with the end of the delivery tube dipped in it. 100 mL of 2.5% NaOH solution was added into the Kjeldah flask which was immediately fited up in the distillation apparatus. The mixture was distilled steadily while

liberated ammonia was collected in a conical flask containing boric acid solution with mixed indicator. It was observed that due to the absorption of ammonia, the original pink colour of the solution turned to green. 100 mL of of the distillate was collected in 30 minutes. The collected distillate was then titrated with 0.02N H_2O_4 to the original pink colour previously observed. A blank titration without sediment sample was also done for the final calculation.

$$\% \text{ Nitrogen in sediment} = \text{N}\frac{R - b}{Weight\ of\ sediment\ sample\ (g)}\ x\ 0.02$$

Where N = atomic weight of nitrogen, R = volume of 0.02N of H_2O_4 used for sediment titration and b = volume of 0.02N of H_2O_4 required for blank titration (without sediment sample).

Determination of sediment available phosphorus in sediment of Gbalegbe River

Available phosphorus in the sediment of Gbalegbe River was determined using the Bray's method. 5g of sediment was introduced into a 150 mL Erlenmeyer flask and 50 mL of Bray extraction solution (1:1 sediment to solution ratio), stoppered and shaken for 5 minutes on a mechanicak shaker. Thereafter, the mixture was filtered through a Whatmann No 42 filter paper.

Five millitres (5 mL) of the aliquot of the extract was introduced into a volumetric flask and 7.5 mL of boric acid (50g of H_3BO_3 in 1 Litre of distilled water) to the aliquot to avoid interference of fluoride. Later, 20 mL distilled water and 4 mL of Murphy Riley solution was added. After 15 minutes, the intensity of a blue colour was measured using a Spectrophotometer at a wave length of 730 nm. The experiment was using a blank (without sediment sample). Calculation:

$$\text{Bray's Phosphorus in sediment} = \text{c x}\ \frac{v}{V\ x\ Weight\ of sample\ (g)}\ x\ 2.24$$

Where v = volume of the extractant, V = volume of aliquot, mg of phosphorus in the aqliquot obtained from standard curve.

Determination of cation exchange capacity (CEC)in sediment of Gbalegbe River

The cation exchange capacity of the Gbalegbe River sediment was determined using 1N Ammonium acetate method. 5g of the sediment sample was placed in a centrifuge tube while 25 mL of 1.0N of sodium acetate was added, stoppered and vigorously shaken for 5 minutes. Thereafter, the tube was unstoppered and centrifuged at s speed of 2000 rpm for 10 minutes. The supernant liquid was the decanted. This procedure was repeated four times. Later, 25 mL of 95% ethanol was added to the tube, stoppered, shaken for 5 minutes, unstopered and

centrifuged for 5 minutes. The supernantant liquid was decanted and discarded. The sample was then washed with 25 mL of ethanol three times.

Twenty five millitres (25 mL) of 1.0N ammonium acetate was then added into the tube, soppered and shaken for 5 minutes, unstoppered and centrifuged at 2000 rpm until the supernantant liquid is clear. The supernantant liquid was decanted into a 100 mL volumetric flask. This extraction was repeated three times to ensure that ammonium ions are replaced by sodium ions which were contained in the supernantant liquid. The content of the volumetric flak was then diluted and made to make. Sodium concentration was then determined using flame photometer, while CEC was calculated using:

$$\text{CEC} = \frac{Na\ Conc.of\ extract\ (meq\ per\ Litre) x 100 x\ volume\ of\ extract\ (mL)}{Weight\ of\ sediment\ sample\ (g) x\ 1000}\ x\ 0.02$$

3.16 Sediment pollution indicators

Sediment pollution indicators are indices used to evaluate the extent of pollution the aquatic environment has been subjected to as a result of the anthropogenic activities going on within and around such water body using the sediment. The sediment pollution indicators used for this study include: index of geo – accumulation, contamination factor, degree of contamination, modified degree of contamination and pollution load index.

Index of geo-accumulation (I_{geo})

$$Igeo = log2\frac{Cn}{1.5Bn}$$ (Muller, 1969)

Where: C_n = Measured concentrations of heavy metals in sediment, B_n and 1.5 = Accounts for natural fluctuations and very small anthropogenic influences.

According to Muller (1981) and Syed *et al.* (2012), the classes of geo-accumulation index in soil or sediment were Class 0 = $I_{geo} \leq 0$ (uncontaminated), Class 1 = $0 < I_{geo} < 1$ (uncontaminated/moderately contaminated), Class 2 = $1 < I_{geo} < 2$ (moderately contaminated), Class 3 = $2 < I_{geo} < 3$ (moderately/strongly contaminated), Class 4 = $3 < I_{geo} < 4$ (strongly contaminated), Class 5 = $4 < I_{geo} < 5$ (strongly/extremely contaminated) and Class 6 = $5 < I_{geo}$ (extremely contaminated).

Contamination factor (C^i_f)

$$C^i_f = \frac{C^i_o}{C^i_n}$$ Kryzysztof *et al.* (2004).

Where:C^i_n = Geochemical background value/ pre – industrial concentrations of heavy metals in sediment and C^i_0 = mean contents of metals from all 8 stations.

According to Hokanson (1980), the levels of contamination factor (C^i_f) for soil or sediment were C^i_f <1, 1≤ C^i_f<3 = moderate contamination factor, 3≤ C^i_f<6 = considerable contamination factor and 6≤ C^i_f = very high contamination factor.

Degree of contamination factor (C_d)

$$C_d = \sum_{i=1}^{n} \left(C^i_f \right)$$ Hokanson (1980)

Where: n = number of contamination factors and C^i_f = contamination factor

Syed *et al*. (2012) reported that the classes of degree of contamination (C_d) were C_d<8 = low degree of contamination, 8≤ C_d<16 = moderate degree of contamination, 32≤ C_d<8 = considerable degree of contamination and 16≤ C_d<32 = very high degree of contamination.

Modified degree of contamination (mC_d)

$$mC_d = \sum_{i=1}^{i=n} \left(C^i_f \right)$$ Abraham and Parker, (2008)

Where: n = number of contamination factors and C^i_f = contamination factor

As reported by Muller (1981), classes of the modified degree of contamination(mC_d) for soil or sediment were mC_d <1.5 (nil to very low degree of contamination), 1.5≤ mC_d<2 (low degree of contamination), 2≤ mC_d<4 (moderate degree of contamination), 4≤ mC_d<8 (high degree of contamination), 8≤ mC_d<16 (very high degree of contamination), 16≤ mC_d<32 (extremely high degree of contamination) and mC_d≥32 (ultra high degree of contamination).

Pollution load index (PLI)

$PLI = n\sqrt{cf_1 * cf_2 * \ldots * cf_n}$ Tomlinson *et al.* (1980).

Where: cf1, cf2---cfn = contamination factors.

According to Hokanson (1980), ranges of pollution load index were PLI>1 (immediate action to reduce pollution), PLI=1 (more detailed study is needed) and PLI<1 (drastic remediation measures not needed).

3.17 Statistical analyses

Data from this study were analysed using descriptive (means and standard deviation) and inferential statistics (one-way ANOVA), correlation, principal component analysis and diversity indices analysis using SPSS (version, 20) and past (version 3). Microsoft Excel (2010) was used to calculate species abundance, condition factor and to plot graphs. Data were pooled and presented as spatial and temporal mean variances and compared by means of one-way ANOVA in order to evaluate if their differences were significant at $p < 0.05$.

Correlation matrix analysis was used to indicate possible significant relationships among the physicochemical parameters at 0.01 and 0.05 significant levels.

- One-way ANOVA and Duncan's Multiple Range Tests were used to illustrate the degree of differences between the heavy metals and TPH found in water, sediment, *Hesperocorixa catanea* and *C. gariepinus* samples with respect to spatial and temporal variations.
- Principal component analyses (PCA) was used to detect the degree of dependency of all physico-chemical parameters, flora and fauna identified.
- Percentage species abundance = $\frac{Number\ of\ individual\ per\ species}{Total\ number\ of\ organisms} \times \frac{100}{1}$ % was calculated to point out the most abundance phytoplankton, zooplankton, sediment macro – invertebrates and fish species.

CHAPTER FOUR

4.0 RESULTS

4.1 Weather data of the study location

The monthly weather data of Ughelli North Local Government Area (LGA) and its environment are presented in Table 4.1. The two years meteorological data revealled that rainfall was throughout the year with the highest (3001.03±23.42 mm) amount occurring in September, while the lowest (28.46±0.98 mm) was in December. Maximum atmospheric temperature of 29.74±2.65^{o}C was recorded in January, while 24.58±0.17^{o}C was obtained as the least in September. The highest (96.18%) and the lowest (25.39%) relative humidity values were recorded in the months of September and December, respectively. The mean distance among stations (S1 – S8) sampled was 1.56 km.

4.2 Physico – chemical parameters of Gbalegbe River, Delta State

The mean values of physico-chemical parameters among stations, between seasons and pearson's correlation coefficient of Gbalegbe River are presented in Tables 4.2, 4.3 and 4.4. Analyses of variance (ANOVA) for physico-chemical parameters among stations and between seasons are shown in Appendices 1 and 2. The least spatial variation in the mean values of total dissolved solids (TDS)recorded was 14.56±5.21 mg/L at Station 1, while the highest was 366.59±35.94 mg/L at Station 2. During the dry and wet seasons, 40.76±11.69 mg/L and 205.15±0.35mg/L were recorded as the leastand highest mean values of Total Disssolved Soilid (TDS), respectively.

The TDS was positively correlated ($p<0.01$) with Total Suspended Solid (TSS) ($r = 0.06$), Electrical Conductivity (EC) ($r = 0.04$), Turbidity (TUR) ($r = 0.17$), Temperature ($r = 0.04$), Biological Oxygen Demand (BOD) ($r = 0.04$), while a negative association existed with Dissolved Oxygen (DO) ($r = -0.08$), velocity (Vel.) ($r = -0.04$), Transparency(-0.06), gross primary productivity (GPP) ($r = -0.15$) and Chll a ($r = -0.03$).

The lowest mean of total suspended solid 23.98±10.51 mg/L was recorded at Station 1, while the highest was 98.60±0.6 mg/L at Station 2. Mean values of Total Suspended Solids (TSS) ranged from 51.46±15.17 mg/L to 123.61±21.01 mg/L dry and wet seasons. The TSS was negatively correlated with DO ($r = -0.09$), Velocity (Vel.) ($r = -0.15$), Transparency ($r = -0.12$), Gross Primary Productivity (GPP) ($r = -0.10$), Chlorophyll a (Chlla) ($r = -0.2$) but positively correlated with Electrical Conductivity (EC) ($r = 0.07$).

Table 4.1. Monthly weather data of the study area (Ughelli North), Delta State.

	2014/2015			2015/2016		
Months	Air temperature (^oC)	Humidity (%)	Rainfall (mm)	Air temperature (^oC)	Humidity (%)	Rainfall (mm)
January	29.74	26.01	29.76	29.94	31.88	45.32
February	28.01	34.79	48.93	26.92	45.36	78.93
March	28.87	29.16	41.47	26.16	68.21	980.34
April	25.85	66.52	1500.59	25.15	74.03	1997.17
May	24.88	82.21	1750.08	24.59	84.35	2003.30
June	25.07	88.75	27505.24	24.02	89.73	2594.09
July	25.36	84.33	2493.57	26.06	75.94	2357.28
August	27.52	39.71	1800.16	27.06	49.37	1245.58
September	24.69	91.89	2906.11	24.58	96.18	3001.03
October	26.53	75.14	1200.13	26.96	71.76	1120.39
November	27.15	63.45	1411.120	27.58	61.04	960.01
December	29.56	25.39	28.46	28.55	26.42	31.03

Source: Metereological Unit, Ughelli North Local Government Headquarters, Delta State, (2017).

Table 4.2. Means physico-chemical parameters among stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
TDS(mg/L)	14.56±5.21^{c} (11.78-17.33)	366.59±35.94^{a} (140.06-531.11)	133.24±91.60^{b} (84.43-182.05)	22.39±12.16^{c} (15.90-28.87)	24.73±12.36^{c} (18.14-31.31)	28.86±21.87^{c} (17.20-40.51)	34.86±46.31^{c} (10.18-59.54)	19.1±13.88^{c} (11.70-26.49)
TSS (mg/L)	23.98±10.51^{d} (18.38-29.58)	98.60±0.6^{a} (27.51-119.69)	31.18±56^{c} (12.67-37.93)	25.91±16.17^{c} (17.29-34.53)	32.55±9.37^{b} (27.57-37.55)	47.93±48.79^{b} (21.94-73.93)	48.39±64.15^{b} (45.21-83.58)	31.36±374.66^{b} (11.72-56.01)
EC (µScm^{-1})	3.36±2.86^{f} (1.83-4.88)	43.26±39.61^{a} (22.15-64.37)	10.41±302.70^{c} (4.11-37.70)	15.76±16.47^{b} (6.98-24.53)	10.41±16.60^{c} (1.57-19.26)	17.43±20.68^{b} (6.41-28.46)	6.77±8.65^{d} (2.17-11.38)	1.58±1.00^{e} (0.61-2.54)
TUR (FTU)	6.96±2.17^{d} (6.71-9.67)	43.59±16.29^{a} (23.91-45.27)	30.15±17.74^{c} (20.70-39.61)	36.08±18.04^{bc} (26.47-45.70)	35.21±14.84^{bc} (27.30-43.12)	25.62±12.35^{d} (19.04-32.20)	39.00±16.62^{b} (30.14-47.86)	33.74±16.57^{b} (24.92-42.57)
Temperature (^{o}C)	26.62±1.75^{b} (25.69-27.55)	28.45±2.06^{a} (24.35-29.55)	24.28±5.84^{c} (21.16-27.39)	25.49±1.59^{b} (24.64-26.33)	25.93±1.75^{b} (25.00-26.87)	26.14±2.00^{b} (25.07-27.21)	26.30±1.34^{b} (25.58-27.01)	24.81±1.53^{c} (23.99-25.62)
DO (mg/L)	4.52±0.56^{a} (3.95-4.55)	3.13±0.67^{ab} (3.10-4.11)	3.45±0.48^{b} (3.19-3.71)	3.88±0.85^{b} (3.43-4.34)	3.91±0.77^{bc} (3.50-4.32)	3.68±0.64^{bc} (3.34-4.02)	3.94±0.74^{bc} (3.54-4.34)	3.55±0.69^{bc} (3.18-3.92)
BOD (mg/L)	0.65±0.03^{b} (0.84-1.61)	1.59±0.69^{a} (0.94-1.64)	1.34±0.87^{a} (0.87-1.80)	1.06±0.50^{a} (0.79-1.32)	1.14±0.64^{a} (0.80-1.49)	1.13±0.73^{a} (0.75-1.52)	0.86±0.60^{c} (0.54-1.19)	1.34±0.66^{a} (0.99-1.70)
Ph	7.15±0.61^{b} (6.82-7.48)	6.99±0.79^{ab} (6.87-7.71)	7.21±0.62^{b} (6.88-7.54)	7.31±0.52^{ab} (7.03-7.59)	7.12±0.57^{b} (6.82-7.43)	7.77±0.84^{a} (7.32-8.22)	7.45±0.79^{ab} (7.03-7.87)	7.03±0.37^{b} (6.83-7.22)
Alkalinity (mg/L)	11.90±0.8^{b} (0.88-15.56)	52.49±5.87^{a} (49.37-55.62)	53.27±6.27^{a} (49.93-56.61)	52.69±6.98^{a} (48.97-56.41)	52.76±7.65^{a} (48.68-56.83)	53.13±7.44^{a} (49.17-57.09)	56.18±6.26^{a} (52.84-59.51)	57.21±5.82^{a} (54.11-60.31)
Salinity (‰)	0.59±0.01^{a} (0.08-1.70)	3.86±0.60^{d} (1.43-4.08)	2.45±0.57^{abc} (1.84-2.56)	2.99±0.36^{bcd} (1.80-2.18)	2.80±0.52^{cd} (1.52-2.88)	2.91±0.55^{a} (2.12-3.01)	2.64±0.41^{ab} (2.12-2.86)	2.81±0.39^{ab} (2.00-2.92)
Chloride (mg/L)	58.65±22.67 (46.57-70.73)	51.64±13.06 (44.68-58.60)	62.14±16.18 (53.52-70.77)	65.36±15.80 (56.94-73.78)	52.94±12.65 (46.20-59.68)	61.35±21.44 (49.92-72.77)	60.25±12.69 (53.49-67.01)	66.41±11.48 (60.29-72.53)
Velocity (m/s^{2})	0.36±0.11^{a} (0.09-0.63)	0.34±0.13^{a} (0.03-0.67)	0.31±0.16^{a} (0.07-0.56)	0.34±0.17^{a} (0.03-0.64)	0.47±0.13^{a} (0.08-0.86)	0.40±0.10^{a} (0.08-0.72)	0.43±0.13^{a} (0.01-0.87)	0.33±0.18^{a} (0.02-0.64)
Transparency (cm)	66.17±2.74^{a} (45.12-67.22)	36.01±3.48^{b} (18.70-53.32)	57.29±2.24^{a} (45.44-69.14)	57.62±2.79^{a} (45.48-69.77)	58.82±4.57^{a} (45.73-71.91)	50.43±2.68^{a} (43.67-57.19)	56.69±3.47^{a} (44.18-69.19)	55.01±2.74^{a} (43.96-66.06)

Note:Means values with same superscripts along the rows were not significantly different at $p > 0.05$.

TDS=total dissolved solids, TSS=total suspended solids, EC=electrical conductivity, TUR=turbidity, DO=dissolved oxygen and BOD=biological oxygen demand.

Table 4.3. Mean values of physico-chemical parameters between seasons

	Range	Wet season	Range	Dry season	P – values	UNICEF, (2008)	FEPA, (1991)	Boyd, (1998)
TDS (mg/L)	65.68 – 217.00	205.15±0.35	30.02 – 45.71	40.76±11.69	0.00*	2000	2000	30 – 200
TSS (mg/L)	100.32 – 150.61	123.61±21.01	27.46 – 53.29	51.46±15.17	0.02*	25.00	30.00	< 10
EC (μScm^{-1})	5.63 – 15.07	9.05±3.16	24.30 – 30.31	22.19±0.43	0.04*	250	240	50 - 500
TUR (FTU)	10.89 – 51.24	45.71±3.93	20.49 – 35.88	25.47±4.89	0.01*	10	10	10
Temperature (^oC)	23.55 – 30.53	26.94±1.97	25.16 – 30.01	27.55±1.60	0.08**	24.5 – 33	20 – 33	25 – 32
DO (mg/L)	2.69 – 5.89	4.00±0.66	2.34 – 7.76	5.57±0.73	0.78**	> 4.0	>5	5 – 10
BOD (mg/L)	0.93 – 2.50	1.38±0.71	0.95 – 2.03	1.10±0.67	0.56**	>10	50	5
Ph	4.51 – 8.76	7.05±1.02	6.51 – 8.83	7.31±2.50	0.45**	6.8 – 8.9	6.5 – 9.0	6.5 – 8
Alkalinity (mg/L)	45.31 – 59.82	50.21±2.91	49.75 – 60.54	56.74±4.21	0.32**	20	20	20
Salinity (‰)	1.51 – 3.12	2.01±0.64	0.99 – 4.52	2.13±0.61	0.76**	5	5	5
Chloride (mg/L)	35.71 – 66.93	55.81±5.20	40.80 – 63.54	59.63±3.81	0.97**	250	250	0 – 75
Velocity (m/s^2)	0.26 – 1.09	0.41±0.21	0.18 – 1.25	0.15±0.14	0.00*	-	-	-
Transparency (cm)	30.34 – 45.18	36.75±5.12	47.49 – 65.32	54.16±6.85	0.00*	≤ 60	40 – 60	30 – 40

Note: * = There are significant differences ($p<0.05$) between means along rows;
** = There are no significant differences ($p>0.05$) between means along the rows
TDS=total dissolved solids, TSS=total suspended solids, EC=electrical conductivity, TUR=turbidity, DO=dissolved oxygen and BOD=biological oxygen demand.

Table 4. 4. Pearson's correlation coefficient of physico-chemical parameters

	TDS	TSS	EC	TUR	TEM	DO	BOD	PH	SAL	Cl	VEl	SDV	GPP	NPP	Mg	Ca	NH4	Nitra	PO4	SO4	Chlla	Nitri
TDS	1.00																					
TSS	0.06	1.00																				
EC	0.04	0.07	1.00																			
TUR	0.17	0.01	0.09	1.00																		
TEM	0.01	0.06	0.06	0.08	1.00																	
DO	-0.08	-0.09	-0.15	-0.01	-.23*	1.00																
BOD	0.04	0.02	0.07	0.01	.27**	-0.17	1.00															
pH	.22*	0.14	0.15	0.06	0.07	0.15	-0.03	1.00														
SAL	0.03	0.11	0.12	0.06	0.09	-0.02	-0.01	0.02	1.00													
Cl	0.13	0.05	0.03	0.02	0.02	-0.11	-0.08	0.15	0.07	1.00												
VEL	-0.04	-0.15	-0.10	-0.06	-0.12	.26**	-0.03	-0.09	-0.04	-0.12	1.00											
SDV	-0.06	-0.12	-0.02	-0.11	-0.05	0.14	-0.16	-0.06	-0.02	-0.12	.23**	1.00										
GPP	-0.15	-0.10	-0.01	-0.10	-0.02	0.04	-0.02	-0.10	-0.09	-0.15	0.07	0.08	1.00									
NPP	-0.09	-0.14	-0.03	-0.11	-0.05	0.11	-0.01	-0.15	-0.05	-0.02	0.03	0.10	0.09	1.00								
Mg	0.03	0.07	0.02	0.15	0.08	-0.17	0.05	0.05	0.02	0.02	-0.14	-0.04	-0.06	-0.01	1.00							
Ca	0.14	0.05	0.01	0.13	0.13	-0.02	0.11	0.16	0.04	0.01	-0.09	-0.10	-0.04	-0.03	0.05	1.00						
NH4	0.05	0.15	0.08	0.13	.21*	-.23**	0.04	0.04	-0.13	-0.01	-.24**	-0.10	-0.06	0.09	-0.04	-.18*	1.00					
Nitrate	0.03	0.15	0.08	0.09	.22*	-.24**	0.05	0.11	-0.07	-0.13	-.18*	-0.03	0.14	0.10	0.02	-0.03	.66**	1.00				
PO4	0.06	0.10	0.15	0.04	.32**	-.24**	0.11	0.06	-0.03	-0.04	-0.08	-0.04	0.02	0.01	0.06	0.03	.29**	.28**	1.00			
SO4	0.14	0.13	0.07	0.07	0.08	-0.11	0.07	0.05	-0.01	-0.09	-0.01	-0.06	-0.02	0.10	0.01	0.02	.21*	.19*	0.02	1.00		
Chlla	-0.03	-.20*	-0.06	-.19*	-0.16	.24**	-0.03	-0.06	-0.54	0.08	.37**	0.09	0.13	0.02	0.05	0.07	-.62**	.53**	.34**	0.17	1.00	
Nitrite	0.03	-0.01	0.01	0.03	0.02	-0.02	0.08	-0.06	-0.06	-0.08	-0.05	-0.01	0.03	-0.06	-0.16	-0.09	-0.17	-0.08	-0.06	-0.09	-.19*	1.00

**Correlation is significant at P<0.01 level (2 tailed)

* Correlation is significant at P<0.05 level (2 tailed)

The least mean of electrical conductivity recorded was 1.58±1.00 μScm^{-1} at Station 8, while the maximum was 43.26±39.62μScm^{-1} at Station 2. The mean values of EC varied from 9.05±3.16$\mu Scm^{-1}$to 22.19±0.43 μScm^{-1}wet and dry seasons. A positive relationship ($p<0.01$) existed between EC and TUR (r = 0.07), temperature (r = 0.06), BOD (r = 0.07) and pH (r = 0.15).

The mean values of Turbidity among stations were lowest 23.19±12.17 FTU at Station 1 and highest 43.59±16.29 FTU at Station. Seasonally, it ranged from 25.47±4.89 to 45.71±3.93 FTU in dry and wet seasons. Turbidity correlated positively with temperature (r = 0.08), BOD (r = 0.01), pH(r = 0.06), Salinity (Sal) (r = 0.12), Cl (r = 0.02), Magnessium (Mg) (r = 0.15), Ca (r = 0.13), Vel (r = -0.06), Transparency (r = -0.11), GPP (r = -0.10) and Chll-a (r = -0.19).

The mean values of water temperature recorded among the stations during the study period were 24.28±5.84 ^{o}C at Station 3, and 28.45±2.06 ^{o}C at Station 2. Seasonally, the least (26.94±1.97) ^{o}C and highest (27.55±1.60)^{o}C mean values of temperature wererecorded in wet and dry seasons. Temperature was positively correlated ($p<0.01$) with BOD (r = 0.27), pH (r = 0.07), Salinity (r = 0.09), Cl (r = 0.02), NH_4 (r = 0.21), Nitrate (0.22), PO_4-P (r =0.32) but negatively related with DO (r = -0.23), Vel (r = -0.12), transparency (r = -0.05) and Chll-a (r = -0.16).

Spatial and temporal concentrations of dissolved oxygen were generally less than 5.00 mg/L except during the late dry season. The highest mean DO concentration recorded among the stations was 4.52±0.56 mg/L at Station 1, and the lowest was 3.13±0.67 mg/L at Station 2. Mean values of DO recorded in wet and dry seasons were 4.00±.066 mg/L and 5.75±0.73 mg/L. There was a positive correlation between DO and Velocity (r = 0.26), transparency (r = 0.14), Chll-a (r = 0.24). A negative correlation also existed between DO and BOD (r = -0.17), pH(r = -0.15), Cl (r = -0.11), Mg (r = -0.17), Ca (r = -0.02), NH_4 (r = -0.23), nitrate (r = -0.24), PO_4 (r = -0.24).

The lowest spatial mean distribution of Biological Oxygen Demand among stations was 0.65±0.03 mg/Lin Station 1, while the highest was 1.59±0.65 mg/Lin Station 2. Seasonal variations showed that the highest (1.38±0.71) mg/L and least (1.10±0.67) mg/L mean values of BOD were recorded in wet and dry seasons. The BOD was positively correlated with Ca (r = 0.11), (r = 0.05), PO_4 (r = 0.11), nitrte (r = 0.08) and negative relationship with Vel (r = -

0.03), Transparency (r = -0.16) and Chll a (r = 0.03). Sources of BOD in aquatic environment are dead plants and animals, animal manure, industrial effluents, faulty septic tanks, market and urban storm water run-off.

The mean values of pH recorded among stations were 6.99±0.79 in Station 2, to 7.77±0.84 at Station 6. Wet season recorded the least (7.05±1.02) while the highest (7.31±2.50) mean values of pH. The pH positively correlated with Cl (r = 0.15), Vel (r = 0.09), Ca (r = 0.16), GPP (r = 0.10), NPP (r = 0.15), Chl-a (r = 0.06) while pH negatively correlated with nitrate (r = -0.11), PO_4 (r = -0.06) and nitrite (r = -0.06).

The lowest mean of total alkalinity among stations was 51.90±6.68 mg/L in Station 1, while the highest was 57.21±5.82mg/L in Station 8. Alkalinity varied from 50.21±2.91 to 56.74±4.21 in wet and dry seasons. Alkalinity was positively correlated ($p<0.01$) with Sal (r = 0.34), Cl (r = 0.23), TDS, (r = 0.63), TSS (r = 0.54) and inversely with Vel (r = -0.64), GPP (r = -0.27) and Chll-a (r = -0.45).

The least mean value of salinity recorded among Stations was 0.59±0.01 ‰ in Station 1, while the maximum was 3.861±0.60 ‰ in station 2. Between seasons, the least and higest mean values of salinity recorded were2.01±0.64 and 2.13±0.61 during the wet and dry seasons. The annual average mean for salinity recorded was 2.13±0.55 ‰. Salinity correlated ($p<0.01$) positively with Cl (r = 0.09) but negatively related with and transparency (r = 0.02).

The overall mean value of chloride measured was 59.84±16.55 mg/L. The minimum mean of chloride measured among stations was 58.65±22.67 mg/L in Station 1, while the maximum was 66.41±11.48 mg/L in Station 8. Mean value of chloride varied from 55.81±5.20 mg/L to 59.63±3.81 mg/L in wet and dry seasons. Chloride negatively correlated with Vel (r = -0.12), tansparency (r = -0.12), GPP (r = -0.15), Chll-a (r = -0.08).

The mean annual velocity of Gbalegbe River determined was 0.37±0.21 ms^{-1}. The lowest mean of velocity recorded among the stations was 0.31±0.16 ms^{-1} in Station 3, and the highest was 0.47±0.13 ms^{-1}in Station 5. The lowest seasonal variation in velocity recorded was 0.15±0.14 ms^{-1} in the dry season, while the highest was 0.41±0.21 during the wet season. Meanwhile, there exists positive correlation ($p<0.01$) between velocity and transparency (r = 0.23), Chll-a (r = 0.37) and negatively related with Mg (r = -0.14), NH_4 (r = -0.24), nitrate (r = -0.18) and nitrite (r = -0.05).

The lowest spatial distribution in the mean values of Transparency among the stations was 36.01±3.04 cm in Station 2, while the highest was 66.17±2.74 cm in Station 1. Seasonal mean values of transparency varied from 36.75±5.12 cm in wet season to 54.16±6.85 cm in dry season. The overall mean of transparency recorded was 57.26±22.76 cm. transparency correlated positively with NPP (r = 0.10), Chll-a (r = 0.09) but negative relationship exists with NH_4 (r = -0.10).

4.3 Waternutrients of Gbalegbe River

The mean values of water nutrients among stations and between seasons of Gbalegbe River are presented in Tables 4.5 and 4.6. Among the stations, the lowest mean of $NH_4$was 0.26±0.13 mg/L – Nin Station 1, while the highest was 0.66±0.18 mg/L – N in Station 2. Between seasons, the mean concentrations of NH_4 varied from 0.49±0.12 mg/L – N during wet season to 1.03±0.01 mg/L – N during the dry season. The lowest mean of nitrate concentration recorded was 1.07±0.03 mg/L – N in Station 6,while the highest was 1.76±0.21 mg/L – N in Station 2. Seasonal variation in the mean concentration of nitrate ranged from 0.98±0.43 mg/L – N to 1.05±0.64 during wet and dry seasons, respectively.

The lowest mean concentration of PO_4-P among the stations was 0.33±0.03 mg/L in Station 6, and the highest was 0.56±0.07 mg/L in Station 2. Seasonal mean concentrations of PO_4-P were0.51±0.20 mg/L and 0.63±0.09 mg/L in dry and wet seasons. Among the stations, the lowest mean value of SO_4 recorded was 0.82±0.21 mg/L in Station 4, while the highest was 1.63±0.26 mg/L in Station 8.Seasonal variation in the mean values of $S0_4$ between seasons ranged from 0.97±0.06 mg/L to 1.24±0.33 mg/L in wet and dry seasons, respectively.

4.4 Primary productivity of Gbalegbe River

The mean values of primary productivity among stations and between seasons in Gbalegbe River are presented in Tables 4.7 and 4.8. The lowest mean value of GPP was 10.05±0.90gC/m^2/d in Station 2 while, the highest mean concentration was 25.75±0.83 gC/m^2/d in Station 1. Seasonally, the mean values GPP ranged from 20.19±4.91 gC/m^2/ to35.34±6.37 gC/m^2/d during wet and dry season. The least average Net Primary Production (NPP) concentration was 7.59±1.41 gC/m^2/d in Station 2, while the highest was 14.24±1.71 gC/m^2/d in Station 1. The least seasonal mean value of NPPwas 15.69±3.88 in the wet season while the highest was 22.57±5.77 in the dry season, respectively.

Table 4.5. Mean values of water nutrient of Gbalegbe River among stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Ammonium (mg/L – N)	0.26±0.13[a] (0.11-0.8)	0.66±0.18[a] (0.27-1.05)	0.52±0.20[a] (0.10-0.95)	0.44±0.16[a] (0.10-0.79)	0.55±0.21[a] (0.11-0.10)	0.33±0.10[a] (0.12-0.55)	0.44±0.16[a] (0.09-0.78)	0.49±0.17[a] (0.12-0.85)
Nitrate (mg/L – N)	1.25±0.18[ab] (0.87-1.64)	1.76±0.21[a] (1.31-2.21)	1.33±0.18[ab] (0.96-1.71)	1.45±0.14[ab] (1.15-1.75)	1.45±0.16[ab] (1.12-1.79)	1.07±0.03[b] (0.79-1.36)	1.24±0.16[b] (0.90-1.57)	1.22±0.14[b] (0.92-1.51)
Phosphate – Phosporus (mg/L - P)	0.47±0.05[a] (0.41-0.61)	0.56±0.07[a] (0.21-0.52)	0.35±0.07[a] (0.20-0.51)	0.33±0.07[a] (0.18-0.47)	0.34±0.08[a] (0.17-0.51)	0.33±0.03[a] (0.18-0.47)	0.41±0.08[a] (0.24-0.57)	0.39±0.08 (0.23-0.56)
Sulphate (mg/L)	1.06±0.19[a] (0.24-1.36)	0.80±0.26[a] (0.78-1.48)	1.13±0.16[a] (0.38-1.26)	0.82±0.21[a] (0.83-1.73)	1.28±0.21[a] (0.84-1.75)	1.29±0.21[a] (0.60-1.80)	1.20±0.28[a] (1.11-2.16)	1.63±0.26[a] (0.99-1.31)
Mg (mg/L)	66.66±3.85[a] (64.61-68.70)	67.51±4.95[a] (62.87-68.14)	66.67±6.09[a] (63.42-69.91)	66.81±5.04[a] (64.13-69.50)	65.34±5.43[a] (62.44-68.23)	65.64±5.23[a] (62.85-68.43)	63.30±6.30[a] (59.94-66.65)	66.93±5.78[a] (63.85-70.01)
Ca (m/L)	30.44±2.89[a] (29.90-32.98)	31.36±2.65[a] (29.94-32.77)	32.10±2.30[a] (30.87-33.33)	32.69±1.49[a] (31.90-33.49)	32.82±3.02[a] (31.21-34.43)	30.98±2.90[a] (29.43-32.53)	22.61±2.42[a] (31.32-30.90)	32.38±2.60[a] (31.00-33.77)

Means with the same superscripts along the rows were not significantly different at P>0.05.

Table 4.6. Mean values of water nutrientof Gbalegbe River in wet and dry seasons

Parameters	Range	Wet season	Range	Dry season	P – value	UNICEF, (2008)	NIS, (2007)	Boyd, (1998)
Ammonia (mg/L – N)	0.15 – 1.06	0.49±0.12	0.50 – 2.03	0.23±0.05	0.00*	0.0 – 1.0	0.01 – 0.15	0.0 – 1.0
Nitrate (mg/L – N)	0.51 – 2.05	0.98±0.43	0.81 – 2.00	1.05±0.64	0.00**	0.01 – 2.5	0.01 – 2.5	0.1 – 3.0
Phosphorus (mg/L-P)	0.48 – 1.69	0.63±0.09	0.37 – 1.04	0.15±0.20	0.03*	250.0	250.0	0.12
SO_4 (mg/L)	0.47 – 1.50	0.97±0.06	0.68 – 1.98	1.24±0.33	0.07**	250.0	200.0	< 400
Nitrite (mg/L-N)	-	ND	-	ND	ND	0.00 – 0.05	0.00 – 0.05	0.0 – 0.5
Magnessium (Mg/L)	45.31 – 75.22	63.13±20.73	60.45 – 70.96	65.94±6.01	0.54**	-	-	150 – 200
Calcium (Mg/L)	25.23 – 40.24	35.30±6.76	29.17 – 42.15	3.01±1.37	0.01*	-	-	200

Note: * = There issignificantly different at $p<0.05$

** = There is no significant difference at $p>0.05$

Table 4.7. Mean primary productivity among stations

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Chll-a (µg/L)	39.15±5.15[a] (20.79-46.51)	9.11±3.57[b] (6.12-22.11)	11.98±8.33[a] (7.34-29.62)	12.55±6.90[a] (9.57-28.52)	13.35±2.75[a] (9.83-24.86)	12.45±2.60[a] (8.36-14.55)	10.84±4.31[a] (4.39-15.30)	11.21±8.39[a] (9.19-25.22)
GPP ($gC/m^2/d$)	25.75±0.83[a] (19.31-25.20)	10.05±0.90[c] (19.57-20.54)	19.91±0.84[b] (19.46-20.36)	19.59±0.67[b] (19.24-19.95)	19.65±0.88[b] (19.18-20.12)	19.90±0.96[b] (19.39-20.41)	19.58±0.70[b] (19.20-19.95)	20.15±0.83[b] (19.71-20.59)
NPP ($gC/m^2/d$)	11.24±1.71[a] (10.33-15.15)	7.59±1.41[b] (6.84-12.34)	11.19±2.06[a] (10.09-12.29)	11.71±1.96[a] (10.67-12.76)	11.00±2.11[a] (9.87-12.12)	10.71±1.97[a] (9.66-11.76)	10.73±1.99[a] (9.67-11.79)	10.89±1.92[a] (9.87-11.91)

Means with the same superscripts along rows were not significantly different at 0.05.
Note: Mg=magnesium, Ca=calcium, Chll-a=chlorophyll-a, GPP=gross primary production and NPP=net primary production

Table 4.8. Mean primary productivity between seasons

	Range	Wet season	Range	Dry season	WHO, (2001)	NIS, (2007)
Chll-a (µg/L)	4.35 – 9.64	7.86±0.60	14.56 – 23.18	19.23±3.91	15	>17
GPP ($gC/m^2/d$)	15.32 – 25.11	20.19±4.91	20.11 – 40.10	35.34±6.37		
NPP ($gC/m^2/d$)	10.97 – 19.45	15.69±3.88	16.27 – 30.61	22.57±5.77		

Means with the same superscripts along the rows were not significantly different at $p>0.05$.
Note: Mg=magnesium, Ca=calcium, Chll-a=chlorophyll-a, GPP=gross primary production and NPP=net primary production.

The least mean value of Chlla was 9.11±3.57 µg/L in Station 2, while the highest was 39.15±5.57 µg/Lin Station 1. Seasonal variation in the mean concentrations of Chlla ranged from 7.86±0.60 during the wet season to 19.23±3.91during the dry season.The least mean of magnessium was 63.30±6.30 mg/L in Station 7,while the highest was 67.51±4.95 mg/L in Station 2. Seasonal variation in the concentration of Mg ranged from 63.13±0.09 mg/L in the wet seson to 65.95±6.01 mg/L during the dry season. The minimum mean of calciumconcentration was recorded inStation 7, with a mean of 22.61±2.42 mg/L, while the highest was 32.82±3.02 mg/Lin Station 5. Seasonal variation in the mean concentration of Caranged from 33.01±1.37 mg/L in the dry season to 35.30±6.76 in the wet season.

4.5 Principal component analyses (PCA) for physico-chemical parameters

The Eigen values and correlation matrix among physico – chemical parameters are shown in Tables 4.9 and 4.10, while the component plot rotated space for physico – chemical parameters is shown in Figure 4.1. Eigen values indicated that, the first three principal components (PC) were the most significant (> 1). These extracted components accounted for 38.45% of the total variance in physico-chemical parameters. Principal Component (PC) 1 accounted for 18.48% of the total variance in the physicochemical parameters and correlated negatively with Chll a (r = -0.83), Transparency (r = -0.74) and Velocity (r = -0.65). The PC 2 described 10.60% of the total variance that existed among the physicochemical parameters of the river and correlated negatively with TDS (r = -0.72), Salinity (r = -0.75), while PC 3 accounted for 9.37% variance in the physico-chemical parameters of Gbalegbe River and correlated positively with turbidity (r = 0.79).

4.6 Phytoplankton abundance and species diversity

The composition, distribution, abundance and checklists of phytoplankton species for wet season are shown in Tables 4.11 and 4.12. Phytoplankton species abundance and checklists for dry season are shown in Tables 4.13 and 4.14, while the diversity indices of phytoplankton species among stations and between seasons are shown in Tables 4.15 and 4.16. Monthly phytoplankton species abundance are shown in Appendices 3 and 4. Monthly phytoplankton species checklists are presented in Appendices 5 and 6. The total individual number of phytoplankton recorded during the study was 981. In the wet season, 3 orders, 4 families and 25 species of phytoplankton were recorded. Station 1 had the highest individual number consisting of 106 (17.2%) phytoplankton respectively.

Table 4.9. Eigen valuesof physico-chemical parameters of Gbalegbe River

Component	Initial Eigenvalues			Rotation Sums of Squared Loadingsa
	Total	% of Variance	Cumulative %	Total
1	2.77	18.48	18.48	2.70
2	1.59	10.60	29.08	1.45
3	1.41	9.37	38.45	1.51
4	1.31	8.74	47.19	1.36
5	1.22	8.16	55.35	1.39
6	1.10	7.35	62.70	1.23
7	0.98	6.50	69.20	
8	0.97	6.47	75.67	
9	0.79	5.29	80.95	
10	0.73	4.89	85.84	
11	0.64	4.25	90.08	
12	0.46	3.05	93.14	
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22	0.27	1.80	100	

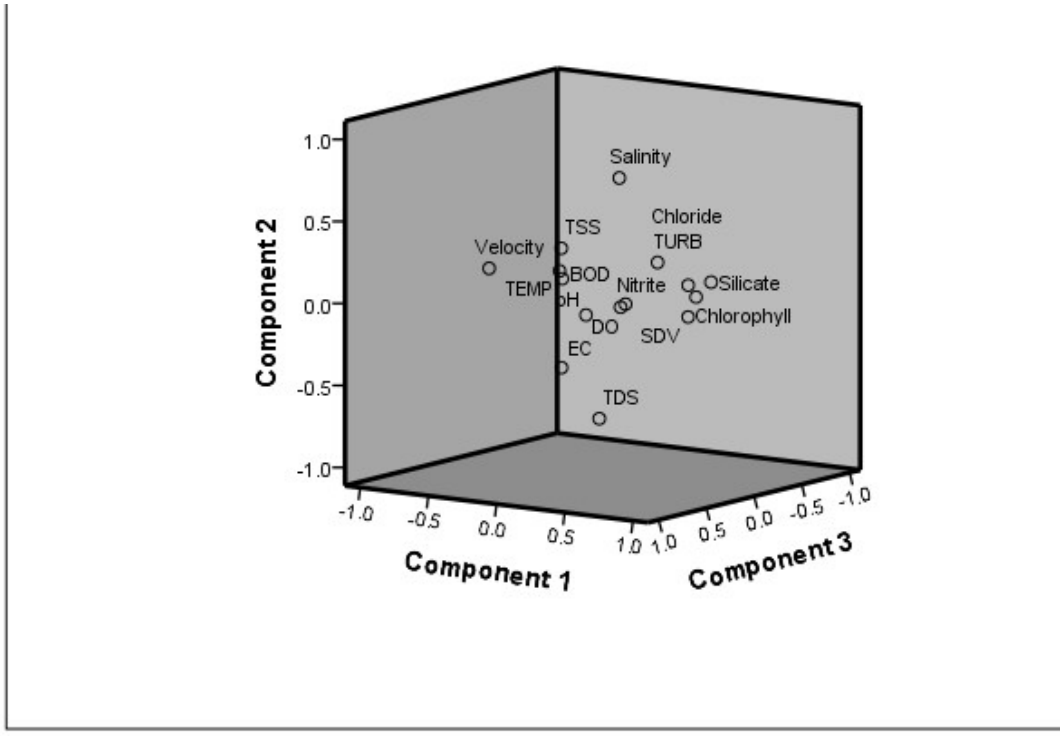

Figure 4.1. Component plot rotated space for physicochemical parameters of Gbalegbe River, Delta State.

Table 4.10. Correlation matrix amongphysico-chemical parameters

Variable	Components					
	1	2	3	4	5	6
TDS	0.05	**0.72**	0.20	-0.08	-0.02	0.18
TSS	0.30	0.24	0.09	-0.04	0.23	-0.36
EC	0.15	0.45	0.28	0.28	-0.06	-0.51
TURB	0.04	0.10	**0.79**	-0.01	0.02	0.02
TEMP	0.21	0.18	0.46	0.06	-0.65	0.32
DO	-0.19	-0.01	-0.07	-0.84	-0.02	-0.03
BOD	0.14	0.11	0.06	0.08	0.75	-0.08
Ph	0.20	0.13	0.08	0.05	-0.07	0.76
Nitrite	0.23	-0.03	0.05	0.34	0.56	0.24
Salinity	0.19	**-0.75**	0.03	-0.01	0.04	0.02
Chloride	0.57	0.09	0.24	0.51	0.10	-0.27
Silicate	0.61	0.10	-0.46	0.07	0.03	-0.10
Chlorophylla	**-0.83**	-0.11	-0.11	0.03	0.00	-0.04
Velocity	**-0.65**	-0.13	-0.50	0.34	-0.10	0.05
Transparency	**-0.74**	-0.02	-0.04	-0.25	0.09	0.01

Note: TDS = total dissolved solids, TSS = total suspended solids, EC = electrical conductivity, TURB = turbidity, TEMP = temperature, DO = dissolved oxygen, BOD = biological oxygen demand

Table 4.11. Composition, distribution and abundance of phytoplankton for wet season

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Fragillariaceae	*Fragillaria striatula*	5	1	1	1	7	2	9	3	29	4.7
	Thalassionema nitzschia	1	1	3	0	6	3	3	4	21	3.4
	Ceratium horridum	6	1	1	2	9	5	6	0	30	4.9
	Fragillariopsis sp	4	2	3	1	0	3	0	2	15	2.4
	Pseudo-Nitzschia autralis	8	1	8	1	4	5	7	8	42	6.8
Bidulphiceae	*Biddulphia autita*	9	5	7	0	1	1	1	4	28	4.5
	Ceratophyllum demersum	6	1	1	2	0	1	2	5	18	2.9
	Vallisnaria sp	4	1	5	3	4	2	7	5	31	5.0
	Anabaena sp	3	3	1	3	1	0	3	3	17	2.8
Soleniceae	*Lauderia annulata*	2	1	2	1	0	2	3	5	16	2.6
	Proboscia alata	1	2	3	8	0	1	8	8	31	5.0
	Nitella turcata	4	1	4	6	3	2	5	1	26	4.2

Table 4.11. Composition, distribution and abundance of phytoplankton for wet season cont'd

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Soleniceae	*Potamogeton pectinatus*	2	0	2	1	7	4	0	6	22	3.6
	Nostoc sp	5	1	3	4	2	5	0	1	21	3.4
	Blastoschizomyces capitatu	3	0	3	1	3	2	1	2	15	2.4
	Microcystic sp	4	1	0	1	7	2	0	3	18	2.9
	Oscillatoria sp	0	3	2	6	3	1	0	4	19	3.1
	Macroconidium persicolor	5	2	1	4	1	3	1	0	17	2.8
	Pinnularia viridis	1	1	7	0	1	2	2	3	17	2.8
	Prorocentrum mican	3	0	8	2	0	6	2	5	26	4.2
	Ttichophyton ajelloi	0	1	0	0	0	0	0	0	1	0.1
	Alexandrium sp	6	2	0	3	7	0	3	2	23	3.7
	Lioloma pacificum	1	1	0	4	0	3	2	3	14	2.3
	Potamogeton pectinatus	2	4	3	3	6	3	6	0	27	4.4
	Rhizosolenia sp	5	0	4	3	4	2	5	2	25	4.0
	Total	106	41	79	68	91	63	86	90		
	% Abundance	17.2	6.6	12.8	11.0	14.7	10.2	13.9	14.6		

Table 4.12. Checklist of phytoplankton species during wet season

		Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Families	Species								
Fragillariaceae	*Fragillaria striatula*	+	+	+	+	+	+	+	+
	Thalassionema nitzschia	+	+	+	-	+	+	+	+
	Ceratium horridum	+	+	+	+	+	+	+	-
	Proboscia alata	+	-	+	+	+	+	+	+
	Fragillariopsis sp	+	+	+	+	-	+	-	+
	Pseudo-Nitzschia autralis	+	+	+	+	+	+	+	+
Bidulphiceae	*Biddulphia autita*	+	+	+	-	+	+	+	+
	Ceratophyllum demersum	+	+	+	+	-	+	+	+
	Vallisnaria sp	+	+	+	+	+	+	+	+
	Proboscia alata	+	+	+	+	+	-	+	+
	Anabaena sp	+	+	+	+	+	-	+	+
Soleniceae	*Lauderia annulata*	+	+	+	+	-	+	+	+
	Proboscia alata	+	+	+	+	-	+	+	+
	Nitella turcata	+	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.12. Checklist of phytoplankton species during wet season of Gbalegbe River, Delta State, Nigeria Cont'd

		Stations							
Families	Species	S1	S2	S3	S4	S5	S6	S7	S8
Soleniceae	*Potamogeton pectinatus*	+	-	+	+	+	+	-	+
	Nostoc sp	+	+	+	+	+	+	-	+
	Blastoschizomyces capitatu	+	-	+	+	+	+	+	+
	Microcystic sp	+	+	-	+	+	+	-	+
	Oscillatoria sp	-	+	+	+	+	+	-	+
	Anabaena sp	+	+	+	-	+	-	+	+
	Macroconidium persicolor	+	+	+	+	+	+	+	-
	Pinnularia viridis	+	+	+	-	+	+	+	+
	Prorocentrum mican	+	-	+	+	-	+	+	+
	Ttichophyton ajelloi	-	+	-	-	-	-	-	-
	Alexandrium sp	+	+	-	+	+	-	+	+
	Lioloma pacificum	+	+	-	+	-	+	+	+
	Potamogeton pectinatus	+	+	+	+	+	+	+	-
	Rhizosolenia sp	+	-	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.13: Composition, distribution and abundance of Phytoplankton for dry season

Families	*Species*	Stations								Total	%Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Soleniceae	*Lauderia annulata*	7	0	2	1	5	1	2	9	27	3.6
	Bacteriastum hyalinum	1	0	4	0	2	0	1	7	15	2.0
	Ceratophyllum demersum	4	0	1	3	0	2	1	6	17	2.2
	Nitella turcata	0	3	5	3	4	2	0	1	18	2.4
	Rhizosolenia sp	4	0	3	0	0	0	3	0	10	1.3
	Alexandrium sp	1	1	0	1	1	3	9	0	16	2.1
	Chara sp	4	1	2	2	2	2	4	0	17	2.2
	Pseudo-Nitzschia autralis	1	1	1	0	0	1	1	5	10	1.3
	Typha sp	7	2	7	0	0	0	1	6	23	3.0
	Proboscia alata	1	2	1	1	6	7	2	3	23	3.0
	Microcystic sp	0	1	0	0	3	0	0	3	7	0.9
Fragillariaceae	*Fragillariopsis* sp	1	2	0	0	0	1	2	0	6	0.8
	Fragellaria oceanica	4	0	3	1	2	7	0	1	18	2.4
Epithemiaceae	*Pseudo-Nitzschia autralis*	2	3	1	7	1	0	0	3	17	2.2
Bidulphiceae	*Biddulphia aurita*	3	2	0	0	0	0	2	3	10	1.3
	Pandorina sp	3	1	1	6	2	3	0	1	17	2.2
Naviculaceae	*Navicula riparia*	4	3	1	1	0	4	1	0	14	1.8
	Potamogeton pectinatus	2	0	2	9	8	0	2	0	23	3.0
	Total	49	27	35	40	41	37	33	48		
	% Abundance	6.5	3.6	4.6	5.3	5.4	4.9	4.4	6.3		

Table 4.14. Checklist of phytoplankton species during dry season

Families	*Species*	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Soleniceae	*Lauderia annulata*	+	-	+	+	+	+	+	+
	Bacteriastum hyalinum	+	-	+	-	+	-	+	+
	Ceratophyllum demersum	+	-	+	+	-	+	+	+
	Nitella turcata	-	+	+	+	+	+	-	+
	Rhizosolenia sp	+	-	+	-	-	-	+	-
	Alexandrium sp	+	+	-	+	+	+	+	-
	Chara sp	+	+	+	+	+	+	+	-
	Pseudo-Nitzschia autralis	+	+	+	-	-	+	+	+
	Typha sp	+	+	+	-	-	-	+	+
	Proboscia alata	+	+	+	+	+	+	+	+
	Microcystic sp	-	+	-	-	+	-	-	+
Fragillariaceae	*Fragillariopsis* sp	+	+	-	-	-	+	+	-
	Fragellaria oceanica	+	-	+	+	+	+	-	+
Epithemiaceae	*Pseudo-Nitzschia autralis*	+	+	+	+	+	-	-	+
Bidulphiceae	*Biddulphia aurita*	+	+	-	-	-	-	+	+
	Pandorina sp	+	+	+	+	+	+	-	+
Naviculaceae	*Navicula riparia*	+	+	+	+	-	+	+	-
	Potamogeton pectinatus	+	-	+	+	+	-	+	-
	Anabaena sp	-	+	+	+	+	+	+	-

Note: + = present and - = absent

Table 4.15. Diversity indices for phytoplankton species among stations

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Dominance (D)	0.14	0.21	0.10	0.09	0.10	0.12	0.09	0.10
Simpson (1-D)	0.86	0.79	0.90	0.91	0.90	0.88	0.91	0.90
Shannon (H)	2.69	2.27	2.77	3.08	3.00	2.77	3.01	3.07
Evenness (E)	0.64	0.44	0.66	0.87	0.80	0.69	0.86	0.83
Margalef	4.96	1.91	2.39	2.62	2.61	2.39	2.63	2.56

Table 4.16. Diversity indices for phytoplankton species between seasons

Indices	Wet season	Dry season
Dominance (D)	0.36	0.16
Simpson (1-D)	0.64	0.84
Shannon (H)	3.61	2.07
Evenness (E)	0.54	0.37
Margalef	2.42	2.24

Stations 3 and 9 ranked next with individual number of phytoplankton as 79 (12.8%) and 91 (14.7%). Station 2 recorded the least individual number of phytoplankton as 41 (6.6%). *Potamogeton pectinatus*, 43 (4.38%) and *Ttichophyton ajelloi*, 1 (0.10%) were recorded as the most and least abundant phytoplankton, respectively. During the dry season, 3 orders, 5 families and 18 species of phytoplankton were identified. The highest individual number of phytoplankton was recorded in station 1 as 49 (6.5%). Stations 5 and 8 ranked next with individual number of phytoplankton as 41 (5.4%) and 48 (6.3%), while station 2 recorded the least with individual number as 27 (3.6%). The most and least abundant phytoplankton recorded were *Pseudo – Nitzschia autralis* 60 (6.9%) and *Bidulphia aurita* 10 (1.14%).

Highest (4.96) and least (1.91) Margalef index were at recorded in Stations 1 and 2; Shannon-H (3.08, 2.7); E (0.87, 0.44) in stations 4 and 2. Highest and least Shannon were 3.61 and 2.07, Evenness (0.83, 0.17) and Dominance (D) (0.36, 0.16) were obtained in wet and dry seasons, while Simpson (1 – D) (0.84, 0.64) and Margalef (2.42, 2.24) were recorded in dry and wet seasons, respectively.

4.6.1 Principal components analyses (PCA) for phytoplankton species abundance

The Eigen values of phytoplankton species and physico – chemical parameters are shown in Table 4.17, Components correlatiom matrix for phytoplankton species and physico – chemical parameters are shown in Table 4.18, Components plot rotated space for phytoplankton species and physico – chemical parameters are shown in Figure 4.2. Eigen values showed that the first three components were the most significant (> 1) and they accounted for 58.53% of the total variance among physicochemical parameters and phytoplankton abundance in Gbalegbe River.

The PC 1accounted for 24.43% of the total variance in the physicochemical parameters and phytoplankton abundance and positively correlated with*Pinninularia viridis* (r = 0.68), *Thalassionema nitzschia* (r = 0.85), but negatively withEC (r = -0.97), *Bidulphia aurita* (r = -0.71), Transparency (r = -0.58), chloride (r = -0.81), TDS (r = -0.95) and nitrate (r = -81). Conversely, PC 2 makes up 18.33% of the total variance in the abundance of phytoplankton and physicochemical parameters in Gbalegbe River. The PC 2 correlated positively with *Oscillatoria* sp (r = 0.89), *Microcystic* species (r = 0.95), SiO_2 (r = 0.95), *Potamogeton pectinatus* (r =0.78), *Fragillaria striatula* (r = 0.80), *Spirogyra* species (r = 0.69) and *Rhizosolenia* species (r = 0.74).

Table 4.17. Eigen values of phytoplankton and physicochemical parameters

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			RSSL
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1.00	12.95	24.43	24.43	12.95	24.43	24.43	9.45
2.00	9.72	18.33	42.77	9.72	18.33	42.77	9.57
3.00	8.35	15.76	58.53	8.35	15.76	58.53	9.11
4.00	7.55	14.24	72.76	7.55	14.24	72.76	7.63
5.00	6.16	11.63	84.39	6.16	11.63	84.39	7.96
6.00	4.34	8.19	92.58	4.34	8.19	92.58	7.58
7.00	3.93	7.42	100.00	3.93	7.42	100.00	7.92
8.00	0.00	0.00	100.00				
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53	2.10	3.96	100				

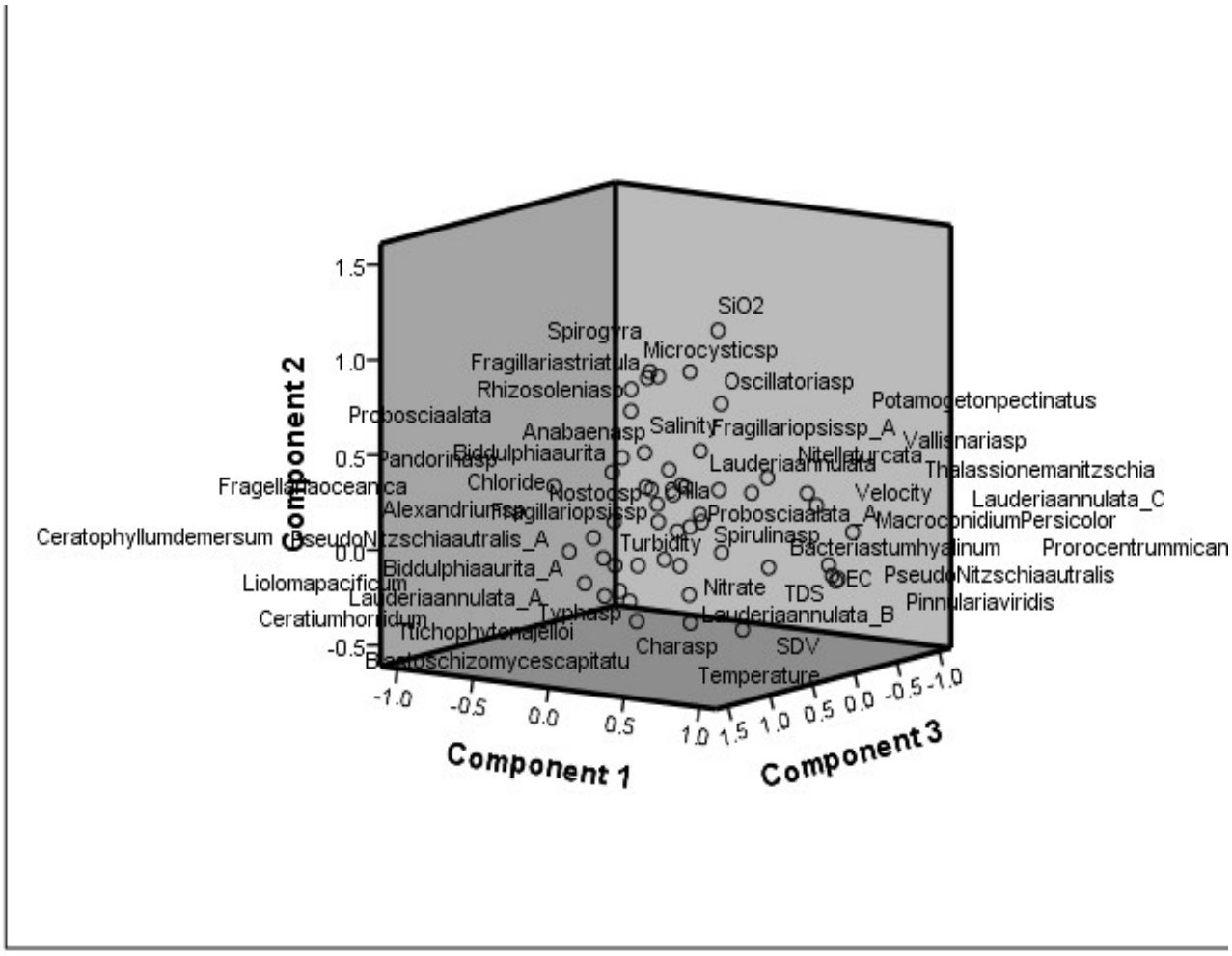

Figure 4.2. Component plot rotated space for physico-chemical parameters and phytoplankton species

Table 4.18. Components correlation matrix for phytoplankton species and physico-chemical parameters

Variables	Components						
	1	2	3	4	5	6	7
Fragillaria striatula	-0.40	0.80	0.37	-0.07	0.25	0.33	0.42
Ttichophyton ajelloi	-0.41	-0.40	-0.53	-0.04	-0.30	0.12	-0.67
Alexandrium sp	0.08	0.56	0.52	0.78	0.06	0.03	-0.01
Lioloma pacificum	-0.05	0.20	0.94	-0.15	0.05	0.09	0.04
Potamogeton pectinatus	0.31	0.78	0.13	0.41	-0.21	0.31	-0.42
Rhizosolenia sp	-0.49	0.74	0.16	0.42	0.24	0.27	0.23
Anabaena sp	-0.53	0.37	0.22	-0.04	0.15	0.10	0.85
Pinnularia viridis	0.68	-0.38	-0.30	-0.43	-0.10	0.08	0.16
Prorocentrum mican	0.36	0.23	0.52	-0.03	-0.13	0.68	0.44
Ceratophyllum demersum	-0.38	0.31	0.70	0.24	0.19	0.39	0.67
Vallisnaria sp	0.58	0.27	0.19	0.06	0.10	-0.73	-0.07
Thalassionema nitzschia	0.83	0.34	0.27	-0.16	-0.22	0.19	0.00
Ceratium horridum	-0.45	0.22	0.84	-0.13	0.25	0.04	0.63
Nostoc sp	0.03	0.44	0.72	0.27	0.39	-0.45	0.43
Blastoschizomyces capitatu	-0.14	-0.17	0.59	0.09	0.59	0.32	0.65
Microcystic sp	-0.07	0.95	0.51	0.30	0.02	0.02	0.11
Oscillatoria sp	-0.03	0.89	0.17	0.30	-0.42	0.17	0.09
Pseudo-Nitzschia autralis	0.25	-0.19	0.05	0.06	0.30	0.10	0.86
Bacteriastum hyalinum	-0.11	-0.21	0.02	0.51	0.60	-0.56	0.41
Fragillariopsis sp	0.15	0.63	0.75	-0.24	-0.04	0.43	0.14
Pseudo-Nitzschia autralis	-0.16	-0.13	0.14	0.46	0.87	-0.30	0.32
Biddulphia aurita	-0.71	-0.34	-0.22	-0.16	0.22	-0.53	0.30
Pandorina sp	-0.07	0.59	0.78	-0.20	0.15	-0.34	0.07
Chara sp	-0.34	-0.08	0.50	-0.41	0.08	-0.43	0.64
Navicula riparia	0.12	0.16	0.76	0.12	-0.38	-0.05	-0.12
TDS	-0.95	-0.2	-0.20	0.20	-0.14	-0.21	-0.31
TSS	0.16	0.25	0.04	0.33	-0.85	0.35	-0.03
EC	-0.97	-0.22	-0.22	0.15	-0.13	-0.15	-0.28
Turbidity	0.54	0.05	-0.04	-0.36	-0.67	0.09	0.31
Temperature	0.17	-0.51	0.04	-0.21	0.54	-0.69	-0.22
DO	-0.30	-0.02	0.00	-0.37	0.84	-0.21	0.12
pH	-0.06	0.49	0.30	-0.06	-0.56	0.76	0.11
Nitrate	-0.81	-0.22	-0.39	0.10	-0.50	-0.15	-0.22
Salinity	0.23	0.35	-0.17	0.07	0.14	0.84	0.16
Chloride	0.81	0.38	0.35	0.13	0.06	0.40	0.43
SiO_2	0.03	0.95	0.05	0.04	-0.22	0.07	-0.10
Chlla	0.38	0.32	0.08	-0.17	-0.80	-0.14	-0.37
Velocity	0.47	-0.08	-0.75	0.50	-0.11	0.11	-0.32
Transparency	-0.58	-0.24	-0.55	-0.11	0.33	-0.07	0.43

The, PC 3 make up 15.76% of the total variance in the physicochemical parameters and phytoplankton abundance of Gbalegbe River but correlated negatively with transparency (r = - 0.55), velocity (r = - 0.75) and positively with *Pandorina* species (r = 0.78), *Navicula riparian* (r = 0.76), *Ceratium horridium* (r = 0.84), *Fragillariopsis* species (r = 0.75), *Rhizosolenia* sp (r = 0.74), *Lioloma pacificum* (r = 0.94), *Ceratophyllum demersum* (r = 0.70) and *Nostoc* sp (r = 0.72).

4.7 Zooplankton abundance and species diversity

The composition, distribution and abundance and checklist of zooplankton for wet season in Gbalegbe River are presented in Tables 4.19 and 4.20. The composition, distribution, abundance and checklist of zooplankton species are shown in Tables 4.21 and 4.22, diversity indices for zooplankton species among stations and between seasons are presented in Tables 4.23 and 4.24, monthly zooplankton species abundance (wet and dry seasons) are presented in Appendices 7 and 8, while monthly zooplankton species checklists for wet and dry seasons are shown in Appendices 9 and 10, respectively.

The total individual number of zooplankton recorded during the study was 5,545. In the wet season, 8 orders, 10 families and 23 species of Zooplankton were identified. Station 1 recorded the highest individual number of zooplankton as 536 (18.5%). Stations 4 and 7 ranked next with individual number of zooplankton sampled as 489 (14.7%) and 481 (14.3%), while the least occurred in Station 2 as 364 (8.9%). The most abundant zooplankton recorded was *Calanus* sp, 251 (3.1%) while the least was *Harpacticoid copepods* 16 (0.4%).

Table 4.19. Composition, distribution and abundance of zooplankton for wet season

Families		Stations								Total	%Abundance
	Species	S1	S2	S3	S4	S5	S6	S7	S8		
Cyclopoidae	*Cyclops* sp	143	2	7	20	23	21	15	17	249	3.0
Cyclopidae	*Eucyclops speratus*	2	2	8	23	14	130	50	17	236	2.9
Diaptomidae	*Calanoid* sp	12	0	102	7	9	6	7	0	143	2.5
	Diaptomus sp	65	0	0	8	5	0	7	4	89	1.9
	Calanoid copepod	1	4	6	13	11	1	24	17	77	1.4
Daphniidae	*Calanus* sp	100	3	20	2	1	0	0	3	129	2.8
	D. longispina	2	0	7	21	0	20	24	16	90	1.3
	Dphnia sp	14	4	23	10	9	4	5	2	71	1.7
	D. similies	2	2	8	11	21	19	13	10	86	1.5
	Diaptomus sp	8	24	40	7	10	24	23	7	251	3.1
	Simocephalus vetulus	12	4	8	16	17	15	24	17	113	2.2
	Cyclotella striata	12	2	10	21	15	16	0	19	195	2.9
Chydoridae	*Moinodaphnia* sp	13	2	7	0	20	17	27	17	103	2.6
	Alona monacantha	1	5	9	6	133	26	0	15	263	2.9
	Chydorus sp	2	4	6	2	10	23	6	4	87	1.6
	Cmtocercus sp	1	5	0	8	1	4	1	0	60	1.5
Bosminidae	*Alona davidi*	10	4	8	5	23	70	7	16	153	2.3
	Bosmina longirostris	12	3	11	23	4	0	9	16	85	1.5
Moinidae	*Moina micrura*	4	4	9	8	12	30	4	14	105	1.9
Brachioniidae	*Brachionus caudatus*	43	4	8	140	5	7	1	15	223	2.7
Harpacticoida	*Harpacticoid copepod*	4	110	143	2	0	3	4	2	16	0.4
	Total	536	364	376	489	427	385	481	464		
	%Abundance	18.5	8.9	10.5	14.7	12.0	9.5	14.3	11.6		

Table 4.20. Checklist of zooplankton during wet season

Families		Stations							
	Species	S1	S2	S3	S4	S5	S6	S7	S8
Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	+	+
Cyclopidae	*Eucyclops speratus*	+	+	+	+	+	+	+	+
Diaptomidae	*Calanoid* sp	+	-	+	+	+	+	+	-
	Diaptomus sp	+	-	-	+	+	-	+	+
	Calanoid copepod	+	+	+	+	+	+	+	+
Daphniidae	*Calanus* sp	+	+	+	+	+	-	-	+
	D. longispina	+	-	+	+	-	+	+	+
	Dphnia sp	+	+	+	+	+	+	+	+
	D. similies	+	+	+	+	+	+	+	+
	Diaptomus sp	+	+	+	+	+	+	+	+
	Simocephalus vetulus	+	+	+	+	+	+	+	+
	Cyclotella striata	+	+	+	+	+	+	-	+
Chydoridae	*Moinodaphnia* sp	+	+	+	-	+	+	+	+
	Alona monacantha	+	+	+	+	+	+	-	+
	Chydorus sp	+	+	+	+	+	+	+	+
	Cmtocercus sp	+	+	-	+	+	+	+	-
Bosminidae	*Alona davidi*	+	+	+	+	+	+	+	+
	Bosmina longirostris	+	+	+	+	+	-	+	+
Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	+
	B. falcatus	+	-	+	+	+	+	+	+
Phasmidae	*Haplopus evadne*	+	+	+	+	-	+	+	+
Harpacticoida	*Harpacticoid copepod*	+	+	+	+	-	+	+	+

A**Note:** + = present and - = absent

Table 4.21. Composition, distribution and abundance of zooplankton for dry season

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Cyclopoidae	*Cyclops* sp	10	1	9	9	0	17	2	12	60	1.8
Cyclopidae	*Eucyclops speratus*	8	0	9	0	0	7	16	16	56	1.3
Diaptomidae	*Calanoid* sp	12	1	2	4	1	0	7	8	35	0.8
	Diaptomus augustaensis	2	2	5	10	20	9	14	61	89	1.7
Arietellidae	*Calanoid copepod*	9	3	7	4	14	1	22	17	77	1.4
	Pontellid copepod	13	0	1	7	4	2	4	2	33	0.5
	Pseudocyclops giussanii	27	3	3	8	5	5	5	9	65	1.2
Daphniidae	*D. longispina*	34	5	10	1	4	9	6	3	72	1.5
	*Diaptomus*sp	73	2	11	15	13	11	15	17	127	3.0
	Simocephalus vetulus	11	10	8	15	19	3	16	16	98	1.9
Chydoridae	*Moinodaphnia* sp	9	0	11	15	16	9	17	15	92	1.5
	Alona monacantha	32	0	7	12	6	5	3	24	89	1.4
Bosminidae	*A. davidi*	12	0	10	14	9	19	5	22	91	2.2
	Bosmina longirostris	21	0	9	3	11	23	15	16	98	1.9
Moinidae	*Moina micrura*	4	4	9	8	12	30	4	14	105	1.9
Brachioniidae	*Brachionus caudatus*	43	4	8	140	5	7	1	15	122	2.8
	Brachionus sp	12	43	0	23	65	20	4	5	112	2.1
Harpacticidae	*Harpacticoid copepod*	16	5	4	6	16	17	22	23	103	2.0
-------	*Camtocercus* sp	9	1	52	4	9	54	15	8	94	1.8
---------	*Haplopus evadne*	34	152	6	4	11	14	8	16	199	2.9
	Total	561	237	343	358	406	413	350	423		
	% Abundance	17.1	7.1	10.4	10.8	12.3	12.5	12.8	16.7		

Table 4.22. Checklist of zooplankton during dry season

Families	Species	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Cyclopoidae	*Cyclops* sp	+	+	+	+	-	+	+	+
Cyclopidae	*Eucyclops speratus*	+	-	+	-	-	+	+	+
Diaptomidae	*Calanoid* sp	+	+	+	+	+	-	+	+
	Diaptomus augustaensis	+	+	+	+	+	+	+	+
	Notodiatomus deitersi	+	+	+	+	+	+	+	+
Arietellidae	*Calanoid copepod*	+	+	+	+	+	+	+	+
	Pontellid copepod	+	-	+	+	+	+	+	+
	Pseudocyclops giussanii	+	+	+	+	+	+	+	+
Daphniidae	*D. longispina*	+	+	+	+	+	+	+	+
	D. similies	+	-	+	+	+	+	+	+
	Simocephalus vetulus	+	+	+	+	+	+	+	+
Chydoridae	*Moinodaphnia* sp	+	-	+	+	+	+	+	+
	Alona monacantha	+	-	+	+	+	+	+	+
Bosminidae	*A. davidi*	+	-	+	+	+	+	+	+
	Bosmina longirostris	+	-	+	+	+	+	+	+
Moinidae	*Moina micrura*	+	-	+	+	+	+	+	+
Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	+
Podonidae	*Evadne* sp	+	+	+	+	+	+	+	+
Harpacticidae	*Harpacticoid copepod*	+	+	+	+	+	+	+	+
Strombidae	*Brachionus* sp	+	+	+	+	+	+	+	+
Simidae	*Camtocercus* sp	+	+	+	+	+	+	+	+
Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	Haplopus evadne	+	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.23. Diversity indices for zooplankton species among stations

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Dominance(D)	0.03	0.06	0.03	0.15	0.17	0.05	0.13	0.03
Simpson(1-D)	0.97	0.94	0.97	0.85	0.83	0.95	0.87	0.97
Shannon(H)	4.50	3.47	4.28	2.85	2.86	4.26	3.13	4.28
Evenness (E)	0.75	0.49	1.00	0.21	0.22	0.63	0.22	0.71
Margalef	4.37	2.98	2.75	2.63	2.60	2.79	2.82	2.69

Table 4.24. Diversity indices for zooplankton species between seasons

Parameters	Wet season	Dry season
Dominance (D)	0.21	0.14
Simpson (1 – D)	0.79	0.86
Shannon (H)	3.81	2.27
Evenness (E)	0.72	0.41
Margalef	2.88	2.19

Margalef diversity index described the wholesomeness of a particular water body. The highest and least Margalef index recorded were 4.37 and 2.60 at Stations 1 and 5; Shannon (4.50, 2.85) in Stations 1 and 4; Evenness (1.00, 0.21) in stations 3 and 4, respectively. Margalef ranged from 2.19 to 2.88; Evenness (0.41, 0.72); Shannon (2.27, 3.81) and Dominance (0.14, 0.21) in dry and wet season, but Simpson (1 – D) ranged from 0.79 to 0.86 in wet and dry seasons, respectively.

4.7.1 Principal component analyses (PCA) for physico – chemical parameters and zooplankton abundance

The Eigen values of physico – chemical parameters and zooplankton of Gbalegbe River and correlation matrix between physico – chemical parameters and zooplankton species abundance are presented in Tables 4.25 and 4.26, while component plot rotated space for zooplankton species and physico – chemical parameters is presented in Figure 4.3. Eigenvalues showed that, the first three principal components (PC) are the most significant (> 1). These extracted components explained 79.41% of the total variation in the physicochemical parameters and zooplankton abundance of Gbalegbe River. PC 1 explained 50.34% of the variance and correlated negatively with *Cyclops* sp (r = -0.96), *Calanus* sp (r = -0.97), *Daphnia* sp (r = -0.97), *D. longirostris* (r = -0.99), *D. similies* (r = -0.86), *Moinadaphnia* sp (r = -0.98), *Alona monacantha* (r = -0.95), *A. davidi* (r = -0.9) *Brachionus longirostris* (r = -0.79), *Moina micrura* (r = -0.85), *B.caudatus* (r = -0.86),*Bosmina longirostris* (r = -0.96), *Harpacticoid* sp (r = -0.91), *Cyclotella* sp (r = -0.96), Velocity (r = -0.78), Nitrate (r = 0.56) but positive with *Brachionus* sp (r = 0.99) and TDS (r = 0.86).

Furthermore, PC 2 described 17.09% of the total variation in zooplankton abundance and physicochemical parameters of Gbalegbe River with positive correlation with TSS (r = 0.97), Turbidity (r = 0.95), Temperature (r = 0.58) but negative with *Harpacticoid* sp (r = -0.56). PC 3 accounted for 11.97% of the total variance in physico-chemical parameters and zooplankton abundance with positive correlation with *Moinamicrura* (r = 0.74).

Table 4.25. Eigen values of physico-chemical parameters and zooplankton

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadingsa
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	18.63	50.34	50.34	18.63	50.34	50.34	17.97
2	6.32	17.09	67.44	6.32	17.09	67.44	6.28
3	4.43	11.97	79.41	4.43	11.97	79.41	4.41
4	3.41	9.21	88.61	3.41	9.21	88.61	8.05
5	1.91	5.16	93.77	1.91	5.16	93.77	7.59
6	1.46	3.94	97.71	1.46	3.94	97.71	4.82
-	0.00	0.00	100.00				
-	0.00	0.00	100.00				
37	0.00	0.00	100.00				

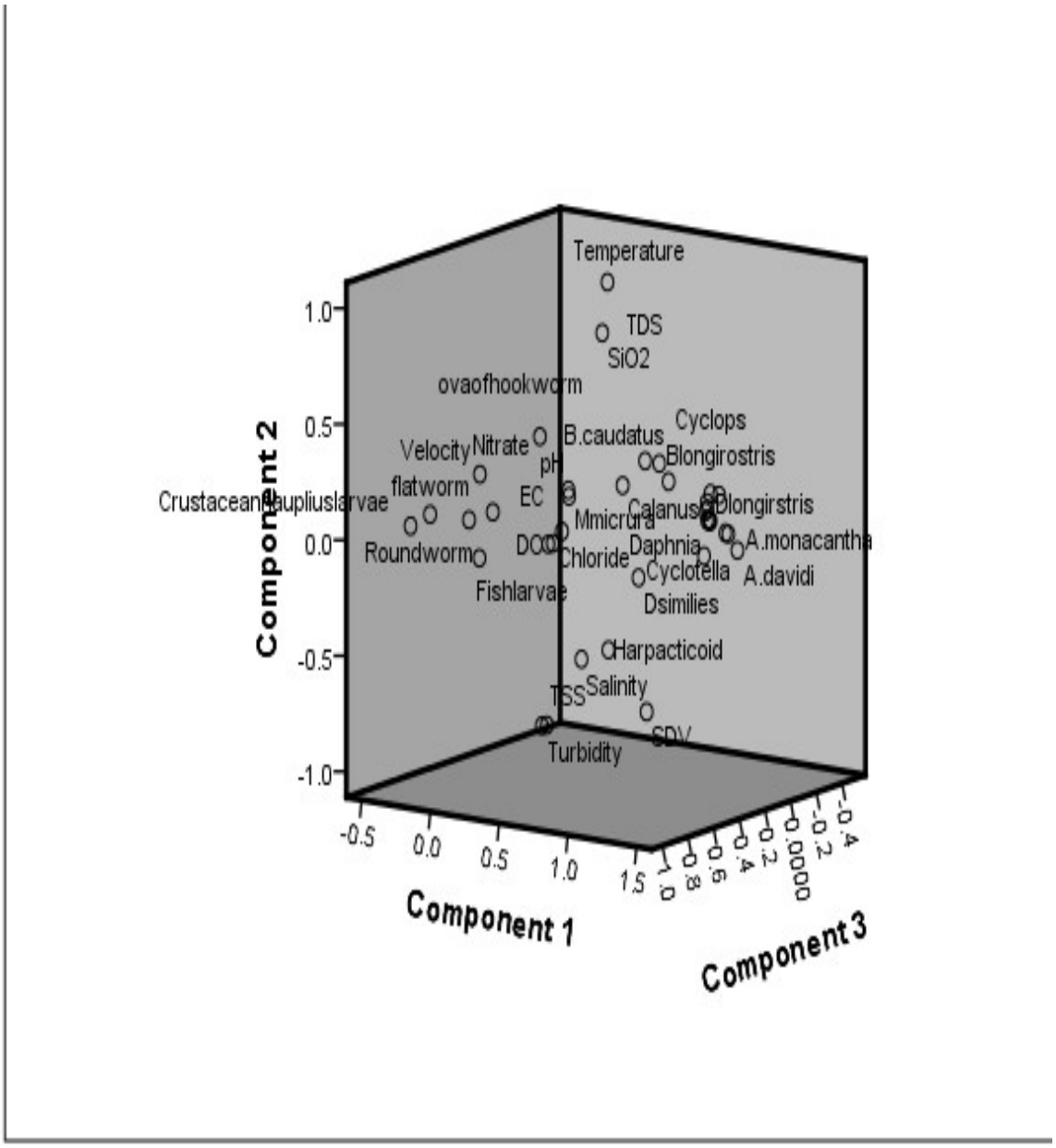

Figure 4.3. Component plot in rotated space for physico-chemical parameters and zooplankton

Table 4.26. Correlation matrix among components, physico-chemical parameters and zooplanktons pecies abundance

Variables	Component					
	1	2	3	4	5	6
Cyclops sp	**-0.96**	0.24	0.11	0.28	-0.16	0.25
Calanus	**-0.97**	0.12	-0.17	0.49	-0.57	0.26
Daphnia	**-0.97**	0.18	-0.14	0.52	-0.54	0.31
D. longirstris	**-0.99**	0.20	-0.10	0.50	-0.50	0.25
D.similies	**-0.86**	-0.10	0.41	0.22	-0.38	-0.02
Moinadaphnia	**-0.98**	0.11	0.04	0.41	-0.32	0.09
A.monacantha	**-0.95**	0.01	-0.09	0.46	-0.30	0.00
A.davidi	**-0.90**	0.01	-0.04	0.10	-0.05	0.13
B.longirostris	**-0.79**	0.50	0.11	0.23	-0.10	0.65
Mmicrura	**-0.85**	0.31	0.15	0.58	-0.72	0.34
B.caudatus	**-0.86**	0.47	0.13	**0.62**	-0.27	0.40
Evadne sp	**-0.96**	0.24	-0.19	0.53	-0.52	0.32
Bosmina longirostris	**0.96**	-0.06	-0.05	0.34	-0.54	0.09
*Harpacticoid*sp	**-0.91**	0.11	-0.32	0.48	-0.61	0.16
Cyclotella	**-0.96**	-0.03	-0.19	0.45	-0.45	0.03
Veliger species	**0.99**	0.12	-0.10	0.49	-0.50	0.21
Moina sp	-0.35	-0.05	**0.74**	-0.19	**0.66**	-0.40
TDS	**0.86**	0.44	0.16	0.41	-0.49	0.43
TSS	0.22	**0.97**	0.02	-0.20	0.02	-0.49
EC	0.45	-0.11	-0.04	**-0.99**	0.49	-0.08
Turbidity	0.24	**0.95**	-0.01	-0.18	0.00	-0.43
Temperature	0.37	0.58	-0.38	-0.45	0.40	-0.06
DO	-0.27	-0.31	0.08	**0.73**	-0.56	-0.52
pH	0.43	0.30	0.09	**0.95**	-0.31	0.27
Nitrate	0.56	0.26	0.26	**-0.72**	0.50	0.38
Salinity	-0.41	-0.85	-0.28	-0.45	0.23	-0.51
Chloride	0.04	0.37	-0.07	-0.01	0.10	**0.96**
SiO2	0.29	**0.88**	0.13	-0.12	0.09	0.59
Chlla	-0.26	-0.06	0.36	-0.33	**0.91**	0.11
Velocity	**-0.78**	-0.32	0.18	-0.68	**0.68**	-0.59
Transparency	0.05	**-0.70**	-0.45	-0.17	**0.06**	0.12

4.8 Composition, distribution, abundance and species diversity of sediment macro-invertebrate

The composition, distribution, abundance and checklist of sediment macro-invertebrate species for wet season are shown in Tables 4.27 and 4.28, abundance and checklist of sediment macro-invertebrate species for dry season are presented in Tables 4.29 and 4.30, diversity indices for sediment macro – invertebrate of Gbalegbe River for wet and dry seasons are shown in Tables 4.31 and 4.32. The monthly sediment macro-invertebrate species abundance (wet and dry seasons) are presented in Appendices 11 and 12, while the checklist is presented in Appendix 13. The total number of individual sediment macro-invertebrates recorded during the study period was 14,675.

During the wet season, 8 orders, 22 families and 22 species of sediment macro – invertebrate were identified.Stations 6 and 7 ranked next with individual number of sediment macro – invertebrates as 1816 (14.5%) and 1821 (14.6%), while Station 2 recorded the least with individual number of 732 (5.9%).*Hesperocorixa castanea* 433 (4.1%) and *Aedes* species 37 (0.30%) occurred as most and least abundant sediment macroinvertebrates.

During the dry season, 7 orders, 22 families and 22 species of sediment macro – invertebrates were identified. Station 1 recorded the highest number of individual sediment macro-invertebrates as 629 (15.7%). Stations 4 and 5 ranked next with the number of individual sediment macro – invertebrates sampled as 613 (14.3%) and 624 (14.6%), while the least occurred in Station 2 with number of sediment macro – invertebrates as 323 (7.5%). The most abundant sediment macro-invertebrates recorded was *Hesperocorixa castanea* 433 (4.4%) while the least was *Belostoma* sp 46 (1.1%).

The highest and least Margalef index recorded were 3.11 and 2.09 at Stations 1 and 2; Shannon (4.19, 3.16) at Stations 3 and 1; Evenness (0.80, 0.47), respectively. The highest and least Evenness were 0.73 and 0.29, Shannon (3.74, 1.99), Dominance (D) (0.15, 0.06), Margalef (2.85, 2.70), while Simpson (1 – D) ranged from 0.85 to 0.94 in wet and dry seasons, respectively.

Table 4.27. Composition, distribution and abundance of sediment macro-invertebrates for wet season

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Corixidae	*Hesperocorixa castanea*	330	54	107	150	298	184	131	244	1498	4.1
Gerridae	*Gerris remigis*	0	33	40	51	76	34	13	39	286	1.5
Cicadellidae	*Lonatura megalopa*	0	8	3	12	34	8	3	18	86	0.7
	Belostoma sp	0	36	45	76	46	31	20	22	276	1.8
Nepidae	*Nepa* sp	0	93	66	74	65	22	17	26	363	2.1
Epemerellidae	*Ephemerella doris*	430	41	104	165	156	89	27	156	1168	4.0
	Hexagenia limbata	122	2	17	12	10	15	23	14	215	1.4
Heptageniidae	*Stenonema exiguum*	168	0	46	52	107	53	120	34	580	3.3
Isonychiidae	*Isonychia arida*	159	0	45	50	51	101	64	50	520	3.1
Leptophlebiidae	*Leptophlebia* sp	174	0	34	45	114	166	80	34	647	3.4
Polymitarcyidae	*Tortopus incertus*	67	0	42	58	48	164	185	49	613	3.2
Potamanthidae	*Potamanthus* sp	81	1	46	38	65	52	196	68	547	2.7
Tricorythidae	*Tricorythodes albilineatus*	73	0	47	33	47	166	207	33	606	3.0
Hydropsychidae	*Hydropsychids* sp	98	0	39	40	68	189	140	37	611	2.7
Libelluidae	*Hemistigma* sp	7	57	83	54	69	63	31	48	412	2.2
	Pantata flarescens	23	94	74	59	74	52	45	49	470	3.5
Aeshnidae	*Helocordulia selysii*	3	78	70	84	86	49	22	37	429	3.3
	Ashna interrupta	30	57	77	46	60	64	36	59	429	4.0
Perlidae	*Perlids sp.*	96	0	30	59	49	59	110	75	478	3.8
Leuctridae	*Latelmis* sp	334	0	37	66	72	66	231	68	874	3.9
Gyrinidae	*Gyrinus* sp	12	58	51	73	50	59	34	77	114	0.3
Vellidae	*Velia* sp	0	65	78	123	56	31	14	12	379	3.0
	Total	2175	732	1252	1527	1801	1816	1821	1358		
	%Abundance	17.4	5.9	10.0	12.2	14.4	14.5	14.6	10.9		

Table 4.28. Checklist of sediment macro-invertebrate species during wet season

Families	Species	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Corixidae	*Hesperocorixa castanea*	+	+	+	+	+	+	+	+
Gerridae	*Gerris remigis*	-	+	+	+	+	+	+	+
Cicadellidae	*Lonatura megalopa*	-	+	+	+	+	+	+	+
	Belostoma sp	-	+	+	+	+	+	+	+
Nepidae	*Nepa* sp	-	+	+	+	+	+	+	+
Epemerellidae	*Ephemerella doris*	+	+	+	+	+	+	+	+
Heptageniidae	*Stenonema exiguum*	+	-	+	+	+	+	+	+
Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
Leptophlebiidae	*Leptophlebia* sp	+	-	+	+	+	+	+	+
Polymitarcyidae	*Tortopus incertus*	+	-	+	+	+	+	+	+
Potamanthidae	*Potamanthus* sp	+	+	+	+	+	+	+	+
Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+
Hydropsychidae	*Hydropsychids* sp	+	-	+	+	+	+	+	+
Libelluidae	*Hemistigma* sp	+	+	+	+	+	+	+	+
	Pantata flarescens	+	+	+	+	+	+	+	+
Aeshnidae	*Helocordulia selysii*	+	+	+	+	+	+	+	+
	Ashna interrupta	+	+	+	+	+	+	+	+
Perlidae	*Perlids sp.*	+	-	+	+	+	+	+	+
Leuctridae	*Latelmis* sp	+	-	+	+	+	+	+	+
Gyrinidae	*Gyrinus* sp	+	+	+	+	+	+	+	+
Vellidae	*Velia* sp	-	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.29 Sediment macro-invertebrate abundance for dry season

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Corixidae	*Hesperocorixa castanea*	0	60	49	82	77	44	48	73	433	4.4
Gerridae	*Gerris remigis*	10	35	28	27	22	32	23	20	196	4.3
Cicadellidae	*Lonatura megalopa*	5	25	29	28	22	28	29	22	186	4.2
Belostomidae	*Belostoma* sp	3	8	7	6	4	5	6	5	46	1.1
Nepidae	*Nepa* sp	9	30	28	28	25	20	20	27	186	3.9
Epemerellidae	*Ephemerella doris*	30	1	8	25	17	18	18	9	129	2.0
	Hexagenia limbata	91	0	4	20	24	30	26	29	123	3.2
Heptageniidae	*Stenonema exiguum*	46	1	6	23	31	26	31	17	181	2.9
Isonychiidae	*Isonychia arida*	64	0	9	21	22	16	21	15	168	3.8
Leptophlebiidae	*Leptophlebia* sp	21	0	3	5	7	5	7	5	52	1.2
Polymitarcyidae	*Tortopus incertus*	32	1	9	24	21	16	25	17	144	2.9
Potamanthidae	*Potamanthus* sp	42	0	8	30	21	24	34	14	172	3.9
Tricorythidae	*Tricorythodes albilineatus*	26	0	6	25	25	23	24	21	148	3.5
Hydropsychidae	*Hydropsychids* sp	47	0	6	23	20	27	21	17	167	3.9
Libelluidae	*Hemistigma* sp	0	13	22	28	28	26	14	8	138	2.4
	Pantata flarescens	0	21	25	35	16	25	25	25	172	2.8
Aeshnidae	*Helocordulia selysii*	0	23	20	27	30	16	21	24	161	2.8
Aeshnidae	*Ashna interrupta*	0	17	34	23	26	29	15	11	155	2.6
Perlidae	*Perlids* sp	15	0	4	6	17	6	7	3	58	1.4
Leuctridae	*Latelmis* sp	55	0	32	17	22	39	29	12	205	4.1
Gyrinidae	*Gyrinus* sp	3	16	16	13	19	11	12	26	114	2.7
Vellidae	*Velia* sp	0	14	20	17	24	21	12	4	112	2.6
	Total	629	323	431	613	624	584	578	434	4215	
	%Abundance	15.69	7.54	10.07	14.32	14.57	13.64	13.51	10.15		

Table 4.30 Checklist of sediment macro-invertebrate species during dry season

Families	Species	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Corixidae	*Hesperocorixa castanea*	-	+	+	+	+	+	+	+
Gerridae	*Gerris remigis*	+	+	+	+	+	+	+	+
Cicadellidae	*Lonatura megalopa*	+	+	+	+	+	+	+	+
Belostomidae	*Belostoma* sp	+	+	+	+	+	+	+	+
Nepidae	*Nepa* sp	+	+	+	+	+	+	+	+
Epemerellidae	*Ephemerella doris*	+	+	+	+	+	+	+	+
	Hexagenia limbata	+	-	+	+	+	+	+	+
Heptageniidae	*Stenonema exiguum*	+	+	+	+	+	+	+	+
Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
Leptophlebiidae	*Leptophlebia* sp	+	-	+	+	+	+	+	+
Polymitarcyidae	*Tortopus incertus*	+	+	+	+	+	+	+	+
Potamanthidae	*Potamanthus* sp	+	-	+	+	+	+	+	+
Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+
Hydropsychidae	*Hydropsychids* sp	+	-	+	+	+	+	+	+
Libelluidae	*Hemistigma* sp	-	+	+	+	+	+	+	+
	Pantata flarescens	-	+	+	+	+	+	+	+
Aeshnidae	*Helocordulia selysii*	-	+	+	+	+	+	+	+
Aeshnidae	*Ashna interrupta*	-	+	+	+	+	+	+	+
Perlidae	*Perlids* sp	+	-	+	+	+	+	+	+
Leuctridae	*Latelmis* sp	+	-	+	+	+	+	+	+
Gyrinidae	*Gyrinus* sp	+	+	+	+	+	+	+	+
Vellidae	*Velia* sp	-	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.31. Diversity indices for sediment macro – invertebrates among stations

Stations	1	2	3	4	5	6	7	8
Dominance(D)	0.07	0.05	0.03	0.05	0.07	0.05	0.05	0.04
Simpson(1-D)	0.93	0.95	0.97	0.95	0.93	0.95	0.95	0.96
Shannon (H')	3.16	3.70	4.19	3.79	3.42	3.74	3.67	3.75
Evenness(E)	0.47	0.59	0.80	0.59	0.46	0.56	0.51	0.60
Margalef	3.11	2.09	2.58	2.47	2.31	2.30	2.55	2.15

Table 4.32. Diversity indices for sediment macro – invertebrates between seasons

Indices	Wet season	Dry season
Dominance (D)	0.15	0.06
Simpson (1-D)	0.85	0.94
Shannon (H')	3.74	1.99
Evenness (E)	0.73	0.29
Margalef	2.85	2.70

4.8.1 Principal component analyses of sediment macro-invertebrates and physicochemical parameters

The Eigen values and components correlation matrix between sediment macro – invertebrates and physico – chemical parameters of Gbalegbe River are shown in Tables 4.33 and 4.34, while the components plot in rotated space for physico – chemical parameters and sediment macro – invertebrates is shown in Figure 4.4. Eigenvalues showed that, the first three PC were the most significant (> 1) and explained 68.22% of the total variance among the physico-chemical parameters and the sediment macro – invertebrates abundance. PC 1 accounted for 29.80% of the accumulated variance and correlated positively with *Pantata flarens* (r = 0.77), *Gyrinus* species (r = 0.70), *Helocordulia selysii* (r = 0.92), nitrate (r = 0.67), *Nepa* species (r = 0.77), *Hemistigma* species (r = 0.94), *Asha interrupta* (r = 0.57), TDS (r = 0.56), TSS (r = 0.52), EC (r = 0.57) but correlated negatively with DO (r = -0.70), *Latelmis* species (r = -0.67), *Isonychia arida* (r = -0.64), Chloride (r = -0.55), *Stenonema exiguum* (r = -0.55), *Tricorithodes albineatus* (r = -0.63) and *Leptophlebia*species (r = -0.74).

The PC 2 accounted for 23.17% of the total variance and correlated negatively withvelocity (r = -0.76), *Ephemerelladoris* (r = - 0.90), *Hexagenia limbata* (r = - 0.90), *Isonychia arida* (r = - 0.63), *Tortpus incertus* (r = - 0.57), *Stenonema exiguum* (r = -0.71), *Hydrosychids* sp (r = - 0.70) and*Perlids* sp (r = - 0.78) but positively correlated with *Asha interrupta* (r = 0.73), salinity (r = 0.58), *Hesperocorixa castanea* (r = 0.76), turbidity (r = 0.55) and and Gyrinus species (r = 0.53). Principle Component 3 accounted for 15.25% of the total variance and positively correlated with TDS (r = 0.58), TSS (r = 0.56), EC (r = 0.56), turbidity (r = 0.67), temperature (r = 0.82), pH (r = 0.82), salinity (r = -0.55) and chloride (r = 0.67).

4.9 Fish species abundance and diversity

Composition, distribution, abundance and checklist of fish species during the wet season are presented in Tables4.35 and 4.36, abundance and checklists of fish species for dry season are shown in Tables 4.37 and 4.38, species diversity indices of fish in wet and dry seasons are presented in Tables 4.39 and 4.40. The monthly fish species abundance (wet and dry seasons) are shown in Appendices 14 and 15, while the fish species checklists for wet and dry seasons are presented in Appendices 16 and 17. The total individual number of fish recorded during the study period was 14,308. During the wet season, 9 orders, 17 families and 32 species of fish were identified.

Table 4.33. Eigen values between sediment macro-invertebrates and physico-chemical parameters

Component	Initial Eigenvalues			Extraction Sums of Squared Loading			SSL
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1.00	11.03	29.80	29.80	11.03	29.80	29.80	9.20
2.00	8.57	23.17	52.96	8.57	23.17	52.96	7.43
3.00	5.64	15.25	68.22	5.64	15.25	68.22	7.15
4.00	3.86	10.44	78.66	3.86	10.44	78.66	7.43
5.00	3.15	8.51	87.16	3.15	8.51	87.16	5.53
6.00	2.88	7.78	94.94	2.88	7.78	94.94	4.64
7.00	1.87	5.06	100.00	1.87	5.06	100.00	4.63
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37	-5.88E-16	-1.59E-15	100.00				

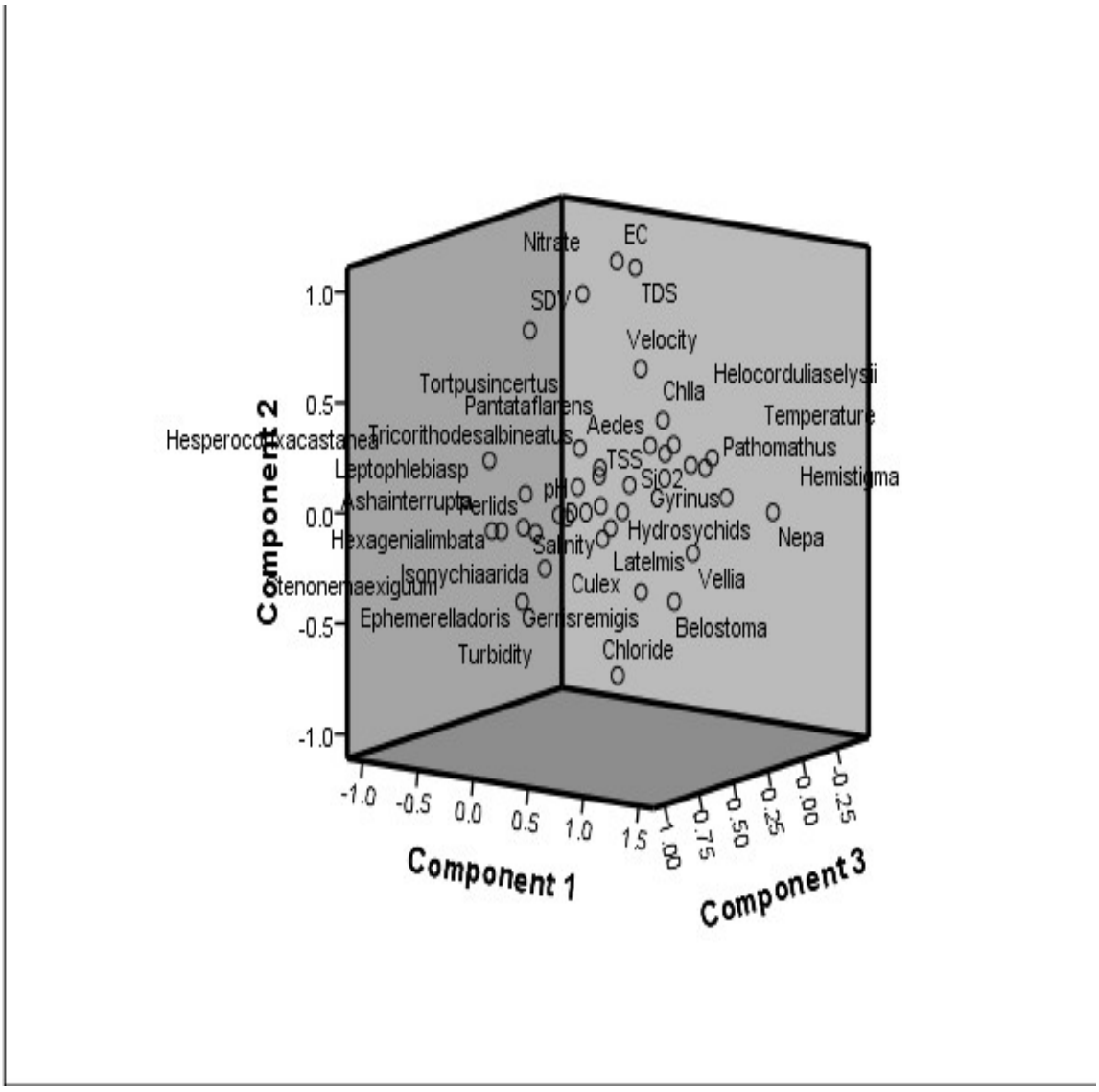

Figure 4.4. Component plot in rotated space for physico-chemical parameters and sediment macro-invertebrates

Table 4.34. Components correlated matrix ofphysico-chemical parameters and sediment macro-invertebrate abundance

Variables	Components						
	1	2	3	4	5	6	7
TDS	0.58	-0.38	0.58	0.27	-0.14	0.21	0.21
TSS	0.52	0.00	0.56	0.38	-0.47	0.18	-0.12
EC	0.57	-0.42	0.56	0.23	-0.16	0.18	0.28
Turbidity	0.11	0.55	0.67	0.28	-0.05	-0.38	0.09
Temperature	0.06	0.19	0.82	-0.28	0.44	-0.10	-0.05
DO	-0.70	-0.02	0.33	-0.34	0.50	-0.12	0.17
pH	0.23	-0.14	0.82	-0.01	-0.27	0.33	0.27
Nitrate	0.67	-0.27	0.32	0.51	-0.23	-0.03	0.26
Salinity	-0.50	0.58	0.55	-0.18	-0.23	-0.05	0.15
Alkalinity	-0.55	0.31	0.67	-0.21	-0.20	0.06	-0.26
BOD	-0.26	-0.21	-0.45	0.59	0.29	0.51	0.07
Chlla	0.70	0.09	-0.29	0.51	0.24	0.30	0.11
Velocity	0.08	-0.76	0.25	0.44	-0.31	-0.19	-0.13
Transparency	0.20	0.24	0.50	-0.35	-0.29	0.39	0.55
Hesperocorixa castanea	0.49	0.69	0.08	0.13	-0.09	-0.35	0.36
Gerris remigis	0.37	0.66	-0.28	-0.52	0.21	0.17	0.02
Vellia sp	0.39	0.41	-0.31	-0.55	0.15	0.51	-0.03
Belostoma sp	0.49	0.48	-0.22	0.25	0.42	-0.40	-0.31
Nepa sp	0.77	0.31	0.09	0.15	0.22	0.20	-0.45
Ephemerella doris	-0.16	-0.90	0.06	0.27	-0.11	-0.23	0.15
Hexagenia limbata	-0.14	-0.90	-0.09	0.17	-0.14	-0.27	0.22
Stenonema exiguum	-0.55	-0.71	0.02	-0.23	-0.36	0.13	0.01
Isonychia arida	-0.64	-0.63	0.32	0.17	-0.16	-0.20	-0.03
Leptophlebia sp	-0.74	-0.50	0.12	0.33	0.25	0.03	0.13
Tortpus incertus	-0.02	-0.57	0.43	0.62	-0.07	0.24	-0.21
Pathomathus sp	-0.43	0.40	0.46	0.37	0.02	0.48	-0.28
Tricorithodes albineatus	-0.63	0.10	0.05	0.41	0.61	0.05	0.21
Hydrosychids sp	-0.36	-0.69	0.03	-0.06	-0.05	0.63	0.04
Hemistigma sp	0.94	-0.04	0.10	-0.30	0.05	-0.03	-0.15
Helocordulia selysii	0.92	0.16	0.15	-0.18	0.22	0.12	-0.10
Pantata flarens	0.77	0.24	0.01	-0.13	0.43	-0.31	0.26
Asha interrupta	0.57	-0.73	-0.17	-0.09	-0.10	-0.07	0.32
Perlids sp	-0.16	-0.78	0.15	0.18	-0.54	-0.16	-0.06
Latelmis sp	-0.67	0.20	0.50	-0.16	-0.38	-0.11	-0.30
Gyrinus sp	0.70	0.53	0.05	0.05	0.06	0.39	-0.27

Table 4.35. Fish species abundance and distribution for wet season

Families	Species	Stations								Total	%Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Clariidae	*Clarias gariepinus*	113	73	201	43	76	34	21	164	725	8.7
	C. anguillaris	17	45	65	10	19	150	300	196	802	9.6
	Heterobranchus bidorsalis	63	72	110	67	10	13	17	54	406	4.9
Latidae	*Lates niloticus*	98	33	0	54	31	24	43	67	350	4.2
Channidae	*Parachanna africana*	234	0	11	9	51	7	15	13	340	4.1
	P. obscura	45	453	32	18	7	12	0	9	576	6.9
Cichlidae	*Coptodon zilli*	66	74	3	0	53	87	86	67	436	5.2
	Oreochromis niloticus	99	9	0	65	54	87	54	45	413	4.9
	Hemichromis fasciatus	61	69	24	87	71	42	153	12	519	6.2
	Oreochromis aureus	74	176	23	8	4	23	9	23	340	4.1
	Sarotherodon galilaeus	41	38	327	45	43	23	12	33	562	6.7
	C. guineensis	50	8	64	302	9	6	4	35	478	5.7
Anabantidae	*Ctenopoma kingsleyae*	36	0	0	19	76	68	14	53	266	3.2
Protopteridae	*Protopterus annectens*	62	26	13	31	43	13	43	47	278	3.3

Table 4.35. Fish species abundance and distribution for wet season Cont'd

Families	Species	S1	S2	S3	S4	S5	S6	S7	S8	Total	%Abundance
Arapamidae	*Heterotis niloticus*	54	13	23	0	30	65	91	12	288	3.4
Pantodontidae	*Pantodon bucholzi*	100	16	0	34	27	0	3	13	193	2.3
Notopteridae	*Papyrocranus afer*	40	23	5	5	153	3	3	34	266	3.2
	Xenomystus nigri	190	2	13	6	3	0	17	22	253	3.0
Mochokidae	*Synodontis clarias*	45	34	21	49	83	0	0	34	266	3.2
	Hemisynodontis membranaceous	56	23	12	59	83	0	73	0	306	3.7
Malapteruridae	*Malapterurus electricus*	21	0	0	0	4	2	0	0	27	0.3
Bagridae	*Bagrus filamentosus*	10	198	62	7	4	3	9	87	380	4.5
Ariidae	*Arius gigas*	34	8	192	9	8	5	9	75	340	4.1
Ichthyboridae	*Phago loricatus*	56	0	0	234	4	2	4	17	317	3.8
Mastacembelidae	*Mastacembelus loennbergii*	19	132	0	0	10	10	4	56	231	2.8
Mormyridae	*Gnathonemus petersii*	54	14	4	16	21	13	26	69	217	2.6
	G. deboensis	64	13	123	216	2	1	0	0	419	5.0
	G. niger	25	45	0	2	101	16	10	0	199	2.4
	G. senegalensis	6	234	0	0	23	0	4	19	286	3.4
	G. cyprinoides	34	5	0	0	4	9	200	98	350	4.2
	G. tamadua	24	12	41	180	18	25	21	57	378	4.5
Polyteridae	*Calamoichthys calabaricus*	200	123	3	1	7	4	3	13	354	4.2
	Total	2091	1971	1372	1576	1132	747	1248	1424		
	% Abundance	15.1	14.4	12.3	13.1	11.4	9.9	11.8	12.5		

Note: *Tilapia zilli* and *Tilapia guineensis* are now known as *Coptodon zilli* and *C. guineensis*

Table 4.36. Checklist of fish species during wet season

Families	Species	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Clariidae	*Clarias gariepinus*	+	+	+	+	+	+	+	+
	C. anguillaris	+	+	+	+	+	+	+	+
	Heterobranchus bidorsalis	+	+	+	+	+	+	+	+
Latidae	*Lates niloticus*	+	+	-	+	+	+	+	+
Channidae	*Parachanna africana*	+	-	+	+	+	+	+	+
	P. obscura	+	+	+	+	+	+	-	+
Cichlidae	*Coptodon zilli*	+	+	+	-	+	+	+	+
	Oreochromis niloticus	+	+	-	+	+	+	+	+
	Hemichromis fasciatus	+	+	+	+	+	+	+	+
	Oreochromis aureus	+	+	+	+	+	+	+	+
	Sarotherodon galilaeus	+	+	+	+	+	+	+	+
	C. guineensis	+	+	+	+	+	+	+	+
Anabantidae	*Ctenopoma kingsleyae*	+	-	-	+	+	+	+	+
Protopteridae	*Protopterus annectens*	+	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.36. Checklist of fish species during wet season Cont'd

Families	Species	S1	S2	S3	S4	S5	S6	S7	S8
Arapamidae	*Heterotis niloticus*	+	+	+	-	+	+	+	+
Pantodontidae	*Pantodon bucholzi*	+	+	-	+	+	-	+	+
Notopteridae	*Papyrocranus afer*	+	+	+	+	+	+	+	+
	Xenomystus nigri	+	+	+	+	+	-	+	+
Mochokidae	*Synodontis clarias*	+	+	+	+	+	-	-	+
	Hemisynodontis membranaceous	+	+	+	+	+	-	+	-
Malapteruridae	*Malapterurus electricus*	+	-	-	-	+	+	-	-
Bagridae	*Bagrus filamentosus*	+	+	+	+	+	+	+	+
Ariidae	*Arius gigas*	+	+	+	+	+	+	+	+
Ichthyboridae	*Phago loricatus*	+	-	-	+	+	+	+	+
Mastacembelidae	*Mastacembelus loennbergii*	+	+	-	-	+	+	+	+
Mormyridae	*Gnathonemus petersii*	+	+	+	+	+	+	+	+
	G. deboensis	+	+	+	+	+	+	-	-
	G. niger	+	+	-	+	+	+	+	-
	G. senegalensis	+	+	-	-	+	-	+	+
	G. cyprinoides	+	+	-	-	+	+	+	+
	G. tamadua	+	+	+	+	+	+	+	+
Polyteridae	*Calamoichthys calabaricus*	+	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.37. Composition, distribution and abundance of fish for dry season

Families	Species	Stations								Total	% Abundance
		S1	S2	S3	S4	S5	S6	S7	S8		
Clariidae	*C. gariepinus*	19	23	16	43	12	98	56	63	330	5.2
	H. bidorsalis	45	23	1	53	29	61	66	14	292	4.6
	C.angullaris	43	12	32	65	67	41	10	35	305	4.8
Phractolaemidae	*Phractolaemus ansorgei*	19	6	237	5	8	4	3	17	299	4.7
Cichlidae	*C. zilli*	53	10	53	45	12	87	18	30	308	4.9
	Oreochromis niloticus	34	34	0	21	27	31	8	12	167	2.7
Schilbeidae	*Schilbe uronoscopus*	31	7	32	5	4	0	2	10	91	1.4
	Siluranodon auritus	44	5	2	0	0	0	0	27	78	1.2
Schilbeidae	*Schilbe uronoscopus*	13	0	0	0	5	2	4	21	45	0.7
Polyteridae	*Calamoichthys calabaricus*	36	0	0	0	0	7	1	65	109	1.7
Hepsetidae	*Hepsetus odoe*	55	1	10	2	6	5	3	15	97	1.5
Malapteruridae	*Malapterurus electricus*	56	4	3	9	2	12	6	39	131	2.1
Cyprinidae	*Cyprinus carpio*	57	2	0	6	2	1	9	26	103	1.6
Polyteridae	*Calamoichthys calabaricus*	41	45	23	4	7	5	4	17	146	2.3
Channidae	*Parachanna africana*	29	27	21	6	1	0	4	45	133	2.1
	P. obscura	12	18	7	4	3	29	31	9	113	1.8
	Total	587	217	437	268	185	383	225	445		
	% Abundance	16.3	10.4	13.9	11.3	9.9	13.1	10.6	14.1		

Table 4.38. Checklist of fish species during dry season

Families	Species	Stations							
		S1	S2	S3	S4	S5	S6	S7	S8
Clariidae	*C. gariepinus*	+	+	+	+	+	+	+	+
	H. bidorsalis	+	+	+	+	+	+	+	+
	C.angullaris	+	+	+	+	+	+	+	+
Phractolaemidae	*Phractolaemus ansorgei*	+	+	+	+	+	+	+	+
Cichlidae	*C. zilli*	+	+	+	+	+	+	+	+
	Oreochromis niloticus	+	+	-	+	+	+	+	+
Schilbeidae	*Schilbe uronoscopus*	+	+	+	+	+	-	+	+
	Siluranodon auritus	+	+	+	-	-	-	-	+
Schilbeidae	*Schilbe uronoscopus*	+	-	-	-	+	+	+	+
Polyteridae	*Calamoichthys calabaricus*	+	-	-	-	-	+	+	+
Hepsetidae	*Hepsetus odoe*	+	+	+	+	+	+	+	+
Malapteruridae	*Malapterurus electricus*	+	+	+	+	+	+	+	+
Cyprinidae	*Cyprinus carpio*	+	+	-	+	+	+	+	+
Polyteridae	*Calamoichthys calabaricus*	+	+	+	+	+	+	+	+
Channidae	*Parachanna africana*	+	+	+	+	+	-	+	+
	P. obscura	+	+	+	+	+	+	+	+

Note: + = present and - = absent

Table 4.39. Diversity indices for fish species among stations

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
Dominance (D)	0.17	0.11	0.28	0.19	0.17	0.16	0.21	0.11
Simpson (1-D)	0.83	0.89	0.72	0.81	0.83	0.84	0.79	0.89
Shannon (H)	2.24	2.97	1.79	2.14	2.17	2.32	1.98	2.77
Evenness (E)	0.56	0.76	0.40	0.47	0.59	0.60	0.52	0.70
Margalef	3.03	1.83	2.70	2.11	2.15	2.29	1.97	2.74

Table 4.40. Diversity indices for fish species between seasons

Indices	Wet season	Dry season
Dominance (D)	0.38	0.17
Simpson (1-D)	0.62	0.83
Shannon (H)	2.96	2.56
Evenness (E)	0.68	0.41
Margalef	2.25	2.45

Station 1 recorded the highest abundance of fish species comprising 2091 (15.1%). Stations 4 and 8 ranked next with the number of fish sampled as 1576 (13.1%) and 1424 (12.5%), while the least occurred at station 6 with number of fish as 747 (9.9%). The most abundant fish species recorded was *Clarias anguillaris* 802 (9.6%), while the least was *Malapterurus electricus* 27 (0.3%).

During the dry season, 8 orders, 11 families and 16 species of fish were identified. Stations 1 recorded the highest individual number of fish comprising 587 (16.3%). Station 3 and 8 ranked next with the number of fish species sampled as 437 (13.9%) and 445 (14.1%), while the least occurred in Station 2 with number of fish species as 217 (10.4%). The most abundant fish species recorded was *C. anguillaris* 330 (5.2) while the least was *Schilbe uronoscopus*, 45 (0.7%).

The highest (3.03) and least (1.83) Margalef index were recorded was at Stations 1 and 2; Shannon (2.79, 1.79); Evenness (0.76, 0.40) in Stations 2 and 3, respectively. Simpson (1 – D) range from 0.62 to 0.83, while highest and least Margalef were 2.66 and 2.45, Evenness (0.71, 0.35), Shannon (3.10, 1.99) and Dominance (0.38, 0.17) were recorded in wet and dry seasons, respectively.

4.9.1 Principal component analyses of fish species abundanceand physico-chemical parameters

The Eigen values of fish species and physico – chemical parameters and component correlation matrix between fish species and physico – chemical parameters are shown in Tables 4.41 and 4.42, while component plot in rotated space for fish species and physico – chemical parameters is presented in Figure 4.5. Eigen values showed that, the first three components (PC) were the most significant (>1). These extracted components accounted for 95.06% of the total variation between physicochemical parameters and fish abundance of Gbalegbe River. PC 1 accounted for 76.94% of the total variance with positive loading of *Clarias gariepinus* (r = 0.75), *C. anguillaris* (r = 0.78), *Heterobranchus bidorsalis* (r = 0.76),

Oreochromis niloticus (r = 0.56), *Papyrocranus afer* (r = 0.64) but negative with PO_4 (r = -*Lates niloticus* (r = 0.61), *Parachanna obscura* (r = 0.75), *Tilapia zilli* (r = 0.74), *Oreochromis niloticus* (r = 0.56), *Papyrocranus afer* (r = 0.64) but negative with PO_4 (r = -0.56). PC 2 accounted for 13.56% of the total variance with positive loading of *C.gariepinus* (r = 0.78), *C. anguillaris* (r = 0.81), *H. bidorsalis* (r = 0.81), O. *niloticus* (r = 0.65), *P. obscura* (r = 0.99), *T. zilli* (r = 0.81), *O. niloticus* (r = 0.76), *P. annectens* (r = 0.54) and *Papyrocranus afer* (r = 0.73), while PC 3 accounted for 4.57% of the total variance with similar positive loading with PC 2.

4.10 Heavy metals (copper, lead, nickel, cadmium, iron, zinc, manganese and chromium) concentrations in water

The mean concentrations of heavy metals in water among stations and between seasons are shown in Tables 4.43 and 4.44. The ANOVA for heavy metal concentrations in water among stations and between seasons are presented in Appendices 18 and 19. The least concentration of copper recorded was 0.11±0.02 mg/L,while the highest was 0.19±0.13 mg/Lin Stations 1 and 2, respectively. The highest seasonal mean value of Cu was 0.25±0.14 mg/L in dry season,while the least was 0.11±0.01 mg/L during the wet season. ANOVA revealed a significant difference ($P<0.05$) between the seasonal mean values of Cu.

The lowest mean leadconcentration in water obtained was 0.10±0.01 mg/L in Station 1, while the maximum was 0.25±0.12 mg/L in Station 2. Seasonally, the least mean value of Pb concentration was 0.17±0.02mg/L during the wet season,while the highest was 0.26±0.15 mg/L during dry season. Significant differences ($p<0.05$) existed in the mean values of Pb measured among stations and between seasons.

Among the stations, the least mean nickel concentration value recorded was 0.02±0.01 mg/L in Station 1, and the maximum was 0.23±0.10 mg/L in Station 2. The maximum seasonal mean value of Ni was 0.25±0.07 mg/L during the dry season, while theleast was 0.13±0.03 mg/L in the wet season. There were significant difference ($p<0.05$)in the mean values of Ni among the stations and between seasons.

The least spatial mean value of cadmium obtained was 0.02±0.01 mg/Lin Station 1, while the highest was 0.19±0.12 mg/L inStation 2. Seasonally, the mean values of Cd ranged from 0.15±0.01 mg/L during the wet season to 0.26±0.06 mg/Lduring the season, respectively. Significant differences ($p<0.05$) existed in the mean values among stations.

Table 4.41. Eigen values of fish species and physico-chemical parameters

Component	Initial Eigenvaluesa			Extraction Sums of Squared Loadings			RSSL
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	55068722	76.94	76.94	55068722	76.94	76.94	5260315
2	9703408	13.557	90.497	9703408	13.557	90.497	43252834
3	3267349	4.565	95.062	3267349	4.565	95.062	23600776
4	1855279	2.592	97.654	1855279	2.592	97.654	3469720
5	1140198	1.593	99.247				
-	-	-	-				
-	-	-	-				
59	-7.792E-009	-1.089E-014	100.000				

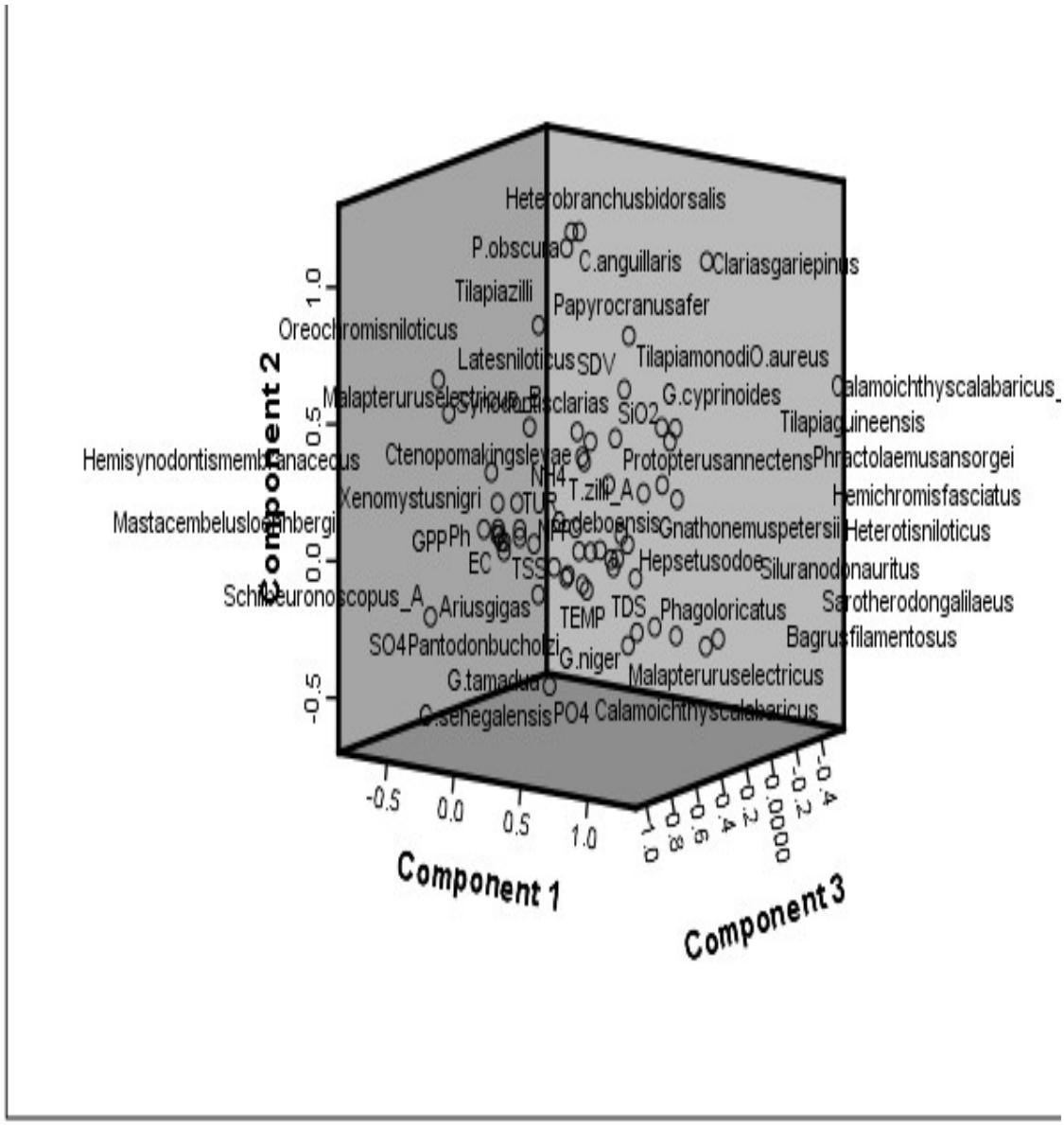

Figure 4.5. Component plot in rotated space for fish species composition and physico-chemical parameters

Table 4.42. Components correlation matrix for fish species and physico-chemical parameters

Fish species and water physicochemical parameters	Compoents			
	1	2	3	4
Clarias gariepinus	0.75	0.78	0.76	0.61
C. anguillaris	0.78	0.81	0.75	0.65
Heterobranchus bidorsalis	0.76	0.81	0.76	0.65
Lates niloticus	0.61	0.65	0.65	0.31
P. obscura	0.75	0.99	0.99	0.67
Coptodon zilli	0.74	0.81	0.81	0.83
Oreochromis niloticus	0.56	0.76	0.76	0.93
Hemichromis fasciatus	0.37	0.32	0.30	0.31
Protopterus annectens	0.41	0.54	0.54	0.56
Heterotis niloticus	0.26	0.30	0.29	0.44
Papyrocranus afer	0.64	0.73	0.72	0.53
Xenomystus nigri	0.47	0.39	0.38	0.80
Coptodon guineensis	0.29	0.50	0.49	0.14
Ctenopoma kingsleyae	0.23	0.47	0.47	0.31
Mastacembelus loennbergii	0.23	0.42	0.41	0.58
Sarotherodon galilaeus	-0.05	0.04	0.02	0.04
Phractolaemus ansorgei	0.23	0.45	0.43	0.31
Calamoichthys calabaricus	0.27	0.45	0.44	0.25
Schilbe uronoscopus	0.25	0.40	0.39	0.61
Parachanna africana	-0.08	0.02	0.00	-0.13
TDS	0.14	-0.18	-0.19	0.10
TSS	-0.23	-0.17	-0.16	-0.15
EC	-0.21	-0.15	-0.14	-0.15
TUR	-0.20	-0.14	-0.13	-0.14
TEMP	-0.16	-0.34	-0.33	-0.21
DO	-0.15	-0.30	-0.29	-0.29
BOD	-0.23	-0.14	-0.13	-0.16
pH	-0.19	-0.09	-0.07	-0.08
Salinity	-0.21	-0.15	-0.14	-0.14
Chloride	-0.13	-0.10	-0.10	-0.08
Velocity	-0.22	-0.17	-0.16	-0.16
Transparency	0.26	0.29	0.30	0.23
GPP	-0.06	0.01	0.04	0.05
NPP	-0.15	-0.24	-0.24	-0.24
NH_4	0.05	0.19	0.19	0.20
NO_2	-0.49	-0.15	-0.15	-0.48
NO_3	-0.26	0.01	0.03	-0.28
PO_4	-0.56	-0.39	-0.37	-0.36
SO_4	-0.06	-0.06	-0.05	0.45
SiO_2	0.31	0.12	0.14	0.04

Table 4.43. Mean concentrations of heavy metals in water among stations

Stations	Cu (mg/L)	Pb (mg/L)	Ni (mg/L)	Cd (mg/L)	Fe (mg/L)	Zn (mg/L)	Mn (mg/L)	Cr (mg/L)
Station 1	0.11±0.02[a]	0.10±0.01[a]	0.02±0.01[a]	0.02±0.01[a]	0.07±0.01[a]	0.08±0.01[a]		0.03±0.01[a]
	(0.10-0.22)	(0.15-0.22)	(0.06-0.22)	(0.11-0.22)	(0.06-0.22)	(0.05-0.22)	ND	(0.01-0.22)
Station 2	0.19±0.03[a]	0.25±0.12[a]	0.23±0.10[a]	0.19±0.12[a]	0.16±0.12[a]	0.19±0.13[a]	0.28±0.13[a]	0.78±0.13[a]
	(0.16-0.22)	(0.15-0.29)	(0.16-0.25)	(0.15-0.21)	(0.14-0.27)	(0.15-0.22)	(0.15-0.22)	(0.16-1.22)
Station 3	0.19±0.02[a]	0.18±0.12[a]	0.18±0.12[a]	0.13±0.03[a]	0.14±0.12[a]	(0.16±0.13[a]	0.17±0.12[b]	0.20±0.13[a]
	(0.16-0.22)	(0.15-0.21)	(0.15-0.21)	(0.12-0.22)	(0.13-0.23)	0.16-0.23)	(0.14-0.21)	(0.17-0.24)
Station 4	0.17±0.12[a]	0.14±0.12[a]	0.20±0.13[a]	0.19±0.13[a]	0.16±0.12[a]	0.18±0.11[a]	0.18±0.14[b]	0.15±0.13[a]
	(0.14-0.20)	(0.13-0.21)	(0.16-0.23)	(0.16-0.23)	(0.16-0.22)	(0.16-0.22)	(0.17-0.24)	(0.14-0.23)
Station 5	0.18±0.11[a]	0.20±0.13[a]	0.19±0.13[a]	0.16±0.13[a]	0.13±0.12[a]	0.18±0.13[a]	0.13±0.11[c]	0.15±0.13[a]
	(0.14-0.21)	(0.16-0.23)	(0.16-0.22)	(0.14-0.22)	(0.16-0.22)	(0.15-0.22)	(0.10-0.22)	(0.12-0.22)
Station 6	0.16±0.13[a]	0.16±0.12[a]	0.20±0.14[a]	0.17±0.13[a]	0.21±0.14[a]	0.19±0.12[a]	0.22±0.12[b]	0.21±0.13[a]
	(0.17-0.23)	(0.16-0.21)	(0.16-0.23)	(0.15-0.22)	(0.18-0.25)	(0.15-0.21)	(0.15-0.21)	(0.17-0.24)
Station 7	0.19±0.00[a]	0.19±0.13[a]	0.18±0.13[a]	0.15±0.12[a]	0.20±0.13[a]	0.18±0.12[a]	0.14±0.12[c]	0.17±0.10[a]
	(0.15-0.22)	(0.16-0.22)	(0.15-0.22)	(0.16-0.22)	(0.17-0.23)	(0.15-0.22)	(0.15-0.22)	(0.14-0.23)
Station 8	0.18±0.13[a]	0.14-0.12[a]	0.18±0.13[a]	0.18±0.13[a]	0.18±0.12[a]	0.17±0.13[a]	0.18±0.13[b]	0.75±0.10[a]
	(0.15-0.22)	(0.13-0.21)	(0.15-0.21)	(0.16-0.23)	(0.17-0.23)	(0.15-0.22)	(0.15-0.21)	(0.15-0.20)
NIS, (2007)	1.00	0.02	0.01 – 0.02	0.003	0.1 – 0.3	2.0 – 3.0	0.2 – 0.35	0.05
WHO, (2004)	2.00	0.01	0.02	0.003	0.30	3.00	0.40	0.05

Mean values with same superscripts along the rows were not significantly different at $p > 0.05$.

Note: Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

Table 4.44. Mean concentrations of heavy metalsin water between seasons

Seasons	Range	Wet season	Range	Dry season	P – value	NIS, (2007)	WHO, (2004)
Cu (mg/L)	0.01 – 1.02	0.11±0.01	0.23 – 0.39	0.25±0.14	0.00*	1	2
Pb (mg/L)	0.03 – 0.95	0.17±0.02	0.11 – 1.08	0.26±0.15	0.00*	0.02	0.01
Ni (mg/L)	0.08 – 0.15	0.13±0.03	0.14 – 1.01	0.25±0.07	0.00*	0.01 – 0.02	0.02
Cd (mg/L)	0.09 – 0.19	0.15±0.01	0.26 – 0.31	0.26±0.06	0.00*	0.003	0.003
Fe (mg/L)	0.12 – 0.35	0.15±0.02	0.17 – 0.33	0.26±0.06	0.00*	0.1 – 0.03	0.3
Zn (mg/L)	0.10 – 0.27	0.10±0.01	0.20 – 0.39	0.22±0.04	0.00*	2.0 – 3.0	3
Mn (mg/L)	0.21 – 0.30	0.18±0.03	0.19 – 0.40	0.25±0.06	0.00**	0.2 – 0.35	0.4
Cr (mg/L)	0.23 – 1.02	0.12±0.01	0.20 – 0.34	0.24±0.02	0.00*	0.05	0.05

Note: * = There were significant differences at $p<0.05$

** There were no significant differences at $p>0.05$

Note: Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

The least mean value of ironconcentration obtained in water among stations was 0.07±0.01 mg/Lin Station 1, while the highest was 0.21±0.14 mg/L in Station 6. Seasonal mean values of Fe were 0.15±0.02mg/L during wet season and 0.26±0.06 mg/L during the dry season.

The least spatial mean value of zinc among stations was 0.08±0.01 mg/L in Station 1,while the highest was 0.29±0.13 mg/Lin Station 2. Among seasons, the least mean value of Zn concentration was 0.10±0.00 mg/L during the wet season, while the highest was 0.22±0.06 mg/L during the dry season. The lowest mean value of manganese was 0.09±0.03, while the highest was 0.28±0.13 mg/L in Stations 1 and 2, respectively. The lowest seasonalmean value of Mn recorded was 0.18±0.03mg/L inthe wet season, while the maximum was 0.25±0.06 mg/L during the dry season. There were significant differences($p<0.05$) in the mean values of Mn between seasons.

Chromium was not detected inStation 1, while the highest was 0.78±0.13 in Station 2.The lowest seasonal mean value of Cr was0.12±0.01 mg/L during thewet season, while the highest0.24±0.06 mg/L during the dry season. Significant differences ($p<0.05$) existed in the mean values among the stations and between seasons.

4.11 Mean Concentrations of heavy metals in *Clarias gariepinus*

Spatial and seasonal mean concentrations of heavy metals in *C. gariepinus* are presented in Tables 4.45 and 4.46. The ANOVA for heavy metal concentrations in *C. gariepinus* among stations and between seasons are shown in Appendices 20 and 21. Among the stations, the lowest mean of copper was 0.04±0.01 mg/Kg at Station 1, while the highest was 0.20±0.03 mg/Kg in Station 2. The least seasonal mean concentration of Cu was 0.15±0.01 mg/Kg in the dry season,while the maximum was 0.17±0.03 mg/Kg during the wet season. The least mean values of Pb concentration in *C. gariepinus* muscles was 0.03±0.01 mg/Kg in Station 1,while the highest was 0.19±0.05 mg/Kg in Station 2. Seasonal mean values of Pb varied from 0.16±0.06 mg/Kg during the dry season,while the highest was 0.24±0.05 mg/Kg in the wet season.

The least and highest mean concentration of Ni were 0.05±0.01 and 0.19±0.04 mg/Kg in Stations 1 and 2 respectively. The lowest seasonal concentration of Ni was 0.11±0.03 mg/Kg during the dry season, while the highest was 0.14±0.07 wete season. Significant difference($P<0.05$) existed in the mean values of Ni among stations. Spatially, the lowest mean value of Cd was 0.03±0.01 mg/Kg in Station 1, while the highest was 0.19±0.09 mg/Kg

in Station 2. The lowest seasonal mean variation of of Cd was 0.17±0.09 mg/Kg during wet season, while the highest was 0.24±0.02 mg/Kg during the dry season.

Table 4.45. Spatial variation of heavy metals' concentrations of*Clarias gariepinus*among stations

	Cu (mg/Kg)	Pb (mg/Kg)	Ni (mg/Kg)	Cd (mg/Kg)	Fe (mg/Kg)	Zn (mg/Kg)	Mn (mg/Kg)	Cr (mg/Kg)
Station 1	0.04±0.01^{b}	0.03±0.01^{b}	0.05±0.01^{c}	0.03±0.01^{b}	0.03±0.03^{c}	0.10±0.03^{c}	0.09±0.04^{b}	0.06±0.02^{b}
	(0.06-0.20)	(0.12-0.20)	(0.04-0.20)	(0.06-0.20)	(0.02-0.19)	(0.10-0.19)	(0.06-0.20)	(0.10-0.20)
Station 2	0.20±0.03^{a}	0.24±0.05^{a}	0.19±0.04^{b}	0.19±0.09^{a}	0.19±0.04^{b}	0.22±0.03^{a}	0.18±0.03^{a}	0.22±0.03^{a}
	(0.15-0.28)	(0.17-0.25)	(0.14-0.22)	(0.17-0.21)	(0.15-0.20)	(0.16-0.29)	(0.16-0.20)	(0.16-0.25)
Station 3	0.18±0.03^{a}	0.17±0.03^{a}	0.18±0.03	0.19±0.03^{a}	0.17±0.04^{b}	0.18±0.04^{a}	0.18±0.03^{a}	0.18±0.03^{a}
	(0.17-0.20)	(0.15-0.19)	(0.16-0.20)	(0.17-0.21)	(0.15-0.19)	(0.16-0.20)	(0.16-0.20)	(0.16-0.20)
Station 4	0.18±0.03^{a}	0.16±0.02^{a}	0.18±0.04^{a}	0.18±0.03^{a}	0.16±0.03^{b}	0.18±0.03^{a}	0.16±0.03^{b}	0.17±0.03^{a}
	(0.16-0.19)	(0.15-0.18)	(0.16-0.20)	(0.17-0.20)	(0.15-0.18)	(0.16-0.19)	(0.15-0.18)	(0.16-0.19)
Station 5	0.19±0.03^{a}	0.18±0.03 ^{a}	0.18±0.04^{a}	0.17±0.03^{a}	0.18±0.03 ^{a}	0.17±0.04^{a}	0.17±0.04^{a}	0.17±0.04^{a}
	(0.15-0.20)	(0.17-0.20)	(0.10-0.20)	(0.15-0.19)	(0.16-0.20)	(0.12-0.19)	(0.11-0.19)	(0.13-0.19)
Station 6	0.17±0.03^{a}	0.18±0.03^{a}	0.18±0.03^{a}	0.19±0.03^{a}	0.17±0.04^{ab}	0.17±0.02^{ab}	0.19±0.03^{a}	0.18±0.04^{a}
	(0.16-0.19)	(0.17-0.20)	(0.16-0.20)	(0.17-0.20)	(0.15-0.19)	(0.16-0.18)	(0.17-0.20)	(0.16-0.20)
Station 7	0.18±0.03^{a}	0.19±0.03^{a}	0.17±0.04^{a}	0.19±0.04^{a}	0.18±0.03^{a}	0.18±0.04^{a}	0.18±0.03^{a}	0.19±0.03^{a}
	(0.16-0.19)	(0.17-0.20)	(0.15-0.19)	(0.17-0.21)	(0.17-0.20)	(0.15-0.20)	(0.17-0.20)	(0.18-0.21)
Station 8	0.17±0.03^{a}	0.19±0.03^{a}	0.18±0.03^{a}	0.18±0.03^{a}	0.17±0.04^{ab}	0.17±0.02^{ab}	0.18±0.03^{a}	0.18±0.03^{a}
	(0.15-0.19)	(0.17-0.20)	(0.17-0.20)	(0.16-0.20)	(0.15-0.19)	(0.16-0.18)	(0.16-0.19)	(0.16-0.20)

Means with the same superscript along rows were not significantly different at p>0.05.
Note: Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

Table 4.46. Mean values of heavy metalin*Clarias gariepinus*between seasons

Heavy metals	Range	Wet season	Range	Dry season	P – value	WHO, (2004)
Cu(mg/Kg)	0.10-0.19	0.17±0.03	0.11-0.18	0.15±0.01	0.08**	2
Pb(mg/Kg)	0.18-0.31	0.24±0.05	0.12-0.19	0.16±0.06	0.00*	0.2
Ni(mg/Kg)	0.11-0.20	0.14±0.07	0.08-0.15	0.11±0.03	0.00**	1
Cd(mg/Kg)	0.13-0.19	0.17±0.09	0.18-31	0.24±0.02	0.04**	0.1
Fe(mg/Kg)	0.10-0.18	0.16±0.02	0.12-0.21	0.18±0.07	0.09**	0.18
Zn(mg/Kg)	0.14-0.19	0.17±0.01	0.15-0.25	0.22±0.03	0.06**	-
Mn(mg/Kg)	0.10-0.20	0.14±0.01	0.09-0.19	0.17±0.04	0.15**	-
Cr(mg/Kg)	0.12-0.22	0.18±0.03	0.11-0.21	0.15±0.03	0.83**	-

Note: * = There were significant differences at $p<0.05$
** There were no significant differences at $p>0.05$
Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

Spatially, the lowest mean value of Fe in fish muscle was 0.03±0.01 mg/Kg in Station 1, while it was 0.19±0.04 mg/Kg in Station 2. The seasonal mean varied from 0.16±0.02 during the wet season, while the highest was 0.18±0.07 mg/Kg during the dry season.The lowest mean value of Zn in fish muscles was 0.10±0.03 mg/Kg in Station 1, while the highest was 0.22±0.03 mg/Kg in Station 2. Seasonal variation in the mean values of Zn ranged from 0.17±0.01 mg/Kg wet season to 0.22±0.03 mg/Kg in the dry season.

The lowest mean value of Mn obtained among stations was 0.09±0.04 mg/Kg in Station 1, while the highest was 0.19±0.03 mg/Kg inStation 6. The least seasonal mean value was 0.14±0.01 mg/Kg in wet season, while the highest was 0.17±0.04 mg/Kg in dry season.The minimum level of Cr concentration recorded in fish muscles among Stations was 0.06±0.07 mg/Kg in station 1, while the highest 0.19±0.03 mg/Kg in Station 2. The lowest seasonal mean value of Cr was 0.15±0.03 mg/Kg during dry season, while the highest was 0.18±0.03 mg/Kg during the late dry season.

4.12 Mean concentrations of heavy metals in the sediment

The mean values of heavy metal concentrations in sediment among stations and between seasons are presented in Tables 4.47 and 4.48. The ANOVA for heavy metal concentrations in sediment among stations and between seasons are shown in Appendices 22 and 23. Among the stations, the lowest mean Cu concentration in sediment was 0.07±0.02 mg/Kg in Station 1,while the highest was 0.19±0.04 mg/Kg in Station 2. The lowest seasonal mean value of Cu in sediment was 0.12±0.02 mg/Kgduring wet season, while the highest was 0.17±0.08 mg/Kg during dry season. There were significance differences ($p<0.05$) in the mean values of Cu among stations. The lowest mean value of Pb concentration among the stations was 0.03±0.01 mg/Kg in Station 1, while the highest was 0.08±0.02 mg/Kg in Station 2.The lowest seasonal mean value of Pb was 0.07±0.02 mg/Kg during wet season,while the highest mean was 0.09±0.04 mg/Kgin dry season.

The highest and least mean of Ni concentrations were 0.06±0.01 mg/Kg Station 1, and 0.25±0.04 mg/Kg in Station 2. Mean seasonal values ofNi ranged from 0.12±0.05 mg/Kg during the dry season to 0.13±0.05 mg/Kg during the dry season. The lowest mean of Cd concentration was 0.10±0.09 mg/Kg in Station 1,while the highest was 0.34±0.13 mg/Kg in Station 2. The seasonal variation in the mean values of Cd ranged from 0.15±0.12 mg/Kg during the dry season to 0.27±0.10 mg/Kg duringthe wet season.

Table 4.47. Meansconcentrations of heavy metals in sediment among stations

	Cu (mg/Kg)	Pb (mg/Kg)	Ni (mg/Kg)	Cd (mg/Kg)	Fe (mg/Kg)	Zn (mg/Kg)	Mn (mg/Kg)	Cr (mg/Kg)
Station 1	0.07±0.02^{c}	0.03±0.01^{b}	0.06±0.01^{b}	0.10±0.01^{b}	0.09±0.01^{b}	0.02±0.01^{b}	0.02±0.01^{d}	0.06±0.02^{c}
	(0.01-0.4)	(0.01-0.50)	(0.03-0.14)	(0.90-0.38)	(0.07-0.31)	(0.01-0.13)	(0.02-0.6)	(0.01-0.10)
Station 2	0.19±0.04^{a}	0.08±0.02^{a}	0.25±0.04^{a}	0.18±0.12^{b}	0.15±0.02^{a}	0.06±0.04^{a}	0.16±0.02^{c}	0.34±0.10^{a}
	(0.10-0.24)	(0.04-0.09)	(0.10-0.26)	(0.21-0.34)	(0.11-0.18)	(0.03-0.07)	(0.05-0.26)	(0.07-0.28)
Station 3	0.12±0.03^{b}	0.06±0.03 ^{a}	0.12±0.04^{a}	0.30±0.09^{a}	0.12±0.04^{a}	0.06±0.02^{a}	0.12±0.02^{b}	0.14±0.09^{b}
	(0.10-0.13)	(0.05-0.07)	(0.10-0.14)	(0.25-0.34)	(0.10-0.14)	(0.04-0.07)	(0.11-0.13)	(0.12-0.15)
Station 4	0.12±0.03^{b}	0.07±0.03^{a}	0.12±0.03^{a}	0.28±0.11^{a}	0.11±0.03^{a}	0.06±0.02^{a}	0.11±0.03^{b}	0.13±0.02^{b}
	(0.10-0.14)	(0.05-0.08)	(0.10-0.13)	(0.22-0.34)	(0.09-0.13)	(0.05-0.08)	(0.09-0.13)	(0.13-0.14)
Station 5	0.15±0.11^{a}	0.07±0.02^{a}	0.14±0.03^{a}	0.25±0.09^{a}	0.12±0.02^{a}	0.06±0.03^{a}	0.13±0.02^{b}	0.12±0.04^{b}
	(0.09-0.21)	(0.06-0.08)	(0.12-0.15)	(0.20-0.30)	(0.11-0.13)	(0.04-0.07)	(0.12-0.14)	(0.10-0.14)
Station 6	0.12±0.02^{b}	0.06±0.03^{a}	0.24±0.46^{a}	0.34±0.12^{a}	0.14±0.06^{a}	0.05±0.03^{a}	0.13±0.02^{b}	0.12±0.04^{b}
	(0.11-0.13)	(0.05-0.08)	(0.01-0.48)	(0.28-0.41)	(0.11-0.17)	(0.04-0.07)	(0.11-0.14)	(0.10-0.14)
Station 7	0.13±0.02^{b}	0.06±0.03^{a}	0.13±0.02^{a}	0.27±0.11^{a}	0.12±0.03^{a}	0.06±0.03^{a}	0.16±0.01^{a}	0.13±0.02^{b}
	(0.12-0.14)	(0.04-0.07)	(0.12-0.14)	(0.21-0.33)	(0.11-0.14)	(0.05-0.08)	(0.09-0.23)	(0.11-0.14)
Station 8	0.16±0.16^{a}	0.05±0.02^{a}	0.13±0.05^{a}	0.28±0.09^{a}	0.13±0.02^{a}	0.06±0.02^{a}	0.14±0.08^{b}	0.17±0.01^{b}
	(0.08-0.25)	(0.04-0.06)	(0.10-0.16)	(0.24-0.33)	(0.12-0.14)	(0.05-0.07)	(0.10-0.19)	(0.08-0.25)
WHO, (2004)	16	40	16	0.6	30	110	30	25

Means with the same superscripts along rows were not significantly different at p>0.05.
Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese, Cr=chromium..

Table 4.48. Mean concentrationsof heavy metal in sediment between seasons

Heavy metals	Range	Wet season	Range	Dry season	P - value	WHO (2004) (mg/Kg)
Cu (mg/Kg)	0.11 – 0.14	0.12±0.02	0.10 – 0.20	0.17±0.08	0.04**	16
Pb (mg/Kg)	0.05 – 010	0.07±0.02	0.04 – 0.10	0.09±0.04	0.07**	40
Ni (mg/Kg)	0.10 – 0.17	0.13±0.05	0.09 – 0.13	0.12±0.05	0.56**	16
Cd (mg/Kg)	0.18 – 30	0.27±0.10	0.11 – 0.19	0.15±0.12	0.01*	0.6
Fe (mg/Kg)	0.09 – 0.15	0.13±0.01	0.10 – 0.20	0.14±0.06	0.98**	30
Zn (mg/Kg)	0.01 – 0.09	0.05±0.03	0.01 – 0.09	0.06±0.02	0.13**	110
Mn (mg/Kg)	0.10 – 0.14	0.12±0.02	0.08 – 1.03	0.15±0.05	0.054**	30
Cr (mg/Kg)	0.08 – 0.19	0.13±0.02	0.10 – 0.18	0.14±0.01	0.064**	25

Note: * = There were significant differences at $p<0.05$
** There were no significant differences at $p>0.05$
Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

The lowest mean value of Fe was 0.09±0.01 mg/Kg in Station 1, while the highest mean was 0.15±0.02 mg/Kg in Station 2. Seasonally, lowest mean value of Fe during the wet season was 0.13±0.01 mg/Kg and the highest 0.14±0.06 mg/Kg during the dry season.The lowest mean concentration of Zn in the sediment of Gbalegbe River was 0.02±0.01 mg/Kg in Station 1,while the highest was 0.06±0.04 mg/Kg in Station 2.

Seasonal mean concentrations of Zn in sediment ranged from 0.05±0.03 mg/Kg during wet season to 0.06±0.02 mg/Kg during the dry season.The lowest mean of Mn concentration in sediment was 0.02±0.01 mg/Kg in Station 1, while the highest was 0.16±0.02 mg/Kg in Station 2. Mean seasonal concentrations ranged from 0.12±0.02 mg/Kg during the wet season to 0.15±0.05 mg/Kg during the dry season.Among stations, the lowest mean of Cr concentration in sediment was 0.06±0.02 mg/Kg in Station 1, while the highest was 0.18±0.10 mg/Kg in Station 2. Seasonal mean values of Cr ranged from 0.13±0.02 mg/Kg during the wet season to 14±0.01 mg/Kg during the dry season.

4.13 Sediment particle sizes among stations and between seasons

The percentage (%) mean particle sizes of sediment among stations and between seasons are presented in Tables 4.49 and 4.50. Spatially, the highest and least clay particle size of sediment in Gbalegbe River were 45.0% and 20.3%, Silt (21.2%, 15.0%), Clay + Silt (colloid) (66.2%, 35.3%) in Stations 2 and 1, but Find Sand (39.4%, 17.7%) occurred in Stations 8 and 2, while Coarse Sand (45.9%, 15.81%) were recorded in Stations 1 and 2, respectively. Seasonally, Clay particle size of sediment in Gbalegbe River ranged from 29.3% to 45.8%, Silt (17.6%, 29.2%) and Silt + Clay (Colloid) (46.9%, 75.0%) during the dry and wet seasons, while highest and least Find Sand were 15.4% and 28.3%, Coarse Sand (9.7%, 24.9%) occurred during the wet and dry seasons, respectively.

4.14 Sediment compositions of Gbalegbe River

The mean values of sediment composition among stations and seasons are presented in Tables 4.51 and 4.52. The ANOVA of sediment compositions among stations and seasons are shown in Appendices 24 and 25. Among the stations, the lowest mean of exchangeable cation was 18.43±10.49, while the maximum 53.79±10.06in stations 1 and 2. Seasonal mean values of exchangeable cation ranged from 35.06±4.67 in the wet season to 41.93±9.01 in the dry season. The least and highest mean values of organic carbon recordedwere 2.33±1.97 mg/Kgand 7.88±1.66 mg/Kg in Stations 1 and 2, respectively.

Table 4.49. Percentage (%) sediment particle sizes among stations

Sediment particle size	S1	S2	S3	S4	S5	S6	S7	S8
Clay	20.26	45.03	33.82	24.19	22.48	30.99	23.57	22.98
Silt	15.01	21.19	17.92	21.17	16.76	14.09	19.13	17.09
Clay+Silt	35.27	66.22	51.74	45.51	39.24	45.08	42.70	40.07
Fine Sand	19.10	17.68	20.40	20.32	22.09	30.54	35.30	39.39
Coarse Sand	45.88	15.81	28.02	34.02	38.91	24.66	22.94	20.87

Note: S1 to S8 = stations 1 to 8.

Table 4.50. Seasonal mean variation of sediment particle sizes (%)

Sediment particle sizes	Wet season	Dry season
Clay	45.81	29.31
Silt	29.15	17.56
Clay+Silt	74.96	46.87
Fine Sand	15.4	28.25
Coarse Sand	9.71	24.88

Table 4.51. Mean sediment composition among stations

Parameters	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
EC	18.43±10.49^{d} (6.32-20.54)	53.79±10.06^{c} (10.90-65.67)	33.32±10.55^{b} (11.17-55.46)	36.12±11.33^{ab} (13.03-59.21)	36.53±11.51^{ab} (14.41-58.65)	41.63±5.14^{ab} (17.58-65.69)	41.12±10.28^{ab} (19.13-63.12)	46.78±12.15^{a} (31.12-62.43)
OC (mg/Kg)	2.33±1.97^{c} (1.27-3.37)	7.88±1.66^{c} (0.99-8.77)	2.20±1.77^{c} (1.26-3.14)	4.01±3.03^{b} (2.39-5.62)	2.72±2.00^{bc} (1.66-3.79)	2.83±2.00^{bc} (1.76-3.89)	3.09±2.26^{bc} (1.89-4.30)	6.15±2.02^{a} (5.07-7.22)
TN (mg/Kg)	47.54±39.32^{a} (26.59-68.49)	43.25±37.01^{a} (23.52-62.97)	45.49±3.98^{a} (25.25-65.73)	51.06±4.41^{a} (28.99-73.12)	43.52±3.53^{a} (24.59-62.45)	44.25±3.30^{a} (25.44-63.06)	48.70±3.76^{a} (30.17-67.22)	44.15±25.36^{a} (30.64-57.67)
AP (mg/Kg)	12.67±7.93^{b} (8.44-16.90)	11.40±7.69^{b} (7.31-15.50)	11.24±7.41^{b} (7.30-15.19)	15.75±8.34^{b} (11.31-20.20)	13.11±8.24^{b} (8.72-17.50)	14.06±8.13^{b} (9.73-18.40)	17.19±12.05^{b} (10.77-23.62)	41.83±22.78^{a} (29.69-53.97)
Mg (mg/Kg)	3.78±0.63^{a} (2.25-17.31)	7.65±6.31^{b} (4.29-11.02)	11.46±6.53^{ab} (7.99-14.94)	13.37±7.37^{a} (9.44-17.30)	13.29±5.25^{a} (10.49-16.08)	16.33±5.21^{a} (13.55-19.11)	15.60±6.57^{a} (12.10-19.10)	14.24±7.38^{a} (10.32-18.18)
Na (mg/Kg)	18.27±4.40^{ab} (15.93-20.62)	11.94±4.95^{ab} (9.30-14.57)	15.86±4.37^{b} (13.53-18.19)	17.01±4.53^{b} (14.59-19.42)	18.15±5.00^{ab} (15.49-20.82)	21.97±5.76^{a} (18.90-25.04)	21.55±5.81^{a} (18.45-24.65)	17.86±6.93^{ab} (14.17-21.56)
Ca (mg/Kg)	34.37±8.125^{c} (30.05-38.70)	14.18±7.44^{d} (10.21-18.14)	31.37±8.70^{c} (26.73-36.00)	32.58±8.93^{bc} (27.83-37.34)	34.52±9.01^{bc} (29.72-39.32)	35.64±8.10^{abc} (31.33-39.96)	38.60±7.38^{ab} (34.66-42.53)	40.83±6.37^{a} (37.44-44.22)
K (mg/Kg)	24.58±2.37^{a} (12.12-37.03)	17.2±18.42^{a} (7.43-27.06)	22.97±2.94^{a} (11.28-34.66)	23.86±2.10^{a} (2.08-35.64)	25.54±2.33^{a} (13.11-37.98)	26.49±23.72^{a} (13.86-39.13)	14.92±1.63^{b} (9.26-20.58)	18.20±6.63^{a} (14.66-21.73)
pH	6.79±0.61^{a} (4.96-5.61)	4.30±0.93^{bc} (2.81-7.80)	6.18±0.56^{b} (5.89-6.48)	6.52±0.44^{a} (6.28-6.75)	5.57±0.77^{bc} (5.16-5.98)	5.57±0.77^{bc} (5.16-5.98)	5.86±0.71^{bc} (5.48-6.24)	6.66±1.00^{a} (6.13-7.19)
EA	2.78±2.12^{a} (1.65-3.90)	0.86±0.50^{a} (0.59-1.12)	2.45±2.04^{a} (1.36-3.54)	2.55±2.04^{a} (1.46-3.64)	2.15±2.07^{a} (1.04-3.25)	2.59±2.15^{a} (1.44-3.73)	2.44±1.47^{a} (1.66-3.22)	3.48±1.59^{a} (2.63-4.32)
CEC ($Cmol^{+}/Kg$)	39.06±7.16^{c} (29.26-58.86)	55.16±27.49^{b} (40.52-69.81)	90.29±35.46^{a} (71.40 -109.19)	95.87±36.33^{a} (76.51-115.22)	99.22±37.20^{a} (79.40-119.04)	108.59±34.43^{a} (90.25-126.94)	98.58±23.83^{a} (85.88-111.28)	105.15±26.17^{a} (91.20-119.10)

Means with the same superscripts along column were not significantly different at p>0.05.

Note: exchangeable cation, OC=organic carbon, TN=total nitrogen, AP=average phosphorus, Mg=magnesium, Na=sodium, Ca=calcium, K=potassium, EA=exchangeable acidity and CEC=cation exchange capacity.

Table 4.52. Mean sediment compositions between seasons

	Range	Wet season	Range	Dry season	P – value
EC	21.51-40.11	35.06±4.67	30.35-51.73	41.93±9.01	0.80**
OC (mg/Kg)	0.51-3.00	2.55±1.29	2.89-6.93	4.51±1.25	0.20*
TN (mg/Kg)	35.22-50.12	36.25±3.47	45.14-61.23	51.13±3.45	0.04*
AP (mg/Kg)	10.81-23.52	14.49±1.78	14.61-30.37	21.18±8.86	0.04*
Mg (mg/Kg)	9.86-15.44	13.12±6.50	9.55-15.99	12.58±6.58	0.07**
Na (mg/Kg)	10.58-22.19	18.44±3.50	11.12-20.82	16.58±7.12	0.08**
Ca (mg/Kg)	23.79-40.91	35.51±3.73	22.51-32.98	30.25±13.56	0.65**
K (mg/Kg)	15.32-25.33	21.56±0.51	15.20-30.00	22.71±1.52	0.43**
pH	3.55-7.16	5.61±0.89	3.74-10.71	6.01±1.65	0.12**
EA	0.91-3.27	2.58±0.34	1.09-3.58	2.31±1.55	0.09**
CEC (Cmol+/Kg)	63.88-105.11	96.56±3.79	59.48-120.18	91.04±3.67	0.23**

Note: * = There were significant differences at $p<0.05$

** There were no significant differences at $p>0.05$

Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

Seasonalmean values of organic carbon ranged from 2.55±1.29mg/Kg during wet season to 4.51±1.25 mg/Kg during dry season.Among the stations, the highest mean of total nitrogen recorded was 51.06±4.41 mg/Kg inStation 4,while the least was 43.25±37.01 mg/Kg in Station 2. The mean values between seasons varied from 46.25±3.47 mg/Kgduring the wet season to 51.13±3.45 mg/Kgduring the dry season.

The minimum mean value ofphosphorus in sediment obtained was 10.67±7.93 mg/Kg in Station 1, while the maximum was 41.83±22.78 mg/Kg in Station 8. The seasonal mean values varied from14.49±1.78mg/Kg to 21.18±8.86 mg/Kg during wet and dry seasons, respectively.The minimum mean value of magnessium among stations was 10.34±5.95 mg/Kg, while the maximum 23.08±4.21 mg/Kg in Stations 1 and 2. The lowest seasonal mean value was 12.58±6.50 mg/Kgduring the season, while the highest was 13.12±6.50 mg/Kg during wet season.

The laest mean of sediment sodium concentration was 11.94±4.95 mg/Kg,while the highest was 21.97±5.76 mg/Kg in Stations 2 and 6, respectively. Seasonlly, the mean values of sodium concentration in sediment were16.58±7.12 mg/Kgand 18.44±3.50 mg/Kg in dry and wet season respectively.Least and highest mean values of calcium in sediment were14.18±7.44 mg/Kg and 40.83±6.37 mg/Kg in Stations 2 and 8. The least (30.25±13.56) mg/Kg and highest (35.51±3.73) mg/Kg seasonal mean values occurred in dry and wet seasons, respectively. There were significant differences ($P<0.05$) in the means of Ca among stations and between seasons.

The least mean concentration of potassium ions was 14.92±1.63 mg/Kg inStation 7, while the highest was 26.49±13.72 mg/Kg in Station 2. The highest seasonal mean value of K ion recorded was 22.71±1.52 mg/Kg during the dry season, while the least was 21.56±0.51 mg/Kg in wet season. There were significant differences ($P<0.05$) in the means of K ions among stations.Spatially, the highest and least mean values of pH in sediment were 6.79±0.61 and 4.30±0.93 in Stations 1 and 2, respectively.The highest (6.01±1.65) and least (5.61±0.89) seasonal mean value of pH in sediment occurred in dry and wet seasons.

Among stations, the lowest exchangeable acidity recorded in sediment was 0.86±0.50 in station 2, while the highest was 3.48±1.59 in Station 8. Seasonal variation in mean value of EA ranged from highest 2.31±1.55 to 2.58±0.34 in wet and dry seasons.Significant differences ($p<0.05$) existed inthe means of exchangeable acidity among stations.Among

stations, the highest and least mean values of cation exchange capacity in sediment were 39.06±7.16 $Cmol^{+}/Kg$and 108.59±34.43$Cmol^{+}/Kg$in Stations 1 and 6. Among the seasons, the lowest mean of CEC recorded was 91.04±3.67 $Cmol^{+}/Kg$ while the highest was 96.56±3.79 $Cmol^{+}/Kg$during the dry and wet seasons. There were significant differences ($p<0.05$) in the means of CECamong stations.

4.15 Contamination factor, degree of contamination, modified degree of contamination and pollution load index of sediment

Mean values of contamination factors, degree of contamination, modified degree oof contamination and pollution load index of sediment in Gbalegbe River among stations and between seasons are shown in Tables 4.53 and 4.54. Spatially, the highest and least mean values of contamination factor (C^{i}_{f}) in sediment of Gbalegbe River for copper were 0.268 and 0.099, lead (0.035, 0.013), nickel (0.260, 0.063), cadmium (0.442, 0.130), iron (0.15, 0.090), zinc (0.036, 0.012), manganese (0.271, 0.034) and chromium (0.167, 0.056) in Stations 2 and 1, respectively.

The C_d ranged from 0.210 (Pb) to 1.644 (Mn), Igeo ranged from -5.602 (Zn) to 0.163 (Cr), while mCd and PLI were 0.150 and 0.121, respectively.During the wet season, the mean values of C^{i}_{f} ranged from 0.05 (lead) to 0.38 (cadmium), C_d ranged from 0.05 (Pb) to 0.41 (Mn), Igeo ranged from -5.71 (Zn) to 0.79 (Fe), while mCd and PLI were 0.21 and 0.11, respectively. In the dry season, the mean values of C^{i}_{f} ranged from 0.03 (Pb) to 0.26 (Mn), C_d ranged from 0.07 (Pb) to 0.51 (Mn), Igeo ranged from -2.56 (Mn) to 0.97 (Pb), while mCd and PLI were 0.35 and 0.14, respectively.

4.16 Means concentrations of heavy metals in *Hesperocorixa castanea*

Mean values of heavy metals concentrations in *H. castanea* among stations and between seasons are presented in Tables 4.55 and 4.56. The ANOVA of heavy metal concentrations in *H. castenea* among stations and between seasons are shown in Appendices 25 and 26. Among the stations, the lowest concentration of Cu in *Hesperocorixa castanea* was 0.01±0.01 mg/Kg in Station 1, while the highest was 0.05±0.01 mg/Kg in Station 2. Seasonally, the lowest mean value of Cu in sediment macro-invertebrates was 0.03±0.01 mg/Kg, while the highest was 0.04±0.01 mg/Kg in dry and wet seasons. The lowest mean lead concentration was 0.02±0.01 mg/Kgin Station 1, while the highest was 0.04±0.02 mg/Kg in Station 2.

Table 4.53. Spatial variation in means of $C^{i}_{f,}$ C_d, mC_d and PLI of sediment

Stations	Cu	Pb	Ni	Cd	Fe	Zn	Mn	Cr
Station 1	0.099	0.013	0.063	0.130	0.090	0.012	0.034	0.056
Station 2	0.268	0.035	0.260	0.442	0.150	0.036	0.271	0.167
Station 3	0.169	0.026	0.125	0.390	0.120	0.035	0.203	0.130
Station 4	0.169	0.031	0.125	0.364	0.110	0.035	0.186	0.120
Station 5	0.211	0.031	0.146	0.325	0.120	0.035	0.220	0.111
Station 6	0.169	0.026	0.250	0.442	0.140	0.029	0.220	0.111
Station 7	0.183	0.026	0.135	0.351	0.120	0.035	0.270	0.120
Station 8	0.225	0.022	0.135	0.364	0.130	0.035	0.237	0.157
Cd	1.493	0.210	1.240	2.805	0.980	0.247	1.644	0.972
mCd	0.150							
PLI	0.121							
Igeo	0.006	0.0840	0.076	0.097	-3.816	-5.602	-2.877	0.163

Note: $C^{i}_{f,}$ = Contamination factor, C_d = Degree of contamination, mC_d = Modified degree of contamination and PLI = Pollution load index

Table 4.54. Means of $C^{i}_{f,}$ C_d, mC_d and PLI in sediment between seasons

Seasons	Indices	Cu	Pb	Ni	Cd	Fe	Zn	Mn	Cr
Wet season	C^{i}_{f}	0.18	0.05	0.14	0.38	0.13	0.03	0.20	0.12
	Cd	0.37	0.05	0.26	0.77	0.25	0.06	0.41	0.24
	mCd	**0.21**							
	I_{geo}	0.02	0.02	0.53	0.02	0.79	-5.71	0.08	0.03
	PLI	**0.11**							
Dry season	C^{i}_{f}	0.22	0.03	0.22	0.37	0.12	0.04	0.26	0.13
	Cd	0.44	0.07	0.44	0.77	0.24	0.08	0.51	0.25
	mCd	**0.35**							
	I_{geo}	0.04	0.97	0.01	0.10	0.04	0.03	-2.56	0.06
	PLI	**0.14**							

Note: $C^{i}_{f,}$ = Contamination factor, C_d = Degree of contamination, mC_d = Modified degree of contamination and PLI = Pollution load index.

Table 4.55. Spatial variation in mean values of heavy metal in *Hesperocorixa castanea*

	Cu (mg/Kg)	Pb (mg/Kg)	Ni (mg/Kg)	Cd (mg/Kg)	Fe (mg/Kg)	Zn (mg/Kg)	Mn (mg/Kg)	Cr (mg/Kg)
Station 1	0.01±0.01[b]	0.02±0.01[b]	0.02±0.01[b]	0.02±0.01[b]	0.02±0.01[b]	0.02±0.01[b]	0.02±0.01[b]	0.03±0.02[b]
	(0.01-0.02)	(0.01-0.03)	(0.02-0.03)	(0.01-0.03)	(0.02-0.03)	(0.01-0.03)	(0.02-0.04)	(0.01-0.05)
Station 2	0.05±0.01[a]	0.04±0.01[a]	0.08±0.01[a]	0.06±0.01[a]	0.05±0.02[a]	0.05±0.02[a]	0.04±0.02[a]	0.06±0.04[a]
	(0.03-0.08)	(0.03-0.04)	(0.03-0.09)	(0.03-0.09)	(0.03-0.06)	(0.02-0.07)	(0.03-0.04)	(0.05-0.07)
Station 3	0.0 3±0.02[a]	0.04±0.02[a]	0.04±0.01[b]	0.03±0.01[a]	0.04±0.01[a]	0.04±0.01[a]	0.03±0.01[a]	0.05±0.03[a]
	(0.02-0.04)	(0.03-0.04)	(0.04-0.05)	(0.03-0.04)	(0.03-0.05)	(0.03-0.04)	(0.02-0.04)	(0.04-0.07)
Station 4	0.03±0.01[a]	0.04±0.02[a]	0.03±0.02[b]	0.03±0.02[a]	0.04±0.01[a]	0.03±0.01[a]	0.03±0.01[a]	0.06±0.03[a]
	(0.02-0.04)	(0.03-0.05)	(0.02-0.04)	(0.02-0.04)	(0.03-0.04)	(0.02-0.04)	(0.03-0.04)	(0.04-0.07)
Station 5	0.04±0.01[a]	0.04±0.01[a]	0.03±0.01[b]	0.04±0.02[a]	0.03±0.02[a]	0.03±0.01[a]	0.03±0.01[a]	0.04±0.02[a]
	(0.03-0.05)	(0.03-0.05)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.06)
Station 6	0.04±0.02[a]	0.03±0.01[a]	0.04±0.02 [a]	0.03±0.01[a]	0.04±0.02[a]	0.04±0.02[a]	0.04±0.01[a]	0.06±0.02[a]
	(0.03-0.04)	(0.02-0.04)	(0.03-0.05)	(0.02-0.04)	(0.03-0.05)	(0.03-0.04)	(0.04-0.05)	(0.05-0.07)
Station 7	0.03±0.01[a]	0.03±0.01[a]	0.04±0.01[a]	0.04±0.02[a]	0.03±0.01[a]	0.03±0.02[a]	0.04±0.02[a]	0.05±0.03[a]
	(0.02-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.05)	(0.02-0.04)	(0.03-0.04)	(0.03-0.04)	(0.04-0.07)
Station 8	0.04±0.01[a]	0.03±0.01[a]	0.03±0.01[a]	0.03±0.02[a]	0.04±0.01[a]	0.03±0.01[a]	0.04±0.01[a]	0.05±0.02[a]
	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.03-0.04)	(0.04-0.07)
CVRLI, (2004)	0.10	0.01	0.01	0.10	10.00	0.05	5.00	0.005

Means with the same superscripts aalong the column were not significantly different at p>0.05.

Note: Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium, CVRLI=central veterinary research laboratory, Ireland.

Table 4.56. Mean concentrations of heavy metal in *H. castanea*between seasons

Metals	Range	Wet season	Range	Dry season	P – value	USEPA, (2004)
Cu (mg/Kg)	0.01 – 0.06	0.04±0.01	0.01 – 0.07	0.03±0.01	0.09**	10
Pb (mg/Kg)	0.02 – 0.08	0.04±0.01	0.01 – 0.09	0.04±0.01	0.65**	-
Ni (mg/Kg)	0.01 – 0.05	0.03±0.01	0.02 – 0.05	0.04±0.02	0.57**	10
Cd (mg/Kg)	0.03 – 0.07	0.04±0.02	0.01 – 0.06	0.04±0.01	0.81**	20
Fe (mg/Kg)	0.01 – 0.06	0.04±0.01	0.01 – 0.07	0.04±0.01	0.054**	7000
Zn (mg/Kg)	0.01 – 0.05	0.03±0.01	0.01 – 0.05	0.03±0.01	0.35**	30
Mn (mg/Kg)	0.01 – 0.04	0.03±0.01	0.02 – 0.07	0.04±0.02	0.87**	3500
Cr (mg/Kg)	0.01 – 0.09	0.05±0.02	0.02 – 0.09	0.05±0.02	0.23**	750

Note: ** There were no significant differences at $p>0.05$
Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium.

Seasonally, the lowest mean of Pb was 0.03±0.01 mg/Kg and the highest was 0.04±0.02 mg/Kg in wet and dry seasons. The lowest mean value of Ni concentration in sediment *Hesperocorixa castanea* was 0.02±0.01 mg/Kg in Station 1, while the highest was 0.08±0.01 mg/Kg Station 2. The lowest seasonal mean value of Ni was 0.03±0.01 mg/Kg, while the highest was 0.04±0.02 mg/Kg in wet and dry seasons.

Among the stations, the lowest mean value of Cd was 0.02±0.01 mg/Kg in Station 1, while the highest was 0.06±0.01 mg/Kg in Station 2. A seasonal mean value of 0.05±0.01 mg/Kg was recorded for Cd in both wet and dry seasons. The lowest mean of Fe recorded in sediment macro invertebrates was 0.02±0.01 mg/Kgin Station 1, while the highest was 0.05±0.02 mg/Kg in Station 2.A seasonal mean value of 0.04±0.02 was recorded for Fe in both wet and dry seasons. Spatial minimum mean of Zn concentration in sediment macro-invertebrates among the stations ranged from 0.02±0.01 mg/Kg in Station 1, and the maximum occurred in Station 2 with a mean value of 0.05±0.02 mg/Kg. A mean value of 0.03±0.01 mg/Kg was recorded for Zn in both wet and dry seasons.

Among the stations, the mean value of Mn concentration in *Hesperocorixa castanea* was lowest in Station 1 with a mean of 0.02±0.01 mg/Kg, while the highest was 0.04±0.02 mg/Kg in Station 2. Seasonal mean value of Mn varied from 0.03±0.01 mg/Kg to 0.04±0.02 mg/Kg in wet and dry seasons. The minimum mean concentration of Cr recorded in *Hesperocorixa castanea* was 0.03±0.02 mg/Kg in Station 1, while the maximum was 0.06±0.04 mg/Kg in Station 2. A seasonal mean value of 0.05±0.02 was recorded for Cr in both wet and dry seasons.

4.17 Total petroleum hydrocarbon (TPH) content in water, *Clarias gariepinus*, sediment and *Hesperocorixa castanea*

The mean values of TPH content in water, *C. gariepinus*, sediment and *H. castanea* among stations and seasons are presented in Tables 4.57 and 4.58. The ANOVA for TPH concentrations in biota among stations and between seasons are shown in Appendices 27 and 28. Spatially, the lowest mean value of TPH in water was 0.91±0.19 mg/L in Station 1, while the highest was 5.66±3.24 mg/L in Station 2. Seasonal means of TPH in water were 3.147±0.54 mg/L and 3.75±0.12 mg/L in dry and wet seasons. There were significant differences ($p<0.05$) in the means of TPH in water among the stations.

Table 4.57. Spatial mean of values of TPH in water, *C. gariepinus*, sediment and *H. castanea*

Stations	TPH-Water (mg/L)	TPH-*C. gariepinus* (mg/Kg)	TPH-Sediment (mg/Kg)	TPH-*Hesperocorixa castenea* (mg/Kg)
Station 1	ND	ND	ND	0.02±0.01[b] (0.01-0.04)
Station 2	5.66±3.24[a] (3.94-7.39)	0.56±0.20[a] (0.25-0.76)	0.53±0.22[ab] (0.41-0.64)	0.69±0.19[a] (0.16-0.85)
Station 3	3.92±2.31[b] (2.70-5.15)	0.36±0.23[a] (0.24-0.48)	0.50±0.29[ab] (0.34-0.65)	0.59±0.15[a] (0.17-0.64)
Station 4	3.85±2.28[b] (2.63-5.06)	0.40±0.20[a] (0.29-0.50)	0.52±0.26[ab] (0.38-0.66)	0.66±0.16[a] (0.17-0.75)
Station 5	2.80±1.75[b] (1.86-3.73)	0.35±0.21[a] (0.25-0.47)	0.43±0.23[b] (0.31-0.56)	0.43±0.14[a] (0.16-0.50)
Station 6	3.17±2.09[b] (2.05-4.28)	0.44±0.25[a] (0.31-0.58)	0.51±0.30[ab] (0.35-0.68)	0.55±0.17[a] (0.16-0.64)
Station 7	4.00±1.42[b] (3.24-4.75)	0.51±0.24[a] (0.38-0.64)	0.46±0.25[ab] (0.32-0.59)	0.45±0.19[a] (0.15-0.56)
Station 8	4.05±0.60[b] (3.20-4.90)	0.37±0.29[a] (0.32-0.62)	0.05±0.03[b] (0.04-0.08)	0.32±0.14[a] (0.15-0.35)
WHO (2001)	----	0. 05	0.003	0.005
FEPA, (1991)	----	0.001	0.002	< 0.005

Means with same superscripts along the column were not significantly different at p>0.05.
Note:ND=not detected, NIS (2007) recommended 0.0007mg/L of TPH for drinking water. TPH-Water=total petroleum hydrocarbon concentration in water, TPH-*C. gariepinus*=total petroleum hydrocarbon concentration in *C. gariepinus*,TPH-sediment=total petroleum hydrocarbon concentration in sediment in sediment and TPH-*Hesperocorixa castanea*=total petroleum hydrocarbon concentration in *Hesperocorixa castanea*

Table 4.58. Mean TPH concentrations in water, *Clarias gariepinus*, sediment and *Hesperocorixa castanea*

Parameters	Range	Wet season	Range	Dry season	P - value	WHO (2001)	FEPA, (1991)
TPH-Water (mg/L)	1.34-4.51	3.75±0.12	2.50-4.50	3.17±0.54	0.09**	----	----
TPH in whole *C. gariepinus* (mg/Kg)	0.09-1.52	0.16±0.03	0.10-0.56	0.44±0.23	0.03*	0.05	0.001
TPH-Sediment (mg/Kg)	0.10-0.59	0.31±0.11	0.30-0.60	0.52-0.19	0.04*	0.003	0.002
TPH-Sediment *H. castenea* (mg/Kg)	1.01-1.95	1.24±0.14	1.00-2.00	1.25±0.70	0.00**	0.005	< 0.005

Note: * = There were significant differences at $p<0.05$; ** = There were no significant differences at $p>0.05$
Cu=copper, Pb= lead, Ni=nickel, Cd=cadmium, Fe=iron, Zn=zinc, Mn=manganese and Cr=chromium; NIS (2007) recommended 0.0007mg/L of TPH for drinking water. TPH-Water=total petroleum hydrocarbon concentration in water, TPH-*C. gariepinus*=total petroleum hydrocarbon concentration in *C. gariepinus*,TPH-sediment=total petroleum hydrocarbon concentration in sediment in sediment and TPH-*Hesperocorixa castanea*=total petroleum hydrocarbon concentration in *Hesperocorixa castanea.*

The least and highest mean values of TPH in *C. gariepinus* were 0.10±0.02 mg/Kgand 0.56±0.20 mg/Kg in Stations 1 and 2. Seasonal mean values varied from 0.16±0.03 mg/Kg to 0.44±0.23 mg/Kg in wet and dry seasons.The lowest (0.14±0.01) mg/Kg and highest (0.53±0.22) mg/Kg spatial meanvalues of TPH in sediment were recorded in Stations 1 and 2, while seasonalmean TPH in sediment ranged from 0.31±0.11 mg/Kg to 0.52±0.19 mg/Kg in wet and dry seasons. The lowest mean TPH concentration recorded in *Hesperocorixa castanea*was 0.02±0.01 mg/Kg in Station 1, while the highest was 0.69±0.19 mg/Kg in Station 2. Seasonal meanvalues of TPH concentration in *Hesperocorixa castanea* ranged from 1.24±0.14 mg/Kg to 1.25±0.07 in wet and dry seasons.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Climatic data of the study area

The climatic data of the area during the study period were typical of tropical regions of the world that experience high rainfall (Balogun and Ajani, 2015). Water temperatures recorded in this study were similar to water temperatures reported by earlier studies in Nigeria South – South coastal waters (Ogbuagu, 2013). Minimal changes in temperature observed among stations and seasons could be associated with their exposure to the same climatic condition.

5.2 Physco-chemical characteristics of Gbalegbe River

The quality of coastal and inland waters is negatively affected due to waste generated through anthropogenic activities and natural processes (Valbo-Jorgensen*et al*., 2009). At present, anthropogenic inputs of metals exceed natural inputs (Vidthayanon, 2002). Very high concentrations of heavy metals in surface water could cause a negative impact on the aquatic environment (Yi *et al.,*2008).

5.2.1 Total dissolved solids (TDS)

The values of TDS recorded during the study periods were less than the maximum acceptable limit of 2000mg/L by NIS, (2007) and United Nations International Children Education Fund, UNICEF, (2008) but higher values than Boyd (1998) recommended range of 30 – 200mg/L for freshwater fish species were recorded at station 2 and during the late rainy season.

The lower values of TDS recorded at Station 1 during the dry season could be associated with the minimal anthropogenic activities at Station 1 (area with minimum activities) and reduced amount of in – flow of sediment load into Gbalegbe River the dry season, while highest mean value recorded at Station 2 and during the wet season could be due to increased petroleum, sand mining, rubber and the glass manufacturing industries emptying their untreated effluents into Gbalegbe River coupled, with the high amount of rainfall during the late rainy season.

These observations were in agreement with Abu and Egenonu, (2008) who reported that, increase in the concentration of TDS might be attributed to high amount of rainfall, especially during the peak periods of rainy season in Calabar River, Cross River State. The principal application of TDS is in the study of water quality for river, lakes and streams (Abowei and Sikoki, 2005). The TDS is not usually considered as a primary pollutant, but it is used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of the presence of chemical contaminants (UNICEF, 2008).

World Health Organisation (2008) reported the primary sources of TDS in receiving water bodies as agricultural, residential run-off, leaching of soil contamination and point source such as water pollution discharged from industrial and sewage treatment plants. The most common chemical constituents found in nutrient run-off and storm water run-off are: phosphate, calcium, sodium, potassium and chloride (Wakama *et al.,* 2008).

Total dissolved solids consists of inorganic salts, organic matter and dissolved materials such as; chlorides, nitrates, sodium, carbonates, calcium, sulphate, magnesium and potassium. Concentration of TDS above the recommended range imparts of undesirable mineral taste, laxative effects due to the presence of salts ($NaSO_4$ and $MgSO_4$), toxaemia fish and cardiac diseases (WHO, 2008).

5.2.2 Total suspended solids (TSS)

Higher quantity of TSS than the recommended levels of 25mg/L (UNICEF, 2008), 30mg/L (FEPA, 1991) and 10mg/L (Boyd, 1998) were recorded in Stations 2, 3, 5 – 8, while the quantity recorded in Stations 1 and 4 were within the acceptable limits. Adefemi *et al.,* (2007) reported that, the presence of TSS in a river above recommended limits interferes with its aesthetics and recreational uses, reduced light penetration through the water column, thereby reducing the productive capacity of the photic zone, decline in primary productivity and eventually leads to the reduction in fish population.

Results of this study were in agreement with Ajibade (2004) who reported an increase in TSS in Asa River and attributed its consequencies on aquatic organisms to reduced visibility, swimming ability, poor growth rate and clogging of fish gills. TSS was listed as a conventional pollutant in US Clean water Act of 1972.

Ajuonu *et al*. (2011) reported that TSS affects the aquatic life in the following ways; high concentration of TSS settles out on the river bed and cover aquatic organisms, eggs and sediment macroinvertebrates larvae. This coating prevents sufficient dissolved oxygen transfer and results in the death of suspended organisms; elevated concentration of TSS decreases the effectiveness of drinking water disinfecting agents by allowing microorganisms to hide from disinfectants within solids aggregate, while many organic and inorganic pollutants sorb to solids so that the concentration of the pollutants on the solid are high. Hence, sorb pollutants (solids) could be transported elsewhere in rivers and lake systems resulting in the exposure of organisms to pollutants away from the point source.

5.2.3 Electrical conductivity (EC)

Means of EC recorded during the study period among stations and seasons were less than the recommended level of 2000µS/cm (ASTM, 2006). There were significant differences ($p<0.05$) among the stations and seasons. Electrical conductivity (EC) is a measure of the ability of the water to conduct electric current, while its presence in a water body is influenced by dissolved salt content, amount of rainfall and freshwater discharge from inland drainages (Adewara and Visser, 2011).

Ampon and Taeng-On (2014) reported that electrical conductivity greater than 2000µS/cm is detrimental to health. Arimoro *et al*. (2007) reported that as the concentrations of salts in water increases, electrical conductivity increases and the warmer the water, the higher the electrical conductivity. The difference between TDS and TSS is that the former can pass through a sieve of 2µm yet indefinitely suspended in solution, but TSS cannot pass through it (Ogbuagu, 2013).

5.2.4 Turbidity

Higher levels of turbidity than recommended rate of 10 FTU by UNICEF, (2008) were recorded except at Station 1 (area of less activities) during the period of the study. The recorded lower level of turbidity recorded at Station 1 might be associated with dilution effects from water aquifer and the absence of sand extraction, glass, petroleum and rubber industrial activities as at the time of this study, while the higher values of turbidity recorded among the other stations and seasons could be attributed to high rate of run-off into the river as well as higher rate of sand extraction coupled with the discharge of untreated effluents into Gbalegbe River by the glass, petroleum and rubber factories. The availability of suspended

particles such as plankton, clay, silt, finely dissolved organic matter made the water to be described as turbid (Udosen and Benson, 2006).

Olatunji *et al*., (2011) reported that settleable materials as a result of rising turbidity concentration form blanket on the river bed thereby causing destruction to sediment macroinvertebrates abundance, blockage to gravel spawninig bed, increased water temperature, reduce primary productivity, reduction in dissolved oxygen which could either lead to a state of hypoxia (DO $\leq$ 3.5ml/L) or anoxic (DO $<$ 0.5mg/L) condition which eventually lead to low fish abundance from the river. Abowei and Sikoki (2008) reported that the presence of turbidity in a river prevents successful development of eggs and larvae, modify natural migration of fish and decrease in fish food supply.

5.2.5 Temperature

The mean water temperatures of Gbalegbe River recorded among stations and season during the study period were within the required limit for warm water fish species. This observation was in agreement with Balogun and Ajani, (2015) who reported similar range of temperature in Badagry Creek. Ampon and Taeng-on (2014) reported that, fluctuation in water temperature of a river could be due to its velocity and the rate of mixing of bottom and surface water, change in the atmospheric conditions and the presence of suspended solids.

Osibanjo *et al.* (2011) reported that temperature affects self purification process of rivers. High temperature promotes increased BOD concentration because biodegradation of organic matters by anaerobic bacteria leads to the reduction in DO level, resulting in an obnoxious condition (Abowei and Sikoki, 2005). Bilota and Brazier (2008) reported that, a unit change in water temperature may alter the existing aquatic community as seen in reduced respiration, reproduction, growth, feeding rate, behaviour, distribution and migration as well as decreased in interspecies relationships.

Beketov (2004) was of the opinion that temperature is one of the most important ecological factors controlling the behavioural characteristics of organisms, solubility of gases and salts in water, while UNICEF (2008) reported that water temperature has a very high influence on the growth and reproductive rate of phytoplankton, zooplankton, sediment macroinvertebrates, feeding and growth rate of fishes. Adeleye and Adebiyi, (2003) also reported that temperature and salinity are important environmental factors that determine the variety and density of freshwater plankton.

5.2.6 Dissolved Oxygen (DO)

Dissolved oxygen concentrations recorded during the period of the study at Station 1, during early rainy season and dry season were within the acceptable limits of >4.0mg/L (UNICEF, 2008), 5 – 10 (Boyd, 1998) and >5.0mg/L (FEPA, 1991). The means values obtained for the other stations and seasons were less than the recommended limits required for the survival of aquatic organisms. The low level of DO recorded among seasons and stations could be due to the presence of high amount of TSS, turbidity, BOD, increased temperature and decrease velocity in Gblegbe River as a result of excess precipitation, increased effluents volume in the water from sand mining, glass, rubber and petroleum industries located around and within the Gbalgbe River.

Increased DO levels at Station 1and from wet to dry seasons could be attributed to inflow of freshwater and atmospheric re-aeration. The reduced industrial activities at Station 1 could also be responsible for the improved DO concentration. Effiong and Akpan (2015) reported that, in a study conducted immediately after a major crude oil spillage in a river within the Niger Delta Region, revealed a very low level of DO (< 1.4mg/L). Similarly, low level of dissolved oxygen has been recorded for coastal water of Warri River (Ogaga *et al*., 2015).

Braide *et al.* (2004) reported that, decreased level of dissolved oxygen could lead to anaerobic decomposition of organic matter in water leading to the production of hydrogen sulphide, methane and carbon dioxide. Dissolved oxygen could be regulated by the oxidation of organic matter, dissolution of atmospheric oxygen and primary productivity by photosynthesis (Chukwu, 2008). A decrease in the level of dissolved oxygen could place aquatic organisms in states of hypoxia (DO < 3.0mg/L) which would cause fish to migrate to places richer in DO supply and anoxia (DO < 0.50mg/L) which results in total fish kill (Abowei *et al.*, 2008).

5.2.7 Biological Oxygen Demand (BOD)

Though BOD values recorded throughout the study period were generally less than the recommended ranges of > 10 mg/L (UNICEF, 2008), 50mg/L (FEPA, 1991), the lowest mean value of BOD in Station 1 compared with the other stations and seasons revealed that Gbalegbe River was gradually becoming polluted. This was further elevated during the late rainy season when the BOD value was highest due to increased rate of run-off as well as heavy metals discharged from industrial waste effluents, agriculture, domestic sewage and the in-flow of total petroleum hydrocarbon into the river (Onyema, 2007).

Low value of BOD recorded at the control Station 1 was an indication of good water quality. BOD directly affects the amount of DO in rivers.The greater the BOD, the more rapidly the DO is depleted in the water as such, aquatic organisms become stressed, suffocated and die off (Ovie and Ovie, 2014). Biological oxygen demand is the removal of dissolved oxygen by micro-organisms in aerobic degradation of dissolved organic matter in water. It is one of the most common measures of pollutants of organic materials in water and it indicates the amount of putricible organic matter present in the water (Ajuonu *et al.*, 2011).

5.2.8 pH

The pH values recorded during the study were within the recommended range of 6.8 – 8.9 (UNICEF, 2008). River water with pH values higher than the recommended ranges are known to have adverse effects on fish production (Ezemonye *et al*., 2009). Fish production is generally poor when pH ranges are 4 and >10 because these ranges are referred to as acid and alkaline dead points (Ovie, 2014). The pH of water indicates whether the water is acidic or alkaline.

The pH is important in chemical and biological systems of natural water. The solubility of sediment metals and suspeneded materials is affected by pH (Boyd and Craig, 1998). Excessive rise in the concentration of pH could cause increase in NH_3 concentration which is a toxic substance capable of affecting the physiology of zooplankton, sediment macro-invertebrates and fish (Olaifa, 2004). The pH plays a significant role in deciding the quality of polluted water because the adsorptive capacity of metals on sediments increases with increasing pH (NIS, 2007). The measurement of pH ranges from 1 to 14 with a pH of 7 indicating a neutral solution. Values lower than 7 indicates acidity while values higher than 7 indicates alkalinity (Brinkman and Johnston, 2008).

An increase in pH encourages the production of ammonia which is toxic to aquatic organisms. The United States Environmental protection Agency (Odiete, 1999) recommended a pH range of 6 – 9 for domestic water; 6.5 – 9.0 for freshwater and 6.5 – 8.5 for marine environment. Drinking water with a pH of between 6.5 and 8.5 is generally considered satisfactory (Ovie and Ovie, 2014).

5.2.9 Alkalinity

Throughout the study period, the lowest mean value of alkalinity was obtained at Station 1, while the highest was at Station 8. Except at Station 1, the mean values of alkalinity recorded among the other stations and seasons were higher than the recommended values of 20mg/L (UNICEF, 2008 and FEPA, 1991) and 0 – 20mg/L (Boyd, 1998).

The decrease in alkalinity at Station 1 could be due to dilution effects from water aquifer and rainfall. The slight variation in the seasonal means value of alkalinity obtained from Gbalegbe River were in agreement with Edet and Worden (2009) who reported that total alkalinity could also show variation from upstream to downstream. Ekiye and Zejiao (2010) reported that high alkalinity in a river system is indicative of its hardness and high buffering capacity.

The alkalinity of water is a measure of its capacity to neutralize acids. Although many materials might contribute to the alkalinity of water, most of the alkalinity in natural water is caused by the presence of hydroxides, carbonates, and bicarbonates (Ebong *et al.*, 2006).Carbonates and bicarbonates are common to most waters because carbonate materials are abundant in nature, whereas the presence of hydroxides is usually due to water treatment or contamination. Due to the fact that these substances act as buffers to resist change in pH, alkalinity could also be viewed as a measure of a water buffering capacity. Alkalinity impacts and is impacted by chemical and biological systems of natural waters (FEPA, 1991).

5.2.10 Salinity

Though salinity values obtained during this study were within the acceptable limits of 5‰ (FEPA, 1991), value at Station 1 compared with the other stations and seasons suggested that salinity in Gbalegbe River was gradually on the increase. Esoka and Umaru (2006) reported that unless the water of a river mixes well, salinity increases with water depth. Salinity and temperature are key factors in the stratification of a river. Ezemonye *et al.* (2009) reported that, salinity levels determine the type of plants and animals that can live within the different zones of a river. Salinity is the measure of the quantity of salts dissolved in water (UNICEF, 2008).

It has been reported that salinity influences the toxicity of heavy metals and crude oil and as such, their effects on aquatic organisms and man are very detrimental (Montasar *et al.* 2010).

As salinity increases, turbidity increases. Salinity measurement is used to accurately determine depth of freshwater and seechi disc visibility at zooplankton sampling stations.

River gradually exhibits changes in salinity through its length (Tamuno, 2005). Freshwater enters the rivers from their tributaries and mixes with sea water, moving from the ocean and eventually raises salinity. Fresh water has a salinity of <5‰. Within the river, salinity levels are classified into Oligohaline (0.5 - 5‰), Mesohaline (5 - 18‰) and Polyhaline (18 - 30‰) (Kaoud and El – Dahshan, 2010).

Near the connection with the open sea, river may be euryhaline, where salinity levels are the same as the ocean (>30.0‰). Freshwater fish species are restricted to the upper reaches of the river while marine species inhabit river's mouth. Salinity causes flocculation of particles while flocculation is the process of particles' aggregation into larger clumps (Galadima *et al.*, 2011).

5.2.11 Chloride

Chloride occurs in all natural water in widely varying concentrations (WHO, 2007). The mean value of chloride recorded during the study period were lower than the acceptable limit of < 250 mg/L (UNICEF, 2008) and 200 – 250mg/L (NIS, 2007) and 200mg/L (Boyd, 1998). This could be attributed to the constant flow and supply of freshwater into Gbalegbe River by its tributaries and increased level of rainfall. Excessive chloride in water is not particularly harmful while the criteria set for this anions are based on palatability and its potential high corrosiveness (Abowei, 2012).

5.2.12 Velocity

The term velocity as it applied to this study connoted the flow rate of Gbalegbe River. Ovie (1993) reported that, river flow velocity might be a very important determining factor of the composition and diversity flora and fauna assemblages. It has also been reported that nutrients concentration are higher in rivers of low velocity than in rivers of high flow rate (JICA, 2008). The rate of flow of a river is determined by the nature of its sediments and suspended particulate matter present in it (Anon, 2005). The velocity of a river determines the area of nutrient concentrations within it and the types of aquatic organisms likely to be found. A slow flowing river tends to accumulate organic matter than a fast flowing one (Popoola and Otalekor, 2011).

5.2.13 Transparency

Transparency determines the extent to which light rays can penetrate the water column (Boyd, 1998). Mean values of transparency measured during the study were lowest during the wet season and highest during the dry season. The reason for reduced Transparency during the late rainy season may be due to the presence of high level of suspended particulate matter.

When there are excessive dissolved solids in water, the intensity of penetration of light through the water column is reduced and as such, there may be an increase in water temperature and a decrease in DO level. Transparency values are used in the determination of the photic zone of rivers. An increase in turbidity level may lead to a decrease in the level of Transparency which will in turn reduce the amount of light penetration through the water body and eventually lead to the reduction in primary productivity and dissolved oxygen.

The high transparencyvalue recorded at Station1 was a good indicator of high primary production while lower values recorded during the wet season were indication of poor water quality leading to an increased sediments load and reduction in primary productivity of GbalegbeRiver. This result supported the findings of Woodcock and Huryn (2007) that made similar observation from their study and ascribed low primary production to the presence of high TSS which drastically decreased the amount of light penetration into the photic zone.

5.2.14 Relationships between transparency and turbidity

Transprency describes how transparent water is, while turbidity defines the cloudy nature of the water system. An increase in Transparency leads to a decrease in turbidity. These two parameters are inversely related. When Transparency is low, turbidity will increase and this may lead to an increase in water temperature because the suspended solids present in water absorb the energy from the sun through the light rays, while crude oil on the water surface prevents atmospheric oxygen from getting in contact with the water. As such, DO levels would begin to decline, leading to an increase in BOD and the rate of primary productivity would also drop which may lead to a decrease in the abundance of zooplankton production.

Sediment macro-invertebrates and fish population may drastically decline if the increase in turbidity and low Transparency continue unabated, a state of hypoxia (DO < 3.0mg/L) could be reached whereby fish will begin to migrate to a safer area while sendentary organisms die off at the state of anoxia (DO < 0.5mg/L) (Babalola and Amosu, 2003).

5.3 Water Nutientsof Gbalegbe River, Delta State

5.3.1 Ammonium-Nitrogen

The mean values of ammonium recorded among stations were less than the recommended values of 1.5mg/L (WHO, 2004) but greater than 0.02mg/L (FEPA, 1991) and 0.01mg/L NIS, (2007). Among stations, the lowest mean value of ammonium was at Station 1, while the highest level of NH_4^+ - N was during the dry season. The period of higher ammonium level can be attributed to the conversion of nitrogen from faecal matter present in water (Kenedy *et al.,* 2004).

NH_4-N is an essential nutrient needed by aquatic plants for growth but at very high concentrations, it becomes toxic and capable of disturbing the aquatic community. High level of NH_3-N in river is attributed to the decomposition of organic materials and farming activities and run-off (Wang and Fingas, 2003) which were very common along Gbalegbe River.

The presence of ammonia in water may serve as indication of pollution and its toxic effects on fish. Jaji *et al.* (2007) reported that the acute effects of ammonia are loss of equilibrium, increased breathing, decrease DO up-take, convulsion, coma and death, while the sub-lethal effects of ammonia are reduction in growth rate, pathological alterations in liver and kidney. Vandyk *et al.,* (2008) reported that the toxic effect of ammonia is reduced by it conversion to ammonium which is less toxic.

5.3.2 Nitrate and nitrite

Nitrate is an important nutrient required for primary productivity. Though the highest concentrations of nitrates were recorded during the late dry season when, concentrations at different stations and seasons were within the recommended limit of 0.1 – 3.0 mg/L Boyd (1998), 10mg/L (WHO, 2004), NIS, (2007) and 20mg/L (FEPA, 1991). This result was in line with Izonfuo and Bariweni (2001) who reported that the rate of nitrate and nitrites build up in an aquatic environment depends on its flow rate. Harrod and Theurer, (2002) reported that static water medium tend to accumulate more nitrite and nitrate under experimental condition where feed are applied to fish.

Therefore, the low level of nitrate and zero level of nitrite detected could be associated with the constant flow of Gbalegbe River which discouraged the excessive accumulation of

organic matter as well as effluents from the glass and rubber industries. Nitrite concentration was not detected throughout the study periods. Nitrate is toxic when reduced to nitrite. Nitrite reacts with haemoglobin to form methemoglobinemia in infants and impaired haemoglobin transport (Boyd, 1998).

5.3.3 Phosphate-phosphorus and Sulphate

Except at Station 1, mean values of phosphate-phosphorus recorded were higher than the recommended value of 0.12 mg/L (Boyd, 1998) but lower than 5mg/L (NIS, 2007) and FEPA, (1991). Higher values than those obtained in this study were reported by (Ogbuagu, 2013). Low concentration could be due to high phytoplankton density. Lower values of sulphate were recorded among stations while higher values were recorded between seasons. Generally, the levels of sulphate observed during this study were below the recommended limit of 200 mg/L (NIS, 2007). Sulphate is an important anion in water. It has been reported that, sea water contains more sulphate than freshwater (Taiwo *et al.,* 2012). The reason for the lower values could be due to the dilution of water by inflow from freshwater sources (Dufour *et al.,* 2000).

5.4 Primary production

5.4.1 Gross and net primary production

Higher mean values of GPP and NPP were recorded at Station 1 and during dry season in Gbalegbe River. Significant differences ($p<0.05$) occurred in the values of GPP and NPP recorded among stations and between seasons during the study period. The higher values obtained at Station 1 might be ascribed to a higher transparency level and reduced turbidity because of less industrial and anthropogenic activities along Gbalegbe River. This led to the uniform distribution of sunlight throughout the water column that facilitated higher rate of photosynthesis and ultimately the productivity of Gbalegbe River.

The ranges of primary productivity indices obtained in this study were higher than the range reported in Krishnasayer Lake (Banerjee and Chattopadhyay, 2008) and range reported in ponds of Otamiri River, Nigeria (Ogbuagu, 2013). The moderately low productivity in this present study could probably be linked to intense release of industrial effluents, oil pollution and sand mining operations. These activities could have negative influences on the productivity of aquatic ecosystems (Tamuno, 2005).

The positive correlation between GPP and NPP in this study revealed that, high GPP was responsible for high NPP. The decreased value of NPP and GPP during the late rainy season in this study agreed with the observation of (Balogun and Ajani, 2015) from Badagry Creek, Nigeria. They reported a drop in primary productivity in the wet season and a rise of the same in the dry periods. This might be attributed to high suspended solids during the flood which restricted light penetration into the water column that led to a decrease in photosynthetic activities and productivity (Joseph and Raj, 2011).

Davies *et al.,* (2009) reported that, phytoplankton photosynthetic activity is one of the major contributors to the overall productivity of open aquatic ecosystems. The distribution of uniform temperature and available nutrients are vital limiting factors for primary production contributing to seasonal variation in an aquatic ecosystem (Wondie *et al.,* 2007).

5.4.2 Clorophylla

The highest value of Chll a was recorded at Station 1 while lowest value was observed at Station 2. Dry season recorded the highest values while the lowest was during the wet season. Values recorded at Station 1 in dry season were within the the recommended range of >15µg/L (WHO, 2008) while Chlorophyll-*a* values greater than15 µg/L are generally considered to indicate high productivity (Balogun and Ajani, 2015).

The decrease in Chll-a among the other stations and seasons may be due to the presence of higher suspended particulate matter emanating from sand extraction activities, effluents from glass, rubber and petroleum industries located within and around Gbalegbe River. The presence of these effluents in the river limited the level of light penetration into the water column.

Gupta (2001) reported that, chlorophyll-a is a useful and easy estimator of phytoplankton standing crop. The fluctuation of Chlorophyll-*a* during the study period showed obvious sign of seasonal variation (WHO, 2008). This could be due to the fact that, season has a direct link with chllorophyll-a production. High Chlorophyll-*a* concentration would result in high values of productivity and reflect on high phytoplankton biomass.

5.4.3 Magnesium and calcium concentrations

Means of magnesium obtained during this study were higher than those recorded for seawater and freshwater. The levels of calcium recorded during this study were generally less than the recommended level of 150 mg/L (Boyd, 1998). There was a significant difference ($p<0.05$) in means of calcium obtained among stations and seasons. World Health Organisation (2008) reported that calcium is an important cation that differentiates between seawater and freshwater.

Mustapha, (2008) reported that, water hardness is caused by the metallic ions that dissolved in it. In freshwater these are primarily calcium and magnesium (USEPA, 2003). According to USEPA (2003) water hardness can be classified as: 0-75 mg $CaCO_3$/L is soft; 75-150 mg $CaCO_3$/L is moderately hard; 150-300 mg $CaCO_3$/L is hard,300 and up mg $CaCO_3$/L is very hard.Therefore, concentrations of Mg and Ca recorded during the study showed that, the hardness of water in Gbalegbe River is within the acceptable limits for the survival of aquatic organisms.

5.5 The PCA amongphysico-chemical parameters of Gbalegbe River, Delta State

The negative correlation among PC1 with Chll a,transparency and velocity implied that Chll a, transparency andvelocity were decreasing, while PC 1 loading rate increased which might be due to increased levels of suspended solids such as increased effluents deposition from petroleum, rubber and glass and sand minning industries in Gbalegbe River that caused a reduction in light penetration.This may discourage photosynthetic activity by the phytoplankton present within the water strata. The decrease in the velocity of water could be associated with increase in turbidity which might eventually lead to a decrease in DO and high temperature.

However, as the river water became more turbid, light penetration reduced due to turbidity emanating from clay, heavy metals and TPH. This could lead to a decrease in phytoplankton abundance which in-turn could cause decreased zooplankton and fish species abundance in Gbalegbe River. The PC 2 correlated negatively TDS and salinity. This implied that as the quantity of TDS and salinity were decreasing, Chll a increased but at a very weak rate revealing that, the rate at which TDS gathered momentum was faster than Chll a production. Though, TDS was considered as one of the indices of nutrient availability for phytoplankton growth, a point might be reached where Chll a production level started to drop because

transparency level was lowered as turbidity increased.This situation might then place aquatic organisms in Gbalegbe River under a state of hypoxia and eventually in an anoxic condition. The positive correlation PC3 with turbidity indicated that the loading rate of PC 3 increased with increasing turbidity. This simply implied that the presence of high amount of TSS in Gbalegbe River caused friction between water molecules and as such, transparency values dropped while the rate of primary production in Gbalegbe River declined.

Results obtained from this study were in agreement with Banerjee and Chattopadhyay, (2008) who reported that rapid increase in turbidity rate could lead to reduction in primary productivity and subsequent decline in plankton, sediment macro-invertebrates and fish abundance of a river. As turbidity level increases, aquatic organisms are subjected to dissolved oxygen stress.

5.6 Phytoplankton abundance and distribution in Gbalegbe River, Delta State

Highest and least abundance of phytoplankton were recorded in Stations 1 and 2. The highest abundance recorded at Station 1 might be associated with nutrient availability that may lead to increased abundance of zooplankton, while decrease in phytoplankton abundance could be attributable to poor quality of water during the wet season. This can also be related to the presence of pollutants derived from anthropogenic activities within the study location.

The results showed that with the exception of station 1, the rest stations were moderately polluted due to the nature of effluents from the anthropogenic activities (petroleum, rubber, glass and sand extraction industries). Effluents from the various natural and anthropogenic activities could carry toxic substances that might have been responsible for the change of the physico – chemical parameters of Gbalegbe River. Station 1 where the highest diversity index in the study was recorded (upstream), had low industrial activities, received freshwater from the water aquifer and dilution effects due to precipitation.

Results of this study agreed with USEPA (2003) that the alteration of the aquatic environment by effluents from anthropogenic activities could actually lead to water quality problems that could adversely affect species abundance of phytoplankton. This was in conformity with Ovie and Ovie, (2014) that, the abundance of phytoplankton species in a river could be altered by the degradation of its physico-chemical qualities.

5.7 The PCAamong of physico-chemical parameters and phytoplankton species of Gbalegbe River, Delta State

There was a negative correlation among PC 1, transparency, EC, TDS, nitrate and chloride. This means the presence of *Pinninularia viridis* and *Thalassionema nitzschia* in PC 1 were encouraged by decrease in the concentrations of transparency, EC, TDS, nitrate and chloride. These two species of phytoplankton growth were enhanced in Gbalegbe River as a result of the physico-chemical parameters that they correlated with. Increase in phytoplankton loading rate in PC 1 could be attributed to the fact that TDS carries large quantity of dissolved nutrients that they required and the poor condition of the water that tend to aid their growth.

The positive correlation among PC 2, *Oscillatoria* sp,*Microcystic* species, SiO_2,*Potamogeton pectinatus, Fragillaria striatula*and *Rhizosolenia* species showed that abundant of phytoplankton species and the loading rates of PC 2 in Gbalegbe River were rising at the same proportion. The resultant effects could be the production of increased quantity of phytoplankton due to nutrient enrichment.

The implication was that it might cause hypoxia and anoxic conditions emerging from the problem of eutrophication in Gbalegbe River. These can result in increased turbidity, water temperature and a decrease in DO concentration. If this situation is not controlled in Gbalegbe River, it could experience algal bloom due to the rapid die off and decomposition of phytoplankton lead to an increase in BOD concentration due to increased rate of anaerobic activities by bacteria. If this should happen, the ability of Gbagbe River to aid zooplankton and fish growth could diminish leading to the problem of reduce fish abundance and harvest.

The PC 3 correlated negatively with transparency and velocity but positively with *Pandorina* species, *Navicula riparian*, *Ceratium horridium, Fragillariopsis* species, *Rhizosolenia* sp, *Lioloma pacificum*, *Ceratophyllum demersum* and*Nostoc* sp. This showed that the reduction in the velocity of the river could be as a result of decreased in watertransparency due to high quantity of TDS and TSS carrying required nutrients for the growth of phytoplankton. The rise in growth of phytoplankton showed in the phytoplankton species in PC 3 signified that there were enough nutrient to meet there growth requirement (Usman *et al*. 2014) in Gbalegbe River.

5.8 Zooplankton species abundance and distribution in Gbalegbe River, Delta State

During the wet and dry seasons, Stations 1 and 2 recorded the highest and least abundance of zooplankton species. The highest individual numbers of zooplankton species recorded in Station 1 could be associated with the fewer anthropogenic activities upstream while the least recorded in Station 2 could be attributed to increase anthropogenic effluents from sand mining, power plant, glass, petrochemical industries and so on. It had been reported that changes in water quality as a result of increased anthropogenic activities and nature are known to negatively impact aquatic fauna (Ogaga *et al.*, 2015).

5.9 Principal component analyses among zooplankton species and physico-chemical parameters of Gbalegbe River, Delta State

The negative correlation of PC 1 with velocity, *Cyclops* sp,*Calanus* sp,*Daphnia* sp,*D. longirostris*, *D. similie*, *Moinadaphnia* sp,*Alona monacantha*, *A. davidi, Brachionus longirostris* indicated that,decrease in water velocity might be caused by increasedquantity of nitrate,TSS and TDS. This signified that, the decreased in velocity of water was caused byincreased levels ofnitrate, TDS and TSS were significant.

Decrease in velocity did not favour high level of transparency and as such low level of light rays penetrated the water depth which could be responsible for the reduced production of phytoplankton on which the zooplankton depend. The negative correlation between the zooplankton and physicochemical parameters recorded means that, zooplankton abundance may decrease. The decrease in velocity observed could be associated with increase in nitrate, TDS concentrations and decrease in zooplankton abundance (Popoola and Otalekor, 2011) in Gbalegbe River.

The positive correlation of PC 2 with TSS, turbidity andtemperature did not favour significantly increased production of zooplankton such as negative *Harpacticoid* sp. The loading rate of TSS, turbidity and temperature were significantly very high. An increase in the level of TSS could lead to an increase in turbidity which might cause a reduction in light penetration into the water column. The TSS present in Gbalegbe River absorbed sunlight energy, thereby leading to the increased water temperature and reduction in DO concentration.

This act could result into low production of zooplankton, because phytoplankton no longer gets enough DO concentration required for their photosynthetic activities (Hynes, 2006). The physico-chemical condition of the constituents in PCA 2 did not significantly favour the loading of zooplankton species, because their concentrations were too high. If the rate of discharge of effluents from the glass, rubber, crude oil exploration and sand extraction industries continue unabated, the level of phytoplankton production would reduce heavily and this could cause low zooplankton and fish abundance.

The positive correlation of PC 3 with round worm, flat worm, *Crustacean*sp and fish larvae meant that, the level of the physico-chemical parameters present in Gbalegbe River favoured the population of round worms, flat worms, *Crustacean nauplius* larvae and fish larvae. The prensence of round and flat worms indicated aquatic pollution. Equally revealed, was the survival ability of the *Crustacean naupius* larvae and fish larvae in this water body. The least number of sediments macro-invertebrates obtained in Station 2 might be due to the scarcity of food materials as a result of high concentrations of TPH, heavy metals and load of sediment deposition (Freund and Petty, 2007). High fine sediment deposition in the form of TSS could reduce food availability, respiratory and oviposition processes (Hynes, 2006).

The highest taxa of Trichoptera (caddisflies), Plecoptera (stoneflies) and Ephemeroptera (mayflies)were obtained in Station 1 which was an indication of good water quality (USEPA, 2003). This may be linked with the relatively low industrial activities, presence of good vegetation cover, food and suitable substrates for breeding (Brinkman and Johnston, 2008). Ampon and Taeng-On, (2014) reported that sediment macro-invertebrates are essentialcomponents of the food chain; recycling nutrients from dead organic materials and serving as food source for other aquatic organisms.

When pollutants build up in the sediment, they reached levels that are harmful to the invertebrates found within them thereby placing the stability of the ecosystem under stressful condition (Echols, 2010). This observation agreed with the results from this study that recorded higher amount of heavy metals and TPH concentrations in water, *C. gariepinus*, sediment and *H. catanea* thanWHO, (2008),FEPA, (1991) and NIS, (2007) limits for drinking water, sediment and aquatic insects, respectively.

Most researches on the impacts of heavy metals on aquatic organisms such as fish, plankton and benthic macro-invertebrates have been conducted in streams, rivers and lakes of Sweden, Ireland (Gray and Delaney, 2008), Spain (Sola` and Prat, 2006), India (WHO, 2008) and China (Xiaodong *et al.*, 2010). In Nigeria, the effects of environmental pollution on aquatic invertebrates are underemphasized due to limited researches in rivers, lakes and streams (Oku *et al.,* 2014).

In general, sediments from more TPH and heavy metal polluted stations affected more aquatic species than sediments from the less polluted station (station 1). Measurement of the abundance and diversity of sediment macroinvertebrates between and among the stations gave an indication of the effects of pollution levels on sediment macro invertebrate communities.

There were variation in the number of Hemipteran, Coleopteran, Dipteran, Emphemeropteran, Plecopteran and Tricopteran among the polluted (stations 2 – 8) compared with Station 1 (area of fewer anthropogenic activities). These resultswere in agreement with Lynes (2006) who reported that in a polluted water body, the highly pollution tolerant sediment macroinvertebrates species such asHemipteran, Coleopteran and Dipteran are more abundant.

5.10 Sediment macro-invertebrates abundance and distribution in Gbalegbe River, Delta State

The main taxonomic groups of sediment macro-invertebrates identifiedwere Hemiptera, Ephemeroptera, Trichoptera, Odonata, Diptera, Plecoptera and Coleoptera. The orders; Hemiptera and Ephemeroptera had the highest number of families as 8 and 5 from a total of 22 families recorded. The highest and lowest number of families occurred during wet and dry seasons. This might be attributed to increased concentration of water nutrients during the wet season due to higher rate of run – off as a result of increased anthropogenic activities(Sola` and Prat, 2006).

5.11 The PCA among sediment macro-invertebrate andphysico-chemical parameters of Gbalegbe River, Delta State

Principle Component (PC) 1 correlated positively with TDS, TSS, EC but negatively with DO, *Latelmis* species, *Isonychia arida*, Chloride,*Tricorithodes albineatus* and *Leptophlebia*species meant that, the increased levels of these physico-chemical parameters of Gbalegbe River had deleterious impacts on the abundance of *Latelmis* species, *Isonychia arida*, *Stenonema exiguum, Tricorithodes albineatus*and*Leptophlebia*species which are highly sensitive to pollution.

However, the abundance of the pollution tolerant species such as *Pantata flarens, Gyrinus* species*, Helocordulia selysii, Nepa* species, *Hemistigma* species and *Asha interrupta* kept on increasing under the same aquatic pollution situation. This was further buttressed by Salman *et al.*, (2011) that in a polluted river ecosystem, only the pollution tolerant benthic invertebrates tend to increase in population.

The reduction in the abundance of pollution sensitive orders (Ephemeropteran, Plecopteran and Tricopteran) could be associated with the presence of untreated effluents from the various industries around and within Gbalegbe River. Low level of DO occurred due to the increased level of TDS and TSS levels, while Hemipteran, Odonatans and Coleopteran population rose because they have the ability to tolerate poor water conditions. This could also serve as a pointer to the fact that the rate of the disruption of Gbalegbe River bed due to sand mining in conjuction with the increased deposition of untreated effluents from glass, rubber, petroleum industries and agricultural activities was rapidly increasing.

The PC 2 correlated negatively withvelocity, Ephemeropteran, Plecopterans and the Tricopterans but positively correlated with salinity, *Asha interrupta*, *Hesperocorixa castanea*, Turbidity and Gyrinus species. This implied that, there was a decrease in the velocity of water due to rise in levels of salinity and turbidity that led to the reduction in the population of Ephemeropteran, Tricopteran and Plecopteran (Salman *et al*., 2011). Despite the poor physico-chemical parameters recorded in Gbalegbe River, the Odonatan, Coleopteran and Hemipterans were able to survive due to their high capacity to tolerate polluted aquatic environment (Hynes, 2006).

The strong positive correlation obtained inPC 3 implied that, the rate of increase in the physicochemical parameters with principal component 3 were at the same. This means that their impact on the sediment macro-invertebrates in Gbalegbe River were significantly high.Sediment macroinvertebrates are among the most vulnerable organisms with respect to surface water pollution (Xiaodong *et al*., 2010). They constitute an important component of biodiversity in lotic systems. They are diverse, sensitive and respond to both natural and anthropogenic induced changes in the environment (Salman *et al*., 2011).Girgin and Kazanci, (2006) reported that, heavy metal pollution causes reduction in the population of aquatic insects, migration, impaired reproduction and mortality.

The findings from this study were in agreement with Ampon and Taen-On, (2014) that reported similar results in June, being a month of the peak of the wet season, and attributed it to the presence of adequate vegetation cover, food materials, suitable substrates for oviposition, attachment and respiration. Salman *et al*. (2011) reported that, vegetation cover provides protection from predators and suitable environment for the growth of periphytic species which are important food sources for many sediment macro-invertebrates.

The presence ofheavy metals, clay and petroleum compounds in a river system could disrupt thestability in the sediment macroinvertebrates community (Brandi *et al.,* 2013). This observation was similar to the findings from this study that observedrelatively elevatedconcentrations of clay particles, crude oil and heavy metals containing substances brought into Gbalegbe River by run-off and anthropogenic activities during the late rainy season. All these induced high sedimentation of fine particles, bounding highly toxic contaminants (heavy metals and TPH), disturbances of the water column and harmful effects on the water bed.

5.12 Fish species abundance and distribution in Gbalegbe River, Delta State

The highest and least fish species abundance were recorded at stations 1 and 2. The least value obtained in Station 2 might be associated with the uncontrolled discharge of effluents from anthropogenic activities into the river. This could have been responsible for the impaired quality of Gbalegbe River as well as its flora and fauna resources. Also, the low abundance and distribution of pollution tolerant orders of fish at station 2 indicated the rate of pollution of Gbalegbe River is rising gradually. The role of water quality in the distribution, abundance and diversity of aquatic organisms is very vital (Popoola and Otalekor, 2011).

5.12.1 The PCA among fish species and physico-chemical parameters, Gbalegbe River, Delta State

The increased positive correlation in species despite negative correlation with PC 1 implied that, irrespective of the poor water conditions of Gbalegbe River, fish abundance continued to increase. This occurred because fish were highly mobile. They might easily move from an area experiencing poor water conditions due to increased effluent deposition from the glass, petroleum and rubber industries as well as agricultural run-off, coupled with high level of sand extraction and anthropogenic sources to areas with tolerable limit of physico-chemical parameters. The results from this study also revealed that fish species are more tolerable to poor water condition compared with phytoplankton, zooplankton and sediment macro-invertebrates (Girgin and Kazanci, 2006).

5.12.2 Diversity indices used for flora and fauna species of Gbalegbe River, Delta State

Shannon, Evenness and Margalef mean values recorded during the wet season were higher than the values recorded during the dry season. This could be associated with inflow of higher amount of nutrients into the river in the wet season than in the dry season due increased agricultural run – off and other anthropogenic activities that were going on within the study location. The higher amount of nutrients available in the river during the wet season might have supported increased flora and fauna growth.

The increased mean value of Margalef index recorded during the wet season than the dry season implied that the rate influx of untreated effluents into Gbalegbe River were higher in the wet season than in the dry season. Based on the ranges of Margalef water quality indices, values greater than 3 indicate good water condition, values within 1 – 3 indicate moderately polluted condition, while values less than 1 indicate heavy aquatic pollution (Lenat *et al.*, 1980; Popoola and Otalekor, 2011). Comparing the results of this study with these values indicated that Gbalegbe River was moderately polluted which could be due to increased influence of anthropogenic activities.

5.13 Concentrations of heavy metals (copper, lead, nickel, cadmium, iron, zinc, manganes and chromium) in water

The lowest and highest concentrations of copper in water were obtained at Stations 1 and 2, while the lowest and highest values were recorded during wet and dry seasons respectively. The mean values of Cu recorded throughout the study period were less than the recommended values of 1.00mg/L (NIS, 2007) and 2.00mg/L (WHO, 2004). Acute toxicity of copper to aquatic organisms depends on the alkalinity and hardness of water.

Copper was more toxic at lower concentrations of alkalinity and hardness. Thoughthe values recorded were lower, this indicated that, water of Gbalegbe River was gradually becoming contaminated with Cu. This result agreed with Vandyk *et al.*, (2008) who reported that, unless the water body is stagnant, concentrations of heavy metals will continue to decrease.

Copper is both useful and at same time a very toxic pollutant. The cupric form of copper (Cu^{2+}) is responsible for its toxicity in the aquatic environment. This form of Cu is commonly found and readily complexed by organic and inorganic substances and absorbed into particulate matter (Osman *et al*., 2009). Plankton and other aquatic animals could take up complexes of copper which is not tightly bound to other to other molecules (Shalaby, 2007). Copper is used in the prophylactic control in fish diseases and parasites (Tyel *et al*., 2007).

The mean values of lead recorded in water among the stations and between seasons were higher than the recommended limits of 0.20mg/L (NIS, 2007), 0.01 (WHO, 2004) 0.05mg/L for rivers (Odiete, 1999). There was a significant difference ($P<0.05$) in the means of Pb among seasons throughout the study period. This result was in agreement with Verlecar *et al*. (2006) who reported that increase in the deposition of effluents into rivers would raise the level of its heavy metal concentrations, especially when substances containing metallic oxides are parts of the raw materials used by such company. Increased concentration of Pb inhibits RBC formation, increase in urinary excretion of acid and interference with haemobiosynthesis. Ogendi *et al*. (2014) reported that, increase in heavy metal levels in a river depends on the source and how frequent effluents are released into such environment.

Spatially, the mean values of Ni recorded during the study were lowest at Station 1 but highest at Station 2. Wet season recorded the lowest mean value of Ni, while the highest occurred during the dry season. Concentrations of Ni recorded during the study were generally higher than the recommended ranges of 0.02mg/L (WHO, 2004) and NIS, (2007). This revealed that, Gbalegbe River mightcontained excess Ni concentration.

Cadmium concentrations recorded among stations and seasons during the period of the study were higher than recommended value of 0.003mg/L (NIS, 2007) and WHO, (2004). The lowest and highest values of cadmium in water were recorded at Stations 1 and 2. The lowest value of Cd was obtained during the wet season, while it was highest during the dry season. It can be bioaccumulated in kidney leading to its dysfunction. Fish, zooplankton and sediment macro-invertebrates are sensitive low concentration (Olaifa, 2004).

The concentrations of Fe recorded were generally lower than recommended value of 0.30mg/L (NIS, 2007) for freshwater. The lowest occurred at Station 1,while the highest values at Stations 6 and 8, respectively. The lowest and highest values among the seasons occurred duringwet and dry seasons, respectively. In this study, the fluctuation in the levels of Fe might be due to the supply and dilution effect of rainfall and freshwater from nearby sources. Ferric hydroxide floc, coats gills of fish, smothering effects of settled Fe precipitates on fish eggs and sediment macro-invertebrates (DID, 2009).

Among stations and between seasons, the meanvalues of zinc concentrations in water during the study periods were generally high compared with Station 1. However, the levels recorded were less than NIS (2007) and WHO, (2004) recommended levels of 2 – 3mg/L and 3mg/L, respectively. Zinc toxicity to aquatic organisms is influenced by hardness, temperature, dissolved oxygen, antagonistic effects of heavy metals and pH.

Zinc concentration in water depends on the mineralization rate and process in the area (Barakat *et al*., 2012). Higher concentration of zinc than acceptable limits causes cellular breakdown of gills, clogging of gills with mucus, retardation in growth and maturation. The toxic effects of zinc on aquatic biota are being enhanced by increase in temperature and decrease in dissolved oxygen concentration.

The lowest value of Mn recorded in water was at station 1, while the highest was at station 2. Seasonally, the lowest value occurred during the wet seasons, while the highest value was during the dry season. Throughout the study period, the concentrations of Mn recorded were lowered than the recommended values of 0.2 – 0.35mg/L (NIS, 2007) and 0.40mg/L (WHO, 2004).

The lowest and highest level, of Chromiumlevels in water were recorded at Stations 1 and 2. Seasonally, the least mean value of Cr was recorded wet season, while the highest was during the dry season. Significant differences ($P<0.05$) occurred in the means of Cr recorded among the stations and between seasons. It is toxic to aquatic benthos and fish. Increased chromium concentration above the acceptable limits could cause lung cancer, ulceration and skin membrane wear – off in fish.

Values recorded in this study were higher than the recommended levels 0.5mg/L (NIS, 2007), 50ug/L for drinking water; 100ug/L in freshwater USEPA (Odiete, 1999) and <1mg/L, FEPA (1991). There are two forms of chromium present in water, Cr (III) and Cr (VI). While chromium (VI) is highly toxic, chromium (III) is non-toxic but>90% of chromium appears to exist in the (VI) oxidation state down to a depth of 200m in the seawater (Uzoekwe and Oghosanine, 2011).

5.14 Concentrations of heavy metals (copper, lead, nickel, cadmium, iron, zinc, manganes and chromium) in *C. gariepinus*

Spatially, the lowest and highest mean values of Cu in *C. gariepinus* during the study period were recorded at Stations 1 and 2, respectively. The lowest mean value of Cu occurred during the dry season, while the highest was during the wet season. Significant differences existed in the mean values of Cu among stations. Means of Cu recorded throughout the study period were less than the recommended value of 2.00mg/kg (WHO, 2004).

The mean of Pb recorded for *C. gariepinus* was lowest at Station 1 but highest at Station 2. The lowest and highest levels of seasonal variation of Pb were during dry and wet seasons. Significant differences existed in the mean values of Pb among the stations. This indicated that seasons have influence on the level of Cu accumulation in *C. gariepinus* in Gbalegbe River.The mean value of Pb recorded was higher in wet season but lowest in the dry season compared with the recommended level of 0.20 mg/kg (WHO, 2004).

This may be associated with the fact that, the deposition of the untreated effluents from the glass, rubber, petroleum and sand extraction industries into Gbalegbe River are on the increase. The nature and volume of effluents in the recipient water body immersely contribute to the levels of concentrations of the metals present (Javed and Usman, 2011). The lowest and highest mean values of Ni recorded or *C. gariepinus*were recorded at Stations 1 and 2. The lowest and highest values between seasons occurred during dry and wet seasons. The mean values of Ni recorded during the study except at Station 1, were closed to the recommended value of 1.00 mg/kg (WHO, 2004). This showed that, *C. gariepinus* in Gbalegbe River is rapidly bioaccumulating Ni in its body.

The lowest and highest value of Cadmium concentration recorded in *C. gariepinus*occurred at stations 1 and 2. Seasonally, the lowest value was obtained during the late rainy season, while the highest was during the late dry season. There was a significant difference ($P<0.05$) in the value of Cd recorded among stations. Generally, the mean values of Cd recorded during this study were higher than the recommended value of 0.10mg/kg (WHO, 2004).

Cadmium is toxic to human (Nikoo *et al*., 2010). Exposure to Cd can cause kidney and liver cancer. Cadmium accumulates mainly in the kidney and liver of both vertebrate and invertebrate. Acute toxic effect on fish may iiduce death. Cd also affects aquatic macrophyte including phytoplankton abundance. The Cd has been shown to enhance the growth of marine diatom (*Thalassiosira weissflogii*) the condition of zinc limitation.

Cadmium as a nutrient for marine diatom has been studied (Odiete, 1999). The lowest and highest mean values of Fe concentration in fish occurred at Stations 1 and 2,respectively, while the seasonal lowest and highest meansoccurred in wet and dry seasons. The spatial and temporal values recorded were relatively the same with recommended value of 0.18mg/kg (WHO, 2004), except at station 1 where the least value occurred.

The lowest and highest value of Zinc in *C. gariepinus* occurred at Stations 1 and 2, while the lowest and highest values obtained between wet and dry seasons. Significant difference ($P<0.05$) occurred in the mean values of Zn recorded among stations. The lowest level of Mn in *C.gariepinus* was obtained at Station 1, while the highest was at Station 6. Seasonally, the lowest and highest values were recorded in wet and dry seasons. There was a significant difference ($p<0.05$) in the value of Mn obtained among the stations.

When mean values obtained in station 1 was compared with the other stations, it might be seen that, there was an increased Mn concentrations in the muscles of *C. gariepinus*.The lowest and the highest levels of chromium detected in *C. gariepinus* were at Stations 1 and 2. Seasonally, the lowest and highest were during the dry and wet seasons. There was a significant difference ($P<0.05$) in the means of Cr recorded among the stations.

5.15 Concentrations of heavy metals(copper, lead, nickel, cadmium, iron, zinc, manganes and chromium)in sediment

Spatially, the lowest concentration of Cu in sediment was at Station 1, while the highest was at Station 2. There were significant differences in the means of Cu observed among stations. The lowest mean value of Cu between seasons was in the wet season while the highest was during the season. There was a significant difference ($p<0.05$) in the mean values of Cu among the stations. Mean values of Cu recorded during the study were lower than the recommended value of 16mg/kg (WHO, 2004).

The lowest and highest mean values of Pb recorded for sediment were at Stations 1 and 2. The least value was during wet season, while the highest was during the dry season. There was a significant difference ($p<0.05$) in the mean value of Pb recorded among stations. Values of Pb recorded were less than the recoomended value of 40mg/kg (WHO, 2004).

The lowest value and highest mean valuesof Ni recorded for sediment were at Stations 1 and 2, respectively. The lowest value recorded among seasons was the wet season, while the highest was during the dry season. There was a significant ($p<0.05$) difference in the means of Ni in sediment among stations. The mean values of Ni recorded during the study were less than the recommended value of 16mg/kg (WHO, 2004).

The lowest and highest values of Cd in sediment recorded were at Stations 1 and 2, respectively. Among the seasons the lowest and highest means of Cd were recorded dry and wet seasons. There was a significant difference ($P<0.05$) in the means of Cd among stations. The mean value of Cd recorded in the wet season wasmore than the recommended level of 0.16mg/kg (WHO, 2004).

The lowest and highest means of iron concentrations in sediment were obtained at Stations 1 and 2, respectively. Significant difference ($P<0.05$) existed among the means recorded for stations. Among seasons, the highest occurred during dry season, while the lowest waswet season. The variations in the means could be associated with freshwater mix up and sources of iron at the various stations. Recorded values were less than the recommended value of 30mg/kg (WHO, 2004).

The lowest and highest values of Zinc in sediments were obtained at Stations 1 and 2 respectively,while among seasons, the lowest and the highest values were during the wet and dry seasons. Values of Zn recorded during the study period were generally less than the recommended value of 30mg/kg (WHO, 2004).Spatially, the lowest mean value of Mn was at Station 1, while the highest was at Station 2. Seasonally, the least level of Mn occurred during the wet season, while the highest was during the dry season.There were significant differences ($p<0.05$) in the mean values of Mn amongs station. Mean valueswere less than the recommended value of 30mg/kg (WHO, 2004).

The lowest mean of Cr level in sediment was at Station 1, while highest was at Station 2. Among seasons, the lowest occurred during the wet season, while the highest was during the dry season. There were significant differences ($P<0.05$) in the mean value of Cr recorded among stations. The low lovels of Cr encountered during the the wet season could be due to supply of freshwater during rainfall, streams and run – off into river. Mean values of Cr obtained were less than the recommended value of 25mg/kg (WHO, 2004).

5.16 Concentrations of heavy metals in *Hesperocorixa castanea* from Gbalegbe River, Delta State

The lowest and highest concentration of Cu recorded in *Hesperocorixa castanea*among stations were at Stations 1 and 2. Seasonal variation in the mean values of Cu was lowest during the dry season but highest during the wet season. There were significant differences ($P<0.05$) in the means of Cu among stations. Cu concentrations recorded were less than the recommended values of 0.10mg/kg (Centre for Veterinary Research Laboratory, India, CVRLI, 2004).

The minimum and maximum values of Pb recorded for *Hesperocorixa castanea*occurred at Stations 1 and 2. Wet and dry seasons recorded similar values. There were significant difference ($p<0.05$) in the mean values of Pb in the *Hesperocorixa castanea* among stations. Pb concentrations recorded were higher than the recommended values of 0.010mg/kg (CVRLI, 2004).

Stations 1 and 2 recorded the lowest and the highest concentrations of nickel in *Hesperocorixa castanea*, while among the seasons. The lowest concentration of Ni in sediment macro-invertebrates was recorded during the wet season, while the highest was in the dry seasons. There was a significant difference in the means of Ni among stations. Ni concentrations recorded were higher than the recommended values of 0.010mg/kg (CVRLI, 2004)

The lowest and highest mean values of cadmium in *H. castanea* were recorded in Stations 1 and 2. Seasonally, wet and dry seasons recorded similar mean values. The Cd concentrations recorded were less than the recommended levels of 0.10mg/kg (CVRLI, 2004). The lowest and highest means of iron concentration in *H. castanea* were recorded atStations 1 and 2 respectively.Seasonally, zinc concentrations were similar in both wet and dry seasons.There were significant differences ($p<0.05$) in the means obtained among stations. The concentrations were less than the recommended values of 10 mg/Kg (CVRLI, 2004)

The lowest value of Zn recorded in *H. castanea* occurred at Station 1, while the highest was at Station 2. Both wet and dry seasons recorded similar mean values of Zn.There was significant difference ($p<0.05$) in the values of Zn in sediment macro-invertebrates among the stations. When compared with Station 1, the values recorded in the other stations were higher. This is an indication that sediment macro-invertebrates had accumulated higher in their tissues and that the sediment and water were highly contaminated with Zn. The Zn concentrations obtained between seasons were less than the recommended levels of 0.05mg/kg (CVRLI, 2004).

Manganese concentration levels in *H. castanea* obtained among the stations was lowest at Station 1 and highest at Station 2, while among the seasons, the lowest was recorded in the wet season, while the highest was during the dry season. When Station 1 was compared with the rest stations, it was observed that, stations 2 – 8were contaminated with higher levels of Mn. The concentrations of Mn recorded were less than the recommended level of 5.00mg/kg (CVRLI, 2004).

Spatially, the minimum mean value of Cr recorded was at Station 1, while the highest was at Station 2. Wet and dry seasons recorded similar levels of Cr. Higher concentrations of Cr than the recommended values of 0.05mg/kg (CVRLI, 2004) were recorded. This was an indication of higher level of Cr bioaccumulation by *H.castanea*. This implied that, sediment macroinvertebrates in Gbalegbe River have been subjected to the deleterious effects of Cr.This revealedthat, sediment macro-invertebrates at Station 1 bioacccumulated less quantity of Cr compared with Stations 2 – 8 where higher levels were obtained. The lowered amount of Cr obtained in sediment macro-invertebrates.

5.17 Characteristics of sediment particle sizes of Gbalegbe River, Delta State

Generally, Stations 1 and 8 recorded the lowest and highest particle size. The low amount of particle size recorded at station 1 might be attributed to the low level of industrial and anthropogenic activities coupled with relative undisturbed nature of the water bed. The highest quantity of sediment particles sizes for all the particles at Station 8 could be attributed to the movement of these particles down stream during the sand mining process and the industrial effluents discharged from the various industries located along Gbalegbe River.

Percentage clay and silt particle sizes were highest during the wet season. The reason being that during the wet season, large quantities of suspended solids and organic materials were transported into Gbalegbe River due to increased rainfall, thereby giving room to high clay and silt content (Hynes, 2006). These particles were easily picked up by the water current and deposited downstream which threatened to the entire aquatic organisms (Salman *et al*., 2011).

The percentage coarse sand was highest during the dry and lowest during the wet seasons. This could be due to reduced inflow of water into Gbalegbe River as a result of lower amount of rainfall. Persistent and uncontrolled sand mining, rubber and petroleum industrial activities are gradually making the water of Gbalegbe River unsuitable for human consumption and survival of aquatic life on a daily basis.

The observed oil sleaks on the surface of the water coupled with the process of sand mining could cause great distortion to the natural build up of the sediment by making the water heavily turbid and higly loaded with heavy metals (Nwankwo, 2004a). This could reduce the amount of dissolved oxygen, increased water temperature, destruction of natural spawing ground for fish which will eventually result into the states of hypoxia and anoxic stress on the fish, zooplankton and sediment macro-invertebrates (Nwoji *et al*., 2010).

5.18 Sediment nutrient composition of Gbalegbe River, Delta State

Gupta, (2001) reported that, cation exchange is an essential feature in sediment nutrient enrichment and plays the roles such as: causes and corrects sediment acidity and basicity; it alters sediment phsico-chemical properties; acts as a purifier of percolating water; it supplies calcium, magnesium and potassium to aquaticmacrophytes from exchangeable forms; cation exchange locations keep the ions of Ca, Mg, K, Na and NH_4 so as to avoid being leached away; cation exchange sites adsorb metals such as Cd, Zn, Ni and Pb that are present in wastewaters.

Wondie *et al*. (2007) reported that nutrient enrichment in aquatic ecosystems are increasingly becoming more useful as a result of sediment quality evaluation.Adsorption removes the ions from the percolating water, thereby cleaning the water that drains into the surface waters. The cations exchange locations immobilized cationsbut keep the exchangeable thereby making them available to the roots of aquatic macrophytes.

Cation exchange capacity was lowest at Station 1 and highest at Station 6. There was a significant difference ($p<0.05$) in the means of CEC recorded among the stations. Ions are atoms or molecules which have electrical charges. Anions have negative charges while cations have positive charges. Doisy and Rabeni, (2001) defined cation exchange as interchange between a cation in solution on the surface of any surface-active material such as clay and organic colloids.

Cations are tightly held together on adsorption sites to reduce their losses through leaching (Ogamba *et al*., 2015b). These cations can move from site on colloids into the sediment water solution where they become available to phytoplankton and other aquatic macrophytes uptake. River sediment with low CEC has little ability to store nutrients, affected by pH and the solubility of the mineral nutrients available to the aquatic plants. The ion exchange of sediment is the number of moles of sorbed ionic charge that can be desorbed from unit mass under given conditions of temperature, pressure and pH (Majolagbe *et al.*, 2011).

It had been reported that cation exchange capacity is a function of grain size, amount of organic matter, coating on the grains and mineral contents of the sorbing material (Ogamba *et al*., 2015b). Grain size is an important factor in determining CEC, the smaller the sediment particle size, the higher the CEC it can carry. Different materials have different CEC e.g organic matter have the highest (200 – 400 meq/100g), iron compounds (goethite and

hematite also have high CEC up to 100 meq/100g). The higher the clay contents of sediment, the higher the CEC (Olowu *et al.*, 2010).

The pH concentration of the sediment determines its degree of acidity and alkalinity levels. The lowest mean value was during the wet season which might be due to dilution effects, while the highest was dry season which might be attributed to higher rate of evaporation. It had been reported that the level of sediment pH determines the types organism found within a water body (Adewuyi *et al*., 2012).

Fine sediment grains of silt and clay are the major carrier of nutrients, heavy metalsand other related aquatic pollutants (Baran and Guerin, 2012). Among the 128 major pollutants enumerated by the USEPA, 65% of them are mainly found sediment. About 95% of phosphorus annual load in surface water migrates in conjuction WITH sediment in suspension.

5.19 Indicators of sediment pollution of Gbalegbe River, Delta State

The determination of the grand contamination on the studied sediment of Gbalegbe River was based on contamination factor (C^i_f). Spatial and seasonal mean values of C^i_f, C_d, Igeo, mCd and PLI recorded from the study area indicated that, Gbalegbe River sediment was moderately contaminated with Cu, Pb, Ni, Cd, Fe, Zn, Mn and Cr. The mC_d adopted in this present study is based on integrating and averaging all the available analysed metal concentration for a sediment samples.

The modified degree of contamination (mC_d) provides an integrated assessment of the overall enrichment and contamination impact of groups of pollutants in the sediment (Syed *et al.,* 2012). The mean values of $mC_d$and PLI obtained between wet and dry seasons showed that the degree of contamination level of the sediment in Gbalegbe Riverwas moderately low. The low mean values recorded could be attributed to the constant flow, turbulence and upwelling of Gbalegbe River which did not encourage sudden build – up of contaminants.

Although the mean values of PLI recorded among stations and between seasons did not indicate immediate intervention to ameliorate pollution in the study area, it calls for a constant monitoring so as to avoid sudden increase because the values were greater than zero (0). This means that, the natural state of the heavy metals in sediment of Gbalegbe River had been altered. The natural background values of heavy metal concentrations in sediment used were according toTaylor and Mclennan(1995).

5.20 Total petroleum hydrocarbon (TPH) in water, *Clarias gariepinus*, *Hesperocorixa castanea* and sediment

The observed oil sleeks on the water surface during the study period showed that, pollution from petroleum sources had occurred. The levels of TPH varied between seasons and stations. The highest level of TPH was recorded at Station 2 and during wet season. Mean values of TPH concentrations recorded in water were higher than the recommended value of 0.0007mg/L(NIS, 2007) for drinking water.

This implied that Gbalegbe River received higher concentrations of crude oil than the maximum acceptable limit. These higher concentrations could be due to high amount of discharged crude oil during the extraction processes. The results of TPH recorded in water during the study period were in consonance with Eco-Consultancy Services (WHO, 2007) that reported the presence of TPH in a water body alters its physico-chemical qualities.

The results of this study were in agreement with Olaifa (2003) who reported similar results from Cross River and Akwa Ibom States, Nigeria. TPH is the measurable amount of petroleum based hydrocarbon in an environmental medium (Ukoli, 2005). Adewuyi *et al.,*(2012) reported that the presence of TPH in any aquatic medium is an indication of crude oil pollution.

Onuoha, (2008) reported that crude oil is both chronically and acutely toxic and that, the lethal effects on fish include coating of gill, thus preventing respiration, potential fish kill due to increased BOD, discreased DO, asphyxiation of benthos life forms, and settled on bottom sediment, drowning of aquatic birds due to clogging feather, fouling shoreline and death of aquatic plants. The film of oil that floats over the water surface affects the transmission of light through the water column thereby reducing the process of photosynthesis by phytoplankton. Oil coating can destroy the insulating property of fur and feathers of aquatic birds and mammals (Tolulope, 2004).

The reduction in the levels of TPH could be due to the following: tidal regime; type of oil spiled and period after the spillage.The type of oil present in the study location was light crude oil (Class A) which is light, highly volatile and usually flammable when fresh.The highest level of TPH recorded in *C. gariepinus* was at Station 2 and dry season. The presence of TPH in fish observed during this study indicated its bioaccumulation in fish population.

The physiogical impacts of TPH on fish as revealed by histopathological analyses were the alteration of the normal structures of the liver and kidney architecture. Montaser *et al.*, (2010) reported similar result in his experiment and attributed the histopathological changes to the failure of the liver to adequately perform its detoxification process due to the presence of the toxicant introduced in the culture medium.

The levels of TPH recorded in sediment among stations and between seasons were highest at Station 2 and during the dry season. These concentrations were higher than the recommended values of 0.003mg/L (WHO, 2001) and 0.002mg/L (FEPA, 1991). WHO, (2001) reported that the detection of varied amount of TPH in sediment revealed that sediment *H.castanea* had been bio-accumualting TPH over the years. The contact of fauna with sediment could lead to a higher bioaccumulation levels in them which would in turn be transferred to man through the food chain (Ali and Abdel – Satar, 2005).

The lowest value recorded at Station 1 could be attributed to less oil – based activities. The variation in the levels of TPH across the stations and seasons may be due to the light and volatile nature of the oil produced within the study area. Compared with water, *C. gariepinus* and sediment, TPH levels in *H. castanea* were the highest during the periods of the study. This showed that,*H. castanea* bioaccumulated more quantity of TPH due to their sedentary nature, slow migratory ability and direct contact with the sediment. Though lower levels of heavy metals and TPH were recorded in sediment, *H. castanea* and *C. gariepinus* downstream, these low concentrattions might be attributed to the effects from the inflow of freshwater from adjoining streams and high rate of precipitation as depicted by climatic data obtained from the study area.

5.21 Conclusion

The study revealed that, the mean values of total suspended solids, turbidity, dissolved oxygen and biological oxygen demand were not within the acceptable limits, while total dissolved solids, electrical conductivity, temperature, pH, alkalinity, salinity, chloride, ammonia, nitrate and sulphate were within the desirable limits for the normal life of aquatic organisms.

Physico-chemical parameters exhibited clear spatial and temporal variations with the highest and lowest values obtained during the early and late rainy seasons. Spatially, the values of Chlorophyll-a, gross primary production and net primary production varied distinctively while temporally, the lowest and the highest values were obtained during the early and late rainy seasons respectively.

The total petroleum hydrocarbon (TPH) and heavy metals' concentrations recorded for water, *C. gariepinus*, sediment and *H. castanea* varied spatially while the lowest mean value was recorded during the wet seasons. There was a marked variation in the levels of sediment compositions spatially and temporally. With the exception of Cu, the values of Pb, Ni, Cd, Fe, Zn, Mn and Cr were above the recommended standards for drinking water by NIS, (2007), FEPA, (1991) and USEPA, (1999). The levels of concentrations of these metals were significantly different spatially and temporally. The values of heavy metals recorded for fish, sediment and sediment macro-invertebrates showed distinct seasonal variations.

Generally, species composition, distribution and abundance for fish, phytoplankton, zooplankton and sediment macro-invertebrates showed significant variations among stations and seasons. Catch composition and abundance are greatly determined by the variation in seasons and the level of pollutants present within a river (Ogamba *et al.*, 2015a).

5.22 Contributions to knowledge

1. This study provided the important information on the pollution status and productivity of Gbalegbe River, Delta State, Nigeria.
2. A check list for phytoplankton species identification of Gbalegbe River was provided.
3. A check list for the identification of zooplankton species ofGbalegbe River was provided.
4. A check list for the identification of macro-invertebrate species ofGbalegbe River was provided.
5. A check listfor the identification offish species inGbalegbe River was provided.
6. The current impact of industrial, agricultural and anthropogenic activities within and around Gbalegbe River on it flora and fauna revealed.
7. It provided the present metals and total petroleum hydrocarbon concentrations in water, *Clarias gariepinus*, sediment and *Hesperocorixa castanea* of Gbalegbe River.
8. Current sediment particle sizes of Gbalegbe River were established.

5.23 Recommendations

Based on the findings from this study, the following recommendations were made:

- Risk management approach should be adopted in the management effluents discharge into Gbalegbe River;
- There should be adequate bio-monitoring of the Gbalegbe River system to ensure that the physico-chemical parameters are within the acceptable limits;
- Research into the use of fish blood, zooplankton and phytoplankton in the determination of total petroleum hydrocarbon and heavy metals in *C. gariepinus* should be carried out to further ascertain the degree to which Gbalegbe River is polluted;
- Education/Enlightment on the inherent danger of heavy metals and TPH in Gbalegbe River should be stressed;
- The absence of pollution sensitive and presence of pollution tolerance species of sediment macro-invertebrates should be considered as the early warning sign of aquatic pollution.

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APPENDICES

Appendice 1.ANOVA of physico-chemical parameters at different stations along Gbalegbe River

		Sum of Squares	df	Mean Square	F	Sig.
Total dissolved solid	Between Groups	10349.47	1	10349.47	0.365	0.047
	Within Groups	3574816	126	28371.56		
	Total	3585166	127			
Total suspended solid	Between Groups	17222.06	1	17222.06	0.588	0.045
	Within Groups	3688712	126	29275.49		
	Total	3705934	127			
Electrical conductivity	Between Groups	4889.74	1	4889.74	0.313	0.047
	Within Groups	1967843	126	15617.8		
	Total	1972732	127			
Turbidity	Between Groups	1580.365	1	1580.365	6.387	0.073
	Within Groups	31177.6	126	247.441		
	Total	32757.96	127			
Temperature	Between Groups	57.178	1	57.178	8.484	0.09
	Within Groups	849.14	126	6.739		
	Total	906.318	127			
Dissolved oxygen	Between Groups	4.194	1	4.194	8.921	0.053
	Within Groups	59.238	126	0.47		
	Total	63.433	127			
Biological oxygen demand	Between Groups	0.886	1	0.886	2.005	0.039
	Within Groups	55.68	126	0.442		
	Total	56.566	127			
Ph	Between Groups	0.013	1	0.013	0.028	0.867
	Within Groups	57.925	126	0.46		
	Total	57.938	127			
Nitrite	Between Groups	0	1	0	0.337	0.563

	Within Groups	0.001	126	0		
	Total	0.001	127			
Salinity	Between Groups	0.253	1	0.253	0.835	0.362
	Within Groups	38.219	126	0.303		
	Total	38.472	127			
Chloride	Between Groups	2899.221	1	2899.221	11.43	0.107
	Within Groups	31959.28	126	253.645		
	Total	34858.5	127			
	Total	67.132	127			
Chlorophyll a	Between Groups	58050.88	1	58050.88	0.718	0.398
	Within Groups	10187260	126	80851.27		
	Total	10245311	127			
Velocity	Between Groups	0.049	1	0.049	0.131	0.718
	Within Groups	47.002	126	0.373		
	Total	47.051	127			
Transparency	Between Groups	14.869	1	14.869	0.028	0.056
	Within Groups	65762.47	126	521.924		
	Total	65777.34	127			

Appendix 2: ANOVA of physico-chemical parameters of Gbalegbe River at different seasons

		Sum of squares	Df	Mean square	F	Sig.
Total dissolved solid	Between groups	1392600	7	198942.9	10.888	0.00
	Within groups	2192565	120	18271.38		
	Total	3585166	127			
Total suspended solid	Between groups	1469480	7	209925.8	11.264	0.00
	Within groups	2236454	120	18637.11		
	Total	3705934	127			
Electrical conductivity	Between groups	558870.3	7	79838.62	6.776	0.00
	Within groups	1413862	120	11782.18		
	Total	1972732	127			
Turbidity	Between groups	3249.007	7	464.144	1.887	0.047
	Within groups	29508.96	120	245.908		
	Total	32757.96	127			
Temperature	Between groups	68.918	7	9.845	1.411	0.207
	Within groups	837.4	120	6.978		
	Total	906.318	127			
Dissolved oxygen	Between groups	7.233	7	1.033	2.206	0.038
	Within groups	56.199	120	0.468		
	Total	63.433	127			
Biological oxygen demand	Between groups	2.827	7	0.404	0.902	0.508
	Within groups	53.739	120	0.448		
	Total	56.566	127			
Ph	Between groups	6.047	7	0.864	1.998	0.061
	Within groups	51.89	120	0.432		
	Total	57.938	127			
Nitrite	Between groups	0	7	0	0.757	0.624
	Within groups	0.001	120	0		

	Total	0.001	127			
Salinity	Between groups	7.452	7	1.065	4.118	0.32
	Within groups	31.021	120	0.259		
	Total	38.472	127			
Chloride	Between groups	3187.016	7	455.288	1.725	0.109
	Within groups	31671.48	120	263.929		
	Total	34858.5	127			
chlorophyll a	Between groups	94004.23	7	13429.18	0.159	0.992
	Within groups	10151307	120	84594.22		
	Total	10245311	127			
Velocity	Between groups	0.347	7	0.05	0.127	0.996
	Within groups	46.704	120	0.389		
	Total	47.051	127			
transparency	Between groups	2115.418	7	302.203	0.57	0.039
	Within groups	63661.93	120	530.516		
	Total	65777.34	127			

Appendix 3. Monthly phytoplankton species abundance (wet season)

Months	Orders	Families	Genus and Species	Numbers of phytoplankton collected per Station									% Abundance
				1	2	3	4	5	6	7	8	TOTAL	
March	Pennales	Fragillariaceae	*Fragillaria striatula*	5	1	1	1	7	2	9	3	29	2.96
			Sub-total	5	1	1	1	7	2	9	3	29	
	Centrales	Bidulphiceae	*Biddulphia autita*	1	1	1	0	3	1	3	2	12	1.22
	Centrales	Soleniceae	*Lauderia annulata*	4	0	4	3	4	1	3	1	21	2.14
			Ttichophyton ajelloi	0	1	0	0	0	0	0	0	1	0.10
			Alexandrium sp	6	2	0	3	7	0	3	2	23	2.34
			Lioloma pacificum	1	1	0	6	0	3	2	3	16	1.63
			Potamogeton pectinatus	2	4	3	3	6	3	6	0	27	2.75
			Rhizosolenia sp	5	0	4	3	4	2	5	2	25	2.55
			Sub-total	21	22	9	18	27	12	30	15	154	
April	Centrales	Soleniceae	*Lauderia annulata*	8	6	3	7	4	1	3	5	37	3.77
			Anabaena sp	8	1	2	1	4	5	7	8	36	3.67
			Macroconidium persicolor	5	2	1	4	1	3	1	0	17	1.73
			Pinnularia viridis	1	1	7	2	1	2	2	3	19	1.94
			Prorocentrum mican	3	0	8	4	0	6	2	5	28	2.85
			Proboscia alata	5	1	1	5	0	5	7	4	28	2.85
			Sub-total	35	14	26	28	10	26	29	27	195	
May	Centrales	Soleniceae	*Lauderia annulata*	2	6	7	1	0	2	4	6	28	2.85
			Proboscia alata	7	1	2	3	2	7	1	4	27	2.75
	Centrales	Bidulphiceae	*Biddulphia auritia*	1	4	0	1	4	0	2	3	15	1.53
			Ceratophyllum demersum	6	1	1	2	7	1	2	5	25	2.55
			Vallisnaria sp	4	1	5	3	4	2	7	5	31	3.16
			Sub-total	20	13	15	10	17	12	16	23	126	

June	Pinnales	Fragillariaceae	*Thalassionema nitzschia*	1	1	8	7	6	3	5	4	35	3.57
			Ceratium horridum	6	1	1	2	9	5	6	0	30	3.06
			Proboscia alata	4	0	4	6	9	3	1	5	32	3.26
			Sub-total	11	6	11	14	23	11	10	11	97	
July.	Centrales	Soleniceae	*Lauderia annulata*	7	2	13	3	0	3	6	3	37	3.77
			Nitella turcata	8	1	4	6	3	2	5	1	30	3.06
			Potamogeton pectinatus	2	0	16	13	7	4	0	6	43	4.38
			Nostoc sp	8	1	3	4	2	5	7	1	31	3.16
August			*Blastoschizomyces capitatu*	3	0	3	1	3	2	1	2	15	1.53
			Microcystic sp	4	1	0	7	7	8	0	3	30	3.06
			Oscillatoria sp	0	3	2	6	3	8	0	4	26	2.65
			Sub-total	32	34	25	30	21	31	20	19	212	
September	Pennales	Fragillariaceae	*Fragillariopsis* sp	4	2	3	1	4	3	0	2	19	1.94
			Pseudo-Nitzschia autralis	8	3	8	5	5	0	5	2	36	3.67
			Sub-total	12	5	11	6	9	3	5	4	55	
October	Centrales	Bidulphiceae	*Biddulphia aurita*	7	0	6	8	2	0	5	6	34	3.47
			Proboscia alata	4	2	2	2	3	0	4	4	21	2.14
			Anabaena sp	3	3	1	3	6	0	3	3	22	2.24
			Rhizosolenia sp	1	0	10	4	7	8	2	4	36	3.67
			Sub-total	15	11	13	17	18	8	14	17	113	
			Total	**151**	**106**	**111**	**124**	**132**	**105**	**133**	**119**	**981**	
			% Abundance	**15.39**	**10.81**	**11.31**	**12.64**	**13.46**	**10.70**	**13.56**	**12.13**		

Appendix 4. Monthly phytoplankton species abundance (dry season)

Months	Orders	Families	Genus and Species	Numbers of phytoplankton collected per Station								Total	% Abundance
				1	2	3	4	5	6	7	8		
Nov.	Centrales	Soleniceae	*Lauderia annulata*	7	9	2	9	5	9	2	9	52	5.94
			Bacteriastum hyalinum	21	0	4	9	2	0	6	7	49	5.60
			Ceratophyllum demersum	4	0	8	3	6	6	8	6	41	4.69
			Sub-total	32	11	12	21	13	16	15	22	142	
	Pennales	Fragillariaceae	*Fragillariopsis* sp	3	3	5	5	9	7	6	5	43	4.91
			Sub-total	3	3	5	5	9	7	6	5	43	
Dec.	Pennales	Fragillariaceae	*Fragellaria oceanica*	6	0	3	1	2	7	3	6	28	3.20
	Pennales	Epithemiaceae	*Pseudo-Nitzschia autralis*	24	3	5	7	10	0	8	3	60	6.86
			Sub-total	30	4	7	8	11	9	10	9	88	
Jan.	Centrales	Bidulphiceae	*Biddulphia aurita*	3	2	0	0	0	0	2	3	10	1.14
			Pandorina sp	3	1	1	6	9	3	8	6	37	4.23
	Centrales	Soleniceae	*Lauderia annulata*	8	3	5	3	4	9	7	7	46	5.26
			Alexandrium sp	8	1	8	8	4	3	9	9	50	5.71
			Chara sp	4	1	2	2	4	2	4	8	27	3.09
			Spirogyra	8	4	1	0	5	3	2	6	29	3.31
			Pseudo-Nitzschia autralis	1	1	1	8	4	4	1	5	25	2.86
			Spirulina sp	9	5	5	9	5	2	9	9	53	6.06
			Typha sp	7	2	7	0	9	8	4	6	43	4.91

			Proboscia alata	9	2	1	7	6	7	2	3	37	4.23
			Sub-total	60	22	31	45	48	41	48	62	357	
Feb	Centrales	Soleniceae	*Lauderia annulata*	4	0	3	0	9	0	3	9	28	3.20
			Microcystic sp	9	1	0	8	3	9	9	3	42	4.80
			Sub-total	13	2	3	9	10	11	11	11	70	
	Pennales	Fragillariaceae	*Fragillariopsis* sp	6	2	5	2	6	3	9	8	41	4.69
			Sub-total	6	2	5	2	6	3	9	8	41	
	Pinnales	Naviculaceae	*Navicula riparia*	1	3	1	8	9	4	1	7	34	3.89
			Potamogeton pectinatus	2	7	2	9	8	0	2	4	34	3.89
			Anabaena sp	5	5	1	5	5	4	2	3	30	3.43
			Sub-total	9	15	4	26	27	29	11	13	134	
			Total	153	59	67	116	124	116	110	130	875	
			%Abundance	17.49	6.74	7.66	13.26	14.17	13.26	12.57	14.86		

Appendix5. Checklist of phytoplankton for wet season

Months				Numbers of phytoplankton collected per Station							
	Orders	Families	Genus/Species	1	2	3	4	5	6	7	8
March	Pennales	Fragillariaceae	*Fragillaria striatula*	+	+	+	+	+	+	+	+
	Centrales	Bidulphiceae	*Biddulphia autita*	+	+	+	-	+	+	+	+
	Centrales	Soleniceae	*Lauderia annulata*	+	-	+	+	+	+	+	+
			Ttichophyton ajelloi	-	1	-	-	-	-	-	-
			Alexandrium sp	+	+	-	+	+	-	+	+
Apri			*Lioloma pacificum*	+	+	-	+	-	+	+	+
			Potamogeton pectinatus	+	+	+	+	+	+	+	-
			Rhizosolenia sp	+	-	+	+	+	+	+	+
May	Centrales	Soleniceae	*Lauderia annulata*	+	+	+	+	+	+	+	+
			Anabaena sp	+	+	+	+	+	+	+	+
			Macroconidium persicolor	+	+	+	+	+	+	+	-
			Pinnularia viridis	+	+	+	+	+	+	+	+
			Prorocentrum mican	+	-	+	+	-	+	+	+
			Proboscia alata	+	+	+	+	-	+	+	+
June	Centrales	Soleniceae	*Lauderia annulata*	+	+	+	+	-	+	+	+
			Proboscia alata	+	+	+	+	+	+	+	+
	Centrales	Bidulphiceae	*Biddulphia auritia*	+	+	-	+	+	-	+	+
			Ceratophyllum demersum	+	+	+	+	+	+	+	+
			Vallisnaria sp	+	+	+	+	+	+	+	+
August	Pinnales	Fragillariaceae	*Thalassionema nitzschia*	+	+	+	+	+	+	+	+
			Ceratium horridum	+	+	+	+	+	+	+	-
			Proboscia alata	+	-	+	+	+	+	+	+
September	Centrales	Soleniceae	*Lauderia annulata*	+	+	+	+	-	+	+	+
			Nitella turcata	+	+	+	+	+	+	+	+
			Potamogeton pectinatus	+	-	+	+	+	+	-	+
			Nostoc sp	+	+	+	+	+	+	+	+
			Blastoschizomyces capitatu	+	-	+	+	+	+	+	+
October			*Microcystic* sp	+	+	-	+	+	+	-	+
			Oscillatoria sp	-	+	+	+	+	+	-	+
	Pennales	Fragillariaceae	*Fragillariopsis* sp	+	+	+	+	+	+	-	+
			Pseudo-Nitzschia autralis	+	+	+	+	+	-	+	+
	Centrales	Bidulphiceae	*Biddulphia aurita*	+	-	+	+	+	-	+	+

Appendix 6. Checklist of phytoplankton for dry season

Months	Orders	Families	Genus and Species	Numbers of phytoplankton collected per Station							
				1	2	3	4	5	6	7	8
Nov.	Centrales	Soleniceae	*Lauderia annulata*	+	+	+	+	+	+	+	+
			Bacteriastum hyalinum	+	-	+	+	+	-	+	+
			Ceratophyllum demersum	+	-	+	+	+	+	+	+
	Pennales	Fragillariaceae	*Fragillariopsis* sp	+	+	+	+	+	+	+	+
Dec.	Pennales	Fragillariaceae	*Fragellaria oceanica*	+	-	+	+	+	+	+	+
	Pennales	Epithemiaceae	*Pseudo-Nitzschia autralis*	+	+	+	+	+	-	+	+
Jan.	Centrales	Bidulphiceae	*Biddulphia aurita*	+	+	-	-	-	-	+	+
			Pandorina sp	+	+	+	+	+	+	+	+
	Centrales	Soleniceae	*Lauderia annulata*	+	+	+	+	+	+	+	+
			Alexandrium sp	+	+	+	+	+	+	+	+
			Chara sp	+	+	+	+	+	+	+	+
			Pseudo-Nitzschia autralis	+	+	+	+	+	+	+	+
			Spirulina sp	+	+	+	+	+	+	+	+
			Typha sp	+	+	+	-	+	+	+	+
			Proboscia alata	+	+	+	+	+	+	+	+
Feb	Centrales	Soleniceae	*Lauderia annulata*	+	-	+	-	+	-	+	+
			Microcystic sp	+	+	-	+	+	+	+	+
	Pennales	Fragillariaceae	*Fragillariopsis* sp	+	+	+	+	+	+	+	+
	Pinnales	Naviculaceae	*Navicula riparia*	+	+	+	+	+	+	+	+
			Spirogyra	+	-	-	+	+	+	+	-
			Potamogeton pectinatus	+	+	+	+	+	-	+	+
			Anabaena sp	+	+	+	+	+	+	+	+

Appendix 7. Monthly zooplankton species abundance (wet season)

Months	Order	Families	Genus/Species	Numbers of Zooplankton collected per Stations								Total	% Abundance
				1	2	3	4	5	6	7	8		
March	Cyclopoida	Cyclopoidae	*Cyclops* sp	14	0	2	2	9	5	4	4	40	0.66
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	18	2	2	0	4	8	9	5	48	0.79
			Sub-total	32	2	4	2	13	13	13	9	88	
	Calanoida	Diaptomidae	*Calanoid nauplius*	12	0	2	7	9	6	7	0	43	0.71
	Calanoida	Diaptomidae	*Diaptomus* sp	19	0	0	8	5	0	7	4	43	0.71
	Calanoida	Diaptomidae	*Calanoid copepod*	16	1	0	1	1	9	5	3	36	0.59
			Sub-total	47	1	1	14	13	17	18	11	122	
	Anomopoda	Daphniidae	*Calanus* sp	180	21	1	9	9	2	8	3	233	3.84
	Anomopoda	Daphniidae	*Daphnia* sp	87	8	2	1	8	4	9	3	122	2.01
	Anomopoda	Daphniidae	*D. longispina*	45	0	1	1	5	2	5	5	64	1.05
	Anomopoda	Daphniidae	*D. similies*	14	1	2	9	8	3	3	3	43	0.71
	Anomopoda	Daphniidae	*Simocephalus vetulus*	17	2	1	6	4	3	6	4	43	0.71
	Anomopoda	Chydoridae	*Moinodaphnia* sp	18	1	3	6	2	2	7	5	44	0.72
	Anomopoda	Chydoridae	*Alona monacantha*	18	2	1	9	2	8	7	4	51	0.84
	Anomopoda	Bosminidae	*A. davidi*	13	1	2	1	6	9	6	3	41	0.68
	Anomopoda	Bosminidae	*Bosmina longirostris*	16	2	4	0	9	0	0	4	35	0.58
			Sub-total	408	38	16	42	53	34	52	33	676	
April	Cladocera	Moinidae	*Moina micrura*	16	1	2	0	7	4	9	4	43	0.71
			Sub-total	16	1	2	0	7	4	9	4	43	
	Ploimida	Brachioniidae	*Brachionus caudatus*	23	2	3	0	3	3	4	4	42	0.69
			Sub-total	23	2	3	0	3	3	4	4	42	
	Phasmida	Phasmidae	*Haplopus evadne*	15	1	3	5	3	2	1	3	33	0.54
			Sub-total	15	1	3	5	3	2	1	3	33	
	Copepoda	Harpacticoida	*Harpacticoid copepod*	16	1	3	0	0	0	0	4	24	0.40

			Harpacticoid sp	13	2	2	4	1	1	3	3	29	0.48
			Sub-total	29	3	5	4	1	1	3	7	53	
			Cyclotella striata	48	1	3	5	5	2	6	5	75	1.23
			Sub-total	48	1	3	5	5	2	6	5	75	
			Camtocerus sp	0	1	2	42	119	56	76	4	300	4.94
			Chydorus sp	1	2	2	44	109	9	45	4	216	3.56
			Sub-total	2	3	7	88	232	72	127	13	544	
			Brachionus falcatus	1	0	2	8	7	5	4	4	31	0.51
			Sub-total	1	0	2	8	7	5	4	4	31	
			Metacyclops sp	81	1	1	5	7	2	6	4	107	1.76
			Sub-total	81	1	1	5	7	2	6	4	107	
May	Cyclopoida	Cyclopoidae	*Cyclops* sp	2	1	2	6	2	2	0	4	19	0.31
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	9	0	2	9	2	6	4	4	36	0.59
			Sub-total	11	1	4	15	4	7	5	8	55	
	Calanoida	Diaptomidae	*Calanoid nauplius*	9	0	2	9	9	9	7	4	49	0.81
	Calanoida	Diaptomidae	*Diaptomus* sp	5	1	3	4	7	2	2	3	27	0.44
	Calanoida	Diaptomidae	*Calanoid copepod*	5	2	1	1	5	8	3	4	29	0.48
			Sub-total	19	3	6	14	21	19	12	11	105	
	Anomopoda	Daphniidae	*Calanus* sp	8	1	3	6	1	9	5	3	36	0.59
	Anomopoda	Daphniidae	*Daphnia* sp	9	1	2	4	7	4	9	4	40	0.66
	Anomopoda	Daphniidae	*D. longispina*	4	0	3	5	2	2	4	3	23	0.38
	Anomopoda	Daphniidae	*D. similies*	2	0	3	1	4	8	4	4	26	0.43
	Anomopoda	Daphniidae	*Simocephalus vetulus*	9	1	2	3	2	5	5	4	31	0.51
	Anomopoda	Chydoridae	*Moinodaphnia* sp	2	0	1	6	6	7	8	4	34	0.56
	Anomopoda	Chydoridae	*Alona monacantha*	6	2	3	6	8	9	7	3	44	0.72
	Anomopoda	Bosminidae	*A. davidi*	5	1	2	1	3	4	4	5	25	0.41
	Anomopoda	Bosminidae	*Bosmina longirostris*	9	0	2	9	4	7	5	4	40	0.66
			Sub-total	54	6	21	41	37	55	51	34	299	
	Cladocera	Moinidae	*Moina micrura*	9	1	2	1	9	5	0	4	31	0.51

			Sub-total	9	1	2	1	9	5	0	4	31	
	Ploimida	Brachioniidae	*Brachionus caudatus*	8	0	1	5	9	9	2	4	38	0.63
			Sub-total	8	0	1	5	9	9	2	4	38	
June	Phasmida	Phasmidae	*Haplopus evadne*	1	2	3	3	7	9	5	3	33	0.54
			Sub-total	1	2	3	3	7	9	5	3	33	
	----------	----------	*Euglena* sp	2	0	2	8	6	6	6	4	34	0.56
			Sub-total	2	0	2	8	6	6	6	4	34	
	Harpacticoida	---------	*Harpacticoid copepod*	7	2	1	9	8	9	2	5	43	0.71
			Harpacticoid sp	8	1	1	3	7	7	9	3	39	0.64
			Sub-total	15	3	2	12	15	16	11	8	82	
			Cyclotella striata	7	0	2	6	2	7	3	4	31	0.51
			Sub-total	7	0	2	6	2	7	3	4	31	
			Camtocerus sp	3	1	2	9	1	6	3	5	30	0.49
			Brachionus falcatus	4	2	1	1	9	5	6	4	32	0.53
			Chydorus sp	2	1	3	4	8	3	5	3	29	0.48
			Sub-total	9	4	6	14	18	14	14	12	91	
			Metacyclops sp	1	1	2	7	4	7	4	4	30	0.49
			Sub-total	1	1	2	7	4	7	4	4	30	
			Brachionus sp	9	2	3	2	8	9	8	0	41	0.68
			Sub-total	9	2	2	2	7	8	7	4	41	
	Cyclopoida	Cyclopoidae	*Cyclops* sp	34	1	2	6	5	6	2	4	60	0.99
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	42	0	3	9	4	6	5	4	73	1.20
			Sub-total	76	1	5	15	9	12	7	8	133	
	Calanoida	Diaptomidae	*Calanoid nauplius*	5	1	2	2	6	1	7	4	28	0.46
	Calanoida	Diaptomidae	*Diaptomus* sp	1	1	3	9	4	7	6	5	36	0.59
July	Calanoida	Diaptomidae	*Calanoid copepod*	8	0	2	6	1	7	7	5	36	0.59
			Sub-total	14	2	7	17	11	15	20	14	100	
	Anomopoda	Daphniidae	*Calanus* sp	8	1	2	2	3	2	9	4	31	0.51
	Anomopoda	Daphniidae	*Daphnia* sp	9	2	3	3	6	2	3	5	33	0.54

	Anomopoda	Daphniidae	*D. longispina*	1	0	1	9	5	8	9	4	37	0.61
	Anomopoda	Daphniidae	*D. similies*	3	2	3	3	3	2	3	4	23	0.38
	Anomopoda	Daphniidae	*Simocephalus vetulus*	5	1	3	2	2	4	4	4	25	0.41
	Anomopoda	Chydoridae	*Moinodaphnia* sp	1	0	1	1	5	5	4	5	22	0.36
	Anomopoda	Chydoridae	*Alona monacantha*	9	0	2	7	7	8	5	5	43	0.71
	Anomopoda	Bosminidae	*A. davidi*	7	0	1	6	8	5	8	4	39	0.64
	Anomopoda	Bosminidae	*Bosmina longirostris*	24	1	3	4	8	7	5	5	57	0.94
			Sub-total	67	7	19	37	47	43	50	40	310	
	Cladocera	Moinidae	*Moina micrura*	38	1	2	3	2	6	3	3	58	0.96
			Sub-total	38	1	2	3	2	6	3	3	58	
	Ploimida	Brachioniidae	*Brachionus caudatus*	42	0	2	9	2	8	5	4	72	1.19
			Sub-total	42	0	2	9	2	8	5	4	72	
	Phasmida	Phasmidae	*Haplopus evadne*	24	1	2	4	6	6	6	5	54	0.89
			Sub-total	24	1	2	4	6	6	6	5	54	
	Harpacticoida		*Harpacticoid copepod*	40	0	1	2	5	5	0	4	57	0.94
			Harpacticoid sp	52	1	1	5	3	8	0	4	74	1.22
			Sub-total	92	1	2	7	8	13	0	8	131	
			Cyclotella striata	30	0	3	9	3	1	7	5	58	0.96
			Sub-total	30	0	3	9	3	1	7	5	58	
			Camtocerus sp										
			Brachionus falcatus	2	1	2	0	6	4	0	4	19	0.31
			Chydorus sp	18	1	1	98	43	13	97	4	275	4.53
			Sub-total	23	2	3	128	6	0	7	3	172	2.83
August			*Metacyclops* sp	36	1	2	2	0	9	1	4	55	
			Sub-total	41	2	2	5	8	6	4	4	72	1.19
			Brachionuscalas	41	2	2	5	8	6	4	4	72	
			Sub-total	40	1	3	3	5	3	7	3	65	1.07

			Metacyclops sp	40	1	3	3	5	3	7	3	65	
			Sub-total	32	1	2	6	6	9	6	4	66	1.09
			Brachionus sp	32	1	2	6	6	9	6	4	66	
	Cyclopoida	Cyclopoidae	Sub-total	27	0	1	6	7	8	9	5	63	1.04
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	41	0	1	5	4	9	9	4	73	1.20
	Calanoida	Diaptomidae	*Diaptomus* sp	23	0	2	7	8	7	6	4	57	0.94
	Calanoida	Diaptomidae	*Calanoid copepod*	56	1	3	5	4	2	9	5	85	1.40
	Anomopoda	Daphniidae	*Calanus* sp	40	0	1	7	3	7	0	5	63	1.04
	Anomopoda	Daphniidae	*Daphnia* sp	35	2	1	2	9	3	7	5	64	1.05
	Anomopoda	Daphniidae	*D. longispina*	55	0	2	6	8	8	6	4	89	1.47
	Anomopoda	Daphniidae	*D. similies*	25	1	3	1	9	8	6	3	56	0.92
	Anomopoda	Daphniidae	*Simocephalus vetulus*	47	0	2	5	9	3	9	5	80	1.32
September	Anomopoda	Chydoridae	*Moinodaphnia* sp	50	1	2	8	7	3	8	3	82	1.35
	Anomopoda	Chydoridae	*Alona monacantha*	42	1	3	4	9	1	9	3	72	1.19
	Anomopoda	Bosminidae	*A. davidi*	44	2	3	2	6	6	6	4	73	1.20
	Anomopoda	Bosminidae	*Bosmina longirostris*	46	0	2	7	6	7	6	3	77	1.27
			Sub-total	531	8	26	65	89	72	92	51	934	
	Cladocera	Moinidae	*Moina micrura*	29	1	3	4	6	3	4	3	53	0.87
			Sub-total	29	1	3	4	6	3	4	3	53	
	Ploimida	Brachioniidae	*Brachionus caudatus*	26	2	2	4	4	7	6	3	54	0.89
			Sub-total	26	2	2	4	4	7	6	3	54	
	Phasmida	Phasmidae	*Haplopus evadne*	29	1	3	6	5	8	0	6	58	0.96
			Sub-total	29	1	2	6	5	7	3	5	58	
	----------	----------	*B. falcatus*	40	0	1	5	4	7	5	4	66	1.09
			Sub-total	40	0	1	5	4	7	5	4	66	
October	Harpacticoida	---------	*Harpacticoid copepod*	30	1	1	8	2	6	6	4	58	0.96
			Harpacticoid sp	32	1	4	2	8	7	0	3	57	0.94

Sub-total	62	2	4	9	9	12	10	7	115	
Cyclotella striata	52	1	2	1	5	6	7	5	79	1.30
Sub-total	52	1	2	1	5	6	7	5	79	
Camtocercus sp	38	1	2	4	6	4	5	3	63	1.04
Sub-total	38	1	2	4	6	4	5	3	63	
Total	2311	120	212	789	812	605	745	416	6010	
% Abundance	38.05	1.98	3.49	12.99	13.37	9.96	12.27	6.85		

Appendix 8. Monthly zooplankton species abundance (dry season)

Months	Order	Families	Genus/Species	Numbers of Zooplankton collected per Stations								Total	% Abundance
				1	2	3	4	5	6	7	8		
November	Cyclopoida	Cyclopoidae	*Cyclops* sp	46	1	3	5	3	4	6	2	70	1.38
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	65	2	3	9	3	5	6	3	96	1.89
			Sub-total	111	3	6	14	6	9	12	5	166	
	Calanoida	Diaptomidae	*Calanoid* sp	89	1	2	4	8	7	7	8	126	2.48
	Calanoida	Diaptomidae	*Diaptomus* sp	12	1	3	7	52	2	23	56	156	3.07
	Calanoida	Diaptomidae	*Calanoid copepod*	25	1	2	9	9	24	1	3	74	1.46
			Sub-total	126	3	7	20	69	33	31	67	356	
	Anomopoda	Daphniidae	*Calanus* sp	5	0	2	1	7	1	3	6	25	0.49
	Anomopoda	Daphniidae	*Daphnia* sp	11	1	2	0	2	4	2	8	30	0.59
	Anomopoda	Daphniidae	*D. longispina*	34	0	3	7	2	2	4	5	57	1.12
	Anomopoda	Daphniidae	*D. similies*	10	1	2	2	8	9	7	7	46	0.91
	Anomopoda	Daphniidae	*Simocephalus vetulus*	30	1	2	1	2	9	3	3	51	1.00
	Anomopoda	Chydoridae	*Moinodaphnia* sp	14	1	3	0	2	1	2	10	33	0.65
	Anomopoda	Chydoridae	*Alona monacantha*	10	2	1	2	3	7	7	9	41	0.81
	Anomopoda	Bosminidae	*A. davidi*	26	0	2	3	3	9	3	7	53	1.04
	Anomopoda	Bosminidae	*Bosmina longirostris*	31	1	3	3	4	9	6	0	57	1.12
	Cladocera	Moinidae	*Moina micrura*	13	2	2	1	8	3	5	4	38	0.75
	Ploimida	Brachioniidae	*Brachionus caudatus*	31	1	2	7	4	6	3	7	61	1.20
			Sub-total	215	10	24	29	44	59	45	66	492	
	----------	----------	*Evadne* sp	17	1	3	2	5	3	1	9	41	0.81
			Sub-total	17	1	3	2	5	3	1	9	41	
	Phasmida	Phasmidae	*Haplopus evadne*	20	1	3	2	9	6	4	9	54	1.06
			Sub-total	20	1	3	2	9	6	4	9	54	
	Harpacticoida	---------	*Harpacticoid copepod*	12	2	1	0	7	1	1	8	32	0.63
			Harpacticoid sp	18	1	2	4	7	9	1	2	44	0.87
			Sub-total	30	3	3	5	13	10	2	10	76	

			Cyclotella striata	9	1	2	4	9	4	5	0	34	0.67
			Sub-total	9	1	2	4	9	4	4	1	34	
			Camtocerus sp	0	0	2	4	7	9	6	1	29	0.57
			Brachionus falcatus	7	1	3	5	3	2	4	9	34	0.67
			Chydorus sp	0	1	1	7	3	2	5	2	21	0.41
			Sub-total	7	2	6	16	13	13	15	12	84	
			Metacyclops sp	19	1	2	2	1	4	6	2	37	0.73
			Sub-total	23	0	2	5	8	6	9	9	62	1.22
			Brachionuscalas	28	2	3	5	7	3	2	3	53	1.04
			Sub-total	70	3	7	12	16	13	17	14	152	
December	Cyclopoida	Cyclopoidae	*Metacyclops* sp	16	1	2	3	9	3	5	6	45	0.89
	Cyclopoida	Cyclopidae	Sub-total	19	0	2	1	4	1	2	6	35	0.69
			Brachionuscaudatus	35	1	4	4	13	4	7	12	80	
	Calanoida	Diaptomidae	*Calanoid* sp	15	1	1	2	3	5	6	9	42	0.83
	Calanoida	Diaptomidae	*Diaptomus sp*	1	1	2	2	8	7	7	5	33	0.65
	Calanoida	Diaptomidae	*Calanoid copepod*	3	0	1	7	1	8	9	7	36	0.71
			Sub-total	19	2	4	11	12	20	22	21	111	
	Anomopoda	Daphniidae	*Calanus sp*	10	1	2	2	4	2	6	0	27	0.53
	Anomopoda	Daphniidae	*Daphnia sp*	29	2	1	3	8	5	1	2	51	1.00
	Anomopoda	Daphniidae	*D. longispina*	2	1	2	6	8	1	3	8	31	0.61
	Anomopoda	Daphniidae	*D. similies*	25	1	2	0	5	8	7	6	54	1.06
	Anomopoda	Daphniidae	*Simocephalus vetulus*	25	2	2	9	9	7	5	9	68	1.34
	Anomopoda	Chydoridae	*Moinodaphnia sp*	3	1	2	7	7	1	3	1	25	0.49
	Anomopoda	Chydoridae	*Alona monacantha*	5	1	2	4	8	4	6	1	31	0.61
	Anomopoda	Bosminidae	*A. davidi*	2	1	3	6	2	2	8	3	27	0.53
	Anomopoda	Bosminidae	*Bosmina longirostris*	7	2	1	4	7	1	5	6	33	0.65
			Sub-total	108	12	16	43	56	31	44	37	347	
	Cladocera	Moinidae	*Moina micrura*	51	1	3	3	2	6	1	5	72	1.42
			Sub-total	51	1	3	3	2	6	1	5	72	
	Ploimida	Brachioniidae	*Brachionus caudatus*	24	2	1	5	6	9	7	4	58	1.14

			Sub-total	24	2	1	5	6	9	7	4	58	
	----------	----------	*Evadne* sp	5	1	3	7	9	5	1	5	36	0.71
			Sub-total	5	1	3	7	9	5	1	5	36	
	Harpacticoida	---------	*Harpacticoid copepod*	6	1	1	0	6	8	6	5	33	0.65
			Harpacticoid sp	36	0	2	5	7	8	0	7	65	1.28
			Sub-total	42	1	3	7	13	16	5	11	98	
			Camtocerus sp	13	1	1	9	9	6	5	8	52	1.02
			Brachionus falcatus	12	2	3	5	7	8	1	7	45	0.89
			Chydorus sp	2	1	2	4	1	4	6	7	27	0.53
			Sub-total	27	4	6	18	17	18	12	22	124	
			Metacyclops sp	19	1	1	5	2	4	4	6	42	0.83
			Sub-total	7	1	1	9	2	5	3	4	32	0.63
			Brachionuscalas	13	2	2	8	1	7	6	2	41	0.81
			Sub-total	39	4	4	22	5	16	13	12	115	
January	Cyclopoida	Cyclopoidae	*Metacyclops* sp	39	2	3	0	5	8	11	2	70	1.38
	Cyclopoida	Cyclopidae	Sub-total	12	1	2	9	2	1	7	0	34	0.67
			Brachionus sp	51	3	5	10	7	9	16	3	104	
	Calanoida	Diaptomidae	*Calanoid nauplius*	13	0	1	7	4	2	4	2	33	0.65
	Calanoida	Diaptomidae	*Diaptomus sp*	22	1	1	4	5	9	2	9	53	1.04
	Calanoida	Diaptomidae	*Calanoid copepod*	11	1	2	3	0	8	10	5	40	0.79
			Sub-total	46	2	4	14	10	19	15	16	126	
	Anomopoda	Daphniidae	*Calanus sp*	35	1	2	2	4	1	5	5	55	1.08
	Anomopoda	Daphniidae	*Daphnia sp*	17	1	3	8	2	7	9	8	55	1.08
	Anomopoda	Daphniidae	*D. longispina*	15	2	2	5	6	4	3	0	37	0.73
	Anomopoda	Daphniidae	*D. similies*	14	1	3	1	8	7	9	0	43	0.85
	Anomopoda	Daphniidae	*Simocephalus vetulus*	12	1	3	2	7	8	2	2	37	0.73
	Anomopoda	Chydoridae	*Moinodaphnia sp*	15	2	3	4	3	5	8	3	43	0.85
	Anomopoda	Chydoridae	*Alona monacantha*	12	1	2	5	7	3	3	8	41	0.81
	Anomopoda	Bosminidae	*A. davidi*	18	2	2	1	2	4	5	7	41	0.81
	Anomopoda	Bosminidae	*Bosmina longirostris*	24	0	2	1	8	7	0	4	46	0.91

			Sub-total	162	11	21	29	47	46	44	38	398	
	Cladocera	Moinidae	*Moina micrura*	27	1	2	1	4	2	5	9	51	1.00
			Sub-total	27	1	2	1	4	2	5	9	51	
	Ploimida	Brachioniidae	*Brachionus caudatus*	23	3	2	3	7	9	11	0	58	1.14
			Sub-total	23	1	2	2	6	9	8	7	58	
	Phasmida	Phasmidae	*Haplopus evadne*	34	1	3	2	2	8	4	7	61	1.20
			Sub-total	34	1	3	2	2	8	4	7	61	
	----------	----------	*Haplopus* sp	27	0	2	4	6	3	8	6	56	1.10
			Sub-total	27	0	2	4	6	3	8	6	56	
	Harpacticoida	---------	*Harpacticoid copepod*	11	0	2	1	3	8	7	3	35	0.69
			Harpacticoid sp	17	1	3	1	4	1	6	9	42	0.83
			Sub-total	28	1	5	2	7	9	13	12	77	
			Cyclotella striata	13	1	1	3	3	3	2	9	35	0.69
			Sub-total	13	1	1	3	3	3	2	9	35	
			Camtocerus sp	6	2	3	3	4	9	3	7	37	0.73
			Brachionus falcatus	1	2	1	1	9	1	7	5	27	0.53
			Chydorus sp	0	0	2	5	2	2	1	5	17	0.33
			Sub-total	7	4	6	9	15	12	11	17	81	
			Metacyclops sp	10	2	3	7	5	9	5	9	50	0.98
			Sub-total	19	2	2	3	1	3	6	8	44	0.87
			Brachionuscalas	11	7	2	8	9	6	7	6	56	1.10
			Sub-total	40	11	7	18	15	18	18	23	150	
February	Cyclopoida	Cyclopoidae	*Cyclops* sp	31	4	1	1	8	2	8	2	57	1.12
	Cyclopoida	Cyclopidae	Sub-total	19	9	2	2	6	0	1	7	46	0.91
			Brachionus sp	50	13	3	3	14	2	9	9	103	
	Calanoida	Diaptomidae	*Calanoid* sp	27	3	3	8	5	5	5	9	65	1.28
	Calanoida	Diaptomidae	*Diaptomus* sp	28	1	3	7	4	8	3	2	56	1.10
	Calanoida	Diaptomidae	*Calanoid copepod*	38	1	2	6	4	9	2	2	64	1.26
			Sub-total	93	5	8	21	13	22	10	13	185	
	Anomopoda	Daphniidae	*Calanus* sp	23	7	0	6	8	8	7	2	61	1.20

Anomopoda	Daphniidae	*Daphnia micrura*	21	2	2	8	6	6	4	2	51	1.00
Anomopoda	Daphniidae	*D. longispina*	25	2	3	1	9	2	7	9	58	1.14
Anomopoda	Daphniidae	*D. similies*	33	1	3	9	2	1	7	7	63	1.24
Anomopoda	Daphniidae	*Simocephalus vetulus*	32	6	1	3	1	1	6	2	52	1.02
Anomopoda	Chydoridae	*Moinodaphnia sp*	6	1	3	4	4	2	4	1	25	0.49
Anomopoda	Chydoridae	*Alona monacantha*	32	2	2	1	6	6	4	6	59	1.16
Anomopoda	Bosminidae	*A. davidi*	37	4	3	4	2	4	8	5	67	1.32
Anomopoda	Bosminidae	*Bosmina longirostris*	9	0	3	5	6	6	4	6	39	0.77
		Sub-total	218	25	21	40	44	36	51	40	475	
Cladocera	Moinidae	*Moina micrura*	3	1	2	1	7	6	4	5	29	0.57
		Sub-total	3	1	2	1	7	6	4	5	29	
Ploimida	Brachioniidae	*Brachionus caudatus*	5	2	3	4	3	0	0	5	22	0.43
		Sub-total	5	1	3	2	1	6	0	4	22	
Phasmida	Phasmidae	*Haplopus evadne*	5	5	1	2	7	0	6	8	34	0.67
		Sub-total	5	5	1	2	7	0	6	8	34	
----------	----------	*Camocercus* sp	8	3	2	5	6	0	3	3	30	0.59
		Sub-total	8	3	2	5	6	0	3	3	30	
Harpacticoida	---------	*Harpacticoid copepod*	25	2	0	5	0	0	8	7	47	0.93
		Cyclotella striata	12	2	0	0	2	9	4	7	36	0.71
		Sub-total	12	0	0	0	2	9	4	7	36	
		Camtocercus sp	2	8	3	0	4	9	1	4	31	0.61
		B. falcatus	21	4	3	7	0	3	0	7	45	0.89
		Chydorus sp	2	7	3	8	3	0	0	7	30	0.59
		Sub-total	25	19	9	15	7	12	1	18	106	
		Metacyclops sp	4	8	2	1	0	8	0	5	28	0.55
		Daphnia micrura	14	3	2	7	2	6	0	6	40	0.79
		Sub-total	19	16	6	10	2	14	0	15	82	
		Total	1938	224	246	463	547	553	510	599	5080	
		% Abundance	38.15	4.41	4.84	9.11	10.77	10.89	10.04	11.79		

Appendix 9. Checklist of zooplankton for wet season

Months	Order	Families	Genus/Species	Numbers of Zooplankton collected per Stations							
				1	2	3	4	5	6	7	8
March	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	-	+	+	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	+	+	-	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	-	+	+	+	+	+	-
	Calanoida	Diaptomidae	*Diaptomus* sp	+	-	-	+	+	-	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	-	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Moinodaphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	+	+	-	+	-	-	+
	Cladocera	Moinidae	*Moina micrura*	+	+	+	-	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	-	+	+	+	+
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	Copepoda	Harpacticoida	*Harpacticoid copepod*	+	+	+	-	-	-	-	+
			Harpacticoid sp	+	+	+	+	+	+	+	+
April			*Cyclotella striata*	+	+	+	+	+	+	+	+
			Camtocercus sp	+	-	+	+	+	+	+	+
			B. falcatus	-	+	+	+	+	+	+	+
			Chydorus sp	+	+	+	+	+	+	+	+
			Metacyclop sp	+	-	+	+	+	+	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	-	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus* sp	+	+	+	+	+	+	+	+

	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
May	Anomopoda	Chydoridae	*Moinodaphnia* sp	+	-	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	=	+	=	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	-	+	+	+	+	+	+
	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	-	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	-	+	+	+	+	+	+
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	----------	----------	*Euglena* sp	+	-	+	+	+	+	+	+
	Harpacticoida	---------	*Harpacticoid copepod*	+	+	+	+	+	+	+	+
			Harpacticoid sp	+	+	+	+	+	+	+	+
			Cyclotella striata	+	-	+	+	+	+	+	+
			Camtocercus sp	+	+	+	+	+	+	+	+
			B. falcatus	+	+	+	+	+	+	+	+
June			*Chydorus* sp	+	+	+	+	+	+	+	+
			Metacyclop sp	+	+	+	+	+	-	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus* sp	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
July	Anomopoda	Chydoridae	*Moinodaphnia* sp	+	-	+	+	+	+	+	+

	Anomopoda	Chydoridae	*Alona monacantha*	+	-	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	-	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	+	+	+	+	+	+	+
August	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	-	+	+	+	+	+	+
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	Harpacticoida		*Harpacticoid copepod*	+	-	+	+	+	+	-	+
			Harpacticoid sp	+	+	+	+	+	+	-	+
			Cyclotella striata	+	-	+	+	+	+	+	+
			Camtocercus sp	+	+	+	-	+	+	-	+
			B. falcatus	+	+	+	+	+	+	+	+
			Chydorus sp	+	+	+	+	+	-	+	+
			Metacyclop sp	+	+	+	+	-	+	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
September	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	-	+	+	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus* sp	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	-	+	+	+	+	-	+
	Anomopoda	Daphniidae	*Daphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	-	+	+	+	+	+	+
October	Anomopoda	Chydoridae	*Moinodaphnia* sp	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	-	+	+	+	+	+	+
	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	+
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	-	+
	Harpacticoida	---------	*H. copepod*	+	+	+	+	+	+	+	+
			Cyclotella striata	+	+	+	+	+	+	+	+

Appendix 10. Checklist of zooplankton for dry season

Months	Order	Families	Genus/Species	Numbers of Zooplankton collected per Stations							
				1	2	3	4	5	6	7	8
November	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus* sp	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia* sp	+	+	+	-	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Moinodaphnia* sp	+	+	+	-	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	-	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	+	+	+	+	+	+	-
	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	+
	----------	----------	*Evadne* sp	+	+	+	+	+	+	+	+
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	Harpacticoida	---------	*Harpacticoid copepod*	+	+	+	-	+	+	+	+
			Harpacticoid sp	+	+	+	+	+	+	+	+
			Cyclotella striata	+	+	+	+	+	+	+	-
			Camtocercus sp	-	-	+	+	+	+	+	+
			B. falcatus	+	+	+	+	+	+	+	+
			Chydorus sp	-	+	+	+	+	+	+	+
			Metacyclop sp	+	-	+	+	+	+	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
December	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	+	+

	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus sp*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	-	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus sp*	+	+	+	+	+	+	+	-
	Anomopoda	Daphniidae	*Daphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	-	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Moinodaphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	+	+	+	+	+	+	+
	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	+
	----------	----------	*Evadne* sp	+	+	+	+	+	+	+	+
	Harpacticoida	---------	*Harpacticoid copepod*	+	+	+	-	+	+	+	+
			Harpacticoid sp	+	-	+	+	+	+	-	+
			Camtocercus sp	+	+	+	+	+	+	+	+
			B. falcatus	+	+	+	+	+	+	+	+
			Chydorus sp	+	+	+	+	+	+	+	+
			Metacyclop sp	+	+	+	+	+	-	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
January	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	-	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	+	+	+	+	+	+	-
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	-	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus sp*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	+	+	-	+	+	+
	Anomopoda	Daphniidae	*Calanus sp*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	+	+	+	+	+	+	-

	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	-
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Moinodaphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
	Anomopoda	Bosminidae	*Bosmina longirostris*	+	-	+	+	+	+	-	+
	Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
	Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	+	+	-
	Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	+	+	+
	Harpacticoida	---------	*Harpacticoid copepod*	+	-	+	+	+	+	+	+
			Harpacticoid nauplius	+	+	+	+	+	+	+	+
			Cyclotella striata	+	+	+	+	+	+	+	+
			Camtocercus sp	+	+	+	+	+	+	+	+
			B. falcatus	+	+	+	+	+	+	+	+
			Chydorus sp	-	-	+	+	+	+	+	+
			Metacyclop sp	+	-	+	+	+	+	+	+
			Brachionus sp	+	+	+	+	+	+	+	+
February	Cyclopoida	Cyclopoidae	*Cyclops* sp	+	+	+	+	+	+	+	+
	Cyclopoida	Cyclopidae	*Eucyclops speratus*	+	+	+	+	+	-	+	+
	Calanoida	Diaptomidae	*Calanoid nauplius*	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Diaptomus* sp	+	+	+	+	+	+	+	+
	Calanoida	Diaptomidae	*Calanoid copepod*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Calanus* sp	+	+	-	+	+	+	+	+
	Anomopoda	Daphniidae	*Daphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. longispina*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*D. similies*	+	+	+	+	+	+	+	+
	Anomopoda	Daphniidae	*Simocephalus vetulus*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Moinodaphnia sp*	+	+	+	+	+	+	+	+
	Anomopoda	Chydoridae	*Alona monacantha*	+	+	+	+	+	+	+	+

Anomopoda	Bosminidae	*A. davidi*	+	+	+	+	+	+	+	+
Anomopoda	Bosminidae	*Bosmina longirostris*	+	-	+	+	+	+	+	+
Cladocera	Moinidae	*Moina micrura*	+	+	+	+	+	+	+	+
Ploimida	Brachioniidae	*Brachionus caudatus*	+	+	+	+	+	-	-	+
Phasmida	Phasmidae	*Haplopus evadne*	+	+	+	+	+	-	+	+
Harpacticoida	---------	*Harpacticoid copepod*	+	+	-	+	-	-	+	+
		Harpacticoid sp	+	+	+	+	-	+	-	+
		Cyclotella striata	+	+	-	-	+	+	+	+
		Camtocercus sp	+	+	+	-	+	+	+	+
		B. falcatus	+	+	+	+	-	+	-	+
		Chydorus sp	+	+	+	+	+	-	-	+
		Metacyclop sp	+	+	+	+	-	+	-	+
		Brachionus sp	+	+	+	+	-	-	-	+

Appendix 11. Monthly abundance of sediment macro-invertebrates (wet season)

Months	Orders	Families	*Genus and Species*	Numbers of sediment macroinvertebrates collected per stations								Total	%Abundance
				1	2	3	4	5	6	7	8		
March	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	7	21	11	1	1	1	57	99	0.79
	Hemiptera	Gerridae	*Gerris remigis*	0	8	1	4	23	2	2	21	61	0.49
	Hemiptera	Cicadellidae	*Lonatura megalopa*	0	8	3	12	34	8	3	18	86	0.69
	Hemiptera	Belostomidae	*Belostoma sp.*	0	14	1	8	3	2	7	15	50	0.40
	Hemiptera	Nepidae	*Nepa sp.*	0	12	2	20	9	1	3	13	60	0.48
			Sub-total	0	49	28	55	70	14	16	124	356	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	30	0	2	9	2	11	23	68	145	1.16
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	11	0	2	3	1	9	7	78	111	0.89
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	14	0	1	2	9	7	5	12	50	0.40
	Ephemeroptera	Isonychiidae	*Isonychia arida*	19	0	1	2	1	3	10	14	50	0.40
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	14	0	1	3	4	5	19	12	58	0.46
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	15	0	1	23	1	4	13	19	76	0.61
April	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	18	0	1	17	8	5	15	10	74	0.59
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	19	0	3	2	3	4	76	12	119	0.95
			Sub-total	140	0	12	61	29	48	168	225	683	
	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	10	0	2	8	12	7	9	11	59	0.47
			Sub-total	10	0	2	8	12	7	9	11	59	
	Odonata	Libelluidae	*Hemistigma sp*	3	20	17	20	17	6	1	15	99	0.79

	Odonata	Aeshnidae	*Helocordulia selysii*	0	15	13	20	16	2	3	16	85	0.68
	Odonata	Libelluidae	*Pantata flarescens*	0	16	16	11	12	3	9	19	86	0.69
	Odonata	Aeshnidae	*Ashna interrupta*	0	4	7	6	9	5	1	21	53	0.42
			Sub-total	3	55	53	57	54	16	14	71	323	
	Diptera	Culicidae	*Aedes sp.*	7	1	4	3	6	5	8	3	37	0.30
	Diptera	Culicidae	*Culex sp.*	3	5	2	2	3	7	12	4	38	0.30
			Sub-total	10	6	6	5	9	12	20	7	75	
	Plecoptera	Perlidae	*Perlids sp.*	15	0	0	6	2	7	1	19	50	0.40
May	Plecoptera	Leuctridae	*Latelmis sp.*	165	0	3	9	12	5	12	18	224	1.79
			Sub-total	180	0	4	15	13	12	13	37	274	
	Coleoptera	Gyrinidae	*Gyrinus sp.*	1	7	2	20	13	3	2	17	65	0.52
			Sub-total	1	7	2	20	13	3	2	17	65	
	Hemiptera	Corixidae	*Hesperocorixa castanea*	430	0	1	11	8	29	13	18	510	4.08
	Hemiptera	Gerridae	*Gerris remigis*	0	13	19	16	15	8	2	14	87	0.70
	Hemiptera	Vellidae	*Velia sp*	0	14	15	19	10	5	5	7	75	0.60
	Hemiptera	Belostomidae	*Belostoma sp.*	0	12	10	16	1	4	9	2	54	0.43
	Hemiptera	Nepidae	*Nepa sp.*	0	11	19	12	17	0	4	2	65	0.52
			Sub-total	0	104	85	100	82	68	30	61	530	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	0	54	23	37	39	48	11	37	249	1.99
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	98	0	5	16	13	14	12	13	171	1.37
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	127	0	1	11	19	0	20	9	187	1.50
	Ephemeroptera	Isonychiidae	*Isonychia arida*	98	0	1	18	10	19	11	28	185	1.48
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	100	0	2	14	1	16	11	4	148	1.18
	Ephemeroptera	Polymitarcyidae	*Tortopus*	12	0	1	13	14	13	18	8	79	0.63

			incertus									
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	15	1	4	2	13	16	12	7	70	0.56
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	17	0	2	10	2	39	1	9	80	0.64
			Sub-total	897	1	17	95	80	147	97	96	1430	
June	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	13	0	2	8	8	20	16	13	80	0.64
			Sub-total	13	0	2	8	8	20	16	13	80	
	Odonata	Libelluidae	*Hemistigma sp*	0	15	20	2	17	8	15	15	92	0.74
	Odonata	Aeshnidae	*Helocordulia selysii*	0	18	11	4	17	4	10	8	72	0.58
	Odonata	Libelluidae	*Pantata flarescens*	0	17	19	7	12	8	21	23	107	0.86
	Odonata	Aeshnidae	*Ashna interrupta*	6	17	20	8	16	5	18	6	96	0.77
			Sub-total	6	67	70	21	62	25	64	52	367	
	Diptera	Culicidae	*Aedes sp.*	20	13	8	14	18	4	13	8	98	0.78
	Diptera	Culicidae	*Culex sp.*	11	15	13	17	8	2	11	20	97	0.78
			Sub-total	31	28	21	31	26	6	24	28	195	
	Plecoptera	Perlidae	*Perlids sp.*	18	0	20	20	13	13	17	9	110	0.88
	Plecoptera	Leuctridae	*Latelmis sp.*	129	0	8	17	14	20	20	12	220	1.76
			Sub-total	147	0	28	37	27	33	37	21	330	
	Coleoptera	Gyrinidae	*Gyrinus sp.*	1	13	15	13	8	13	3	15	81	0.65
			Sub-total	1	13	15	13	8	13	3	15	81	
July	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	19	43	77	79	34	6	27	285	2.28
	Hemiptera	Gerridae	*Gerris remigis*	0	3	0	14	19	13	6	0	55	0.44
	Hemiptera	Vellidae	*Velia sp*	0	8	33	82	13	10	7	0	153	1.22
	Hemiptera	Belostomidae	*Belostoma sp.*	0	2	12	17	17	15	3	0	66	0.53
	Hemiptera	Nepidae	*Nepa sp.*	0	65	14	15	13	8	2	8	125	1.00
			Sub-total	0	96	107	204	140	79	23	35	684	

	Ephemeroptera	Epemerellidae	*Ephemerella doris*	120	0	2	13	19	19	2	19	194	1.55
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	17	0	6	14	16	17	24	16	110	0.88
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	12	0	8	16	34	19	65	6	160	1.28
	Ephemeroptera	Isonychiidae	*Isonychia arida*	13	0	9	1	13	14	8	5	63	0.50
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	34	0	0	4	87	67	14	14	224	1.79
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	11	0	7	3	16	49	95	6	187	1.50
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	14	0	8	18	15	1	100	23	179	1.43
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	13	0	8	19	12	89	65	3	209	1.67
			Sub-total	234	0	52	88	212	275	373	92	1326	
August	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	45	0	7	18	14	128	45	8	265	2.12
			Sub-total	45	0	7	18	14	128	45	8	265	
	Odonata	Libelluidae	*Hemistigma sp*	1	9	17	16	16	18	13	9	99	0.79
	Odonata	Aeshnidae	*Helocordulia selysii*	1	18	18	29	19	16	8	6	115	0.92
	Odonata	Libelluidae	*Pantata flarescens*	7	19	12	16	14	15	12	5	100	0.80
	Odonata	Aeshnidae	*Ashna interrupta*	8	13	20	15	9	21	11	0	97	0.78
			Sub-total	17	59	67	76	58	70	44	20	411	
	Diptera	Culicidae	*Aedes* sp.	17	3	10	17	8	18	9	19	101	0.81
	Diptera	Culicidae	*Culex* sp.	8	10	19	11	15	11	3	16	93	0.74
			Sub-total	25	13	29	28	23	29	12	35	194	
	Plecoptera	Perlidae	*Perlids* sp.	9	0	0	9	18	15	5	21	77	0.62
September	Plecoptera	Leuctridae	*Latelmis* sp.	9	0	14	18	19	12	19	17	108	0.86
			Sub-total	18	0	19	26	36	26	23	37	185	

	Coleopteran	Gyrinidae	*Gyrinus* sp.	8	11	15	10	9	9	6	18	86	0.69
			Sub-total	8	11	15	10	9	9	6	18	86	
	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	15	39	66	68	25	7	54	274	2.19
	Hemiptera	Gerridae	*Gerris remigis*	0	9	20	17	19	11	3	4	83	0.66
	Hemiptera	Vellidae	*Velia* sp	0	43	30	22	33	16	2	5	151	1.21
	Hemiptera	Belostomidae	*Belostoma* sp.	0	8	22	35	25	10	1	5	106	0.85
	Hemiptera	Nepidae	*Nepa* sp.	0	5	31	27	26	13	8	3	113	0.90
			Sub-total	0	80	142	167	171	75	21	71	727	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	29	0	35	22	23	36	36	8	189	1.51
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	25	0	32	36	185	30	16	5	329	2.63
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	15	0	36	23	45	27	35	7	188	1.51
	Ephemeroptera	Isonychiidae	*Isonychia arida*	29	0	34	29	27	65	35	3	222	1.78
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	26	0	31	24	22	78	36	4	221	1.77
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	29	0	33	19	17	98	59	16	271	2.17
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	34	0	33	1	29	30	69	28	224	1.79
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	24	0	34	2	30	34	65	9	198	1.59
			Sub-total	211	0	268	156	378	398	351	80	1842	
October	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	30	0	28	6	34	34	70	5	207	1.66
			Sub-total	30	0	28	6	34	34	70	5	207	
	Odonata	Libelluidae	*Hemistigma sp*	3	13	29	16	19	31	2	9	122	0.98
	Odonata	Aeshnidae	*Helocordulia selysii*	2	27	28	31	34	27	1	7	157	1.26
	Odonata	Libelluidae	*Pantata flarescens*	16	42	27	25	36	26	3	2	177	1.42

Odonata	Aeshnidae	*Ashna interrupta*	16	23	30	17	26	33	6	32	183	1.47
		Sub-total	37	105	114	89	115	117	12	50	639	
Diptera	Culicidae	*Aedes sp.*	1	5	32	21	36	34	5	21	155	1.24
Diptera	Culicidae	*Culex sp.*	23	5	0	34	16	33	34	32	177	1.42
		Sub-total	24	8	39	54	51	66	38	52	332	
Plecoptera	Perlidae	*Perlids sp.*	54	0	10	24	16	24	87	26	241	1.93
Plecoptera	Leuctridae	*Latelmis sp.*	31	0	12	22	27	29	180	21	322	2.58
		Sub-total	85	0	22	46	43	53	267	47	563	
Coleopteran	Gyrinidae	*Gyrinus sp.*	2	27	19	30	20	34	23	27	182	1.46
		Sub-total	2	27	19	30	20	34	23	27	182	
	Grand total		2175	729	1273	1524	1797	1817	1821	1355	**12,491**	
	%Abundance		17.41	5.84	10.19	12.20	14.39	14.55	14.58	10.85		

Appendix 12. Monthly abundance of sediment macro-invertebrates (dry season)

Months	Orders	Families	Genus and Species	Numbers of sediment macroinvertebrates collected per station								Total	%Abundance
				1	2	3	4	5	6	7	8		
November	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	97	41	76	62	8	49	56	389	2.27
	Hemiptera	Gerridae	*Gerris remigis*	0	16	10	22	36	35	31	4	154	0.90
	Hemiptera	Cicadellidae	*Lonatura megalopa*	0	21	25	35	16	25	25	25	172	1.00
	Hemiptera	Belostomidae	*Belostoma* sp.	0	30	29	17	34	24	26	8	168	0.98
	Hemiptera	Nepidae	*Nepa* sp.	0	24	35	28	29	29	19	29	193	1.13
			Sub-total	0	188	140	178	177	121	150	122	1076	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	15	0	1	21	34	12	16	18	117	0.68
	Ephemeroptera												
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	27	0	3	16	35	37	26	27	171	1.00
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	28	1	8	31	28	25	27	31	179	1.05
	Ephemeroptera	Isonychiidae	*Isonychia arida*	30	1	16	33	29	17	15	27	168	0.98
	Ephemeroptera	Leptophlebiidae	*Leptophlebia* sp.	22	0	19	32	36	12	33	36	190	1.11
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	16	0	11	37	18	21	24	26	153	0.89
	Ephemeroptera	Potamanthidae	*Potamanthus* sp.	21	0	10	32	18	22	32	29	164	0.96
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	33	0	3	27	36	19	19	35	172	1.00
			Sub-total	192	2	71	229	234	165	192	229	1314	
	Trichoptera	Hydropsychidae	*Hydropsychids* sp.	18	0	5	29	18	21	22	19	132	0.77
			Sub-total	18	0	5	29	18	21	22	19	132	
	Odonata	Libelluidae	*Hemistigma* sp	18	34	27	19	35	29	25	17	204	1.19

	Odonata	Aeshnidae	*Helocordulia selysii*	10	31	24	22	31	20	35	26	199	1.16
	Odonata	Libelluidae	*Pantata flarescens*	1	35	34	27	29	27	31	26	210	1.23
	Odonata	Aeshnidae	*Ashna interrupta*	3	32	28	34	31	34	15	23	200	1.17
			Sub-total	32	132	113	102	126	110	106	92	813	
	Diptera	Culicidae	*Aedes* sp.	12	29	10	10	0	26	27	20	134	0.78
	Diptera	Culicidae	*Culex* sp.	3	55	0	17	27	32	16	10	160	0.93
			Sub-total	15	79	11	34	44	51	36	24	294	
	Plecoptera	Perlidae	*Perlids* sp.	24	0	10	30	17	65	18	8	172	1.00
	Plecoptera	Leuctridae	*Latelmis* sp.	16	0	35	13	23	87	25	14	213	1.24
			Sub-total	40	0	45	43	40	152	43	22	385	
	Coleopteran	Gyrinidae	*Gyrinus* sp.	1	13	14	27	26	0	26	37	144	0.84
			Sub-total	1	11	14	27	22	18	19	33	144	
December	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	120	51	86	72	38	43	79	489	2.86
	Hemiptera	Gerridae	*Gerris remigis*	0	5	27	29	21	16	22	3	123	0.72
	Hemiptera	Vellidae	*Velia* sp	0	10	33	0	22	16	21	9	115	0.67
	Hemiptera	Belostomidae	*Belostoma* sp.	0	8	11	31	25	0	29	4	108	0.63
	Hemiptera	Nepidae	*Nepa* sp.	0	15	35	10	28	27	16	0	131	0.77
			Sub-total	0	152	157	168	168	97	130	94	966	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	57	5	10	28	0	35	16	0	164	0.96
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	64	1	4	24	33	30	21	43	220	1.29
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	45	0	8	19	35	29	34	1	171	1.00
	Ephemeroptera	Isonychiidae	*Isonychia arida*	23	0	9	15	16	17	29	2	111	0.65
	Ephemeroptera	Leptophlebiidae	*Leptophlebia* sp.	39	0	10	0	23	25	35	5	137	0.80
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	70	2	11	15	35	0	30	14	177	1.03

	Ephemeroptera	Potamanthidae	*Potamanthus* sp.	89	0	6	24	26	20	30	3	198	1.16
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	19	0	8	33	25	26	19	7	137	0.80
			Sub-total	396	4	53	170	216	196	214	66	1315	
	Trichoptera	Hydropsychidae	*Hydropsychids* sp.	121	0	14	18	25	19	0	8	235	1.37
			Sub-total	111	0	11	18	25	19	0	35	235	
	Odonata	Libelluidae	*Hemistigma* sp	1	35	22	35	0	34	32	23	182	1.06
	Odonata	Aeshnidae	*Helocordulia selysii*	3	35	33	28	0	22	19	33	173	1.01
	Odonata	Libelluidae	*Pantata flarescens*	1	15	21	19	3	33	24	23	139	0.81
	Odonata	Aeshnidae	*Ashna interrupta*	7	36	36	28	5	27	27	48	214	1.25
			Sub-total	10	121	112	110	13	116	102	124	708	
	Diptera	Culicidae	*Aedes* sp.	2	5	32	31	6	15	28	3	122	0.71
	Diptera	Culicidae	*Culex* sp.	5	7	26	18	0	24	23	9	112	0.65
			Sub-total	7	14	58	49	16	39	51	0	234	
	Plecoptera	Perlidae	*Perlids* sp.	27	0	19	16	26	21	32	9	150	0.88
	Plecoptera	Leuctridae	*Latelmis* sp.	65	0	36	15	31	18	30	6	201	1.17
			Sub-total	92	0	55	31	57	39	62	15	351	
	Coleopteran	Gyrinidae	*Gyrinus* sp.	1	18	0	0	0	0	0	26	45	0.26
			Sub-total	1	18	0	0	0	0	0	26	45	
January	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	13	57	88	92	70	99	38	457	2.67
	Hemiptera	Gerridae	*Gerris remigis*	0	16	17	35	19	28	0	17	132	0.77
	Hemiptera	Vellidae	*Velia sp*	0	27	22	34	36	34	23	5	181	1.06
	Hemiptera	Belostomidae	*Belostoma* sp.	0	29	32	24	32	20	28	6	171	1.00
	Hemiptera	Nepidae	*Nepa* sp.	0	9	36	33	21	28	19	12	158	0.92
			Sub-total	0	94	164	214	200	166	197	64	1099	
	Ephemeroptera	Epemerellidae	*Ephemerella*	33	0	10	21	20	0	16	19	119	0.70

		doris									
Ephemeroptera	Ephemeridae	*Hexagenia limbata*	85	0	7	18	23	23	34	36	226	1.32
Ephemeroptera	Heptageniidae	*Stenonema exiguum*	35	1	6	24	35	18	30	28	177	1.03
Ephemeroptera	Isonychiidae	*Isonychia arida*	89	0	4	15	18	12	17	21	176	1.03
Ephemeroptera	Leptophlebiidae	*Leptophlebia* sp.	33	2	9	35	21	21	27	35	183	1.07
Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	20	0	6	21	16	24	28	23	138	0.81
Ephemeroptera	Potamanthidae	*Potamanthus* sp.	30	0	6	33	15	21	35	15	155	0.91
Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	32	1	5	15	9	24	23	31	140	0.82
		Sub-total	357	4	46	182	154	156	210	205	1314	
Trichoptera	Hydropsychidae	*Hydropsychids* sp.	27	0	2	11	4	33	36	33	146	0.85
		Sub-total	27	0	2	11	4	33	36	33	146	
Odonata	Libelluidae	*Hemistigma* sp	6	33	34	28	20	32	17	31	201	1.17
Odonata	Aeshnidae	*Helocordulia selysii*	3	31	35	32	16	18	32	22	189	1.10
Odonata	Libelluidae	*Pantata flarescens*	6	30	31	39	25	28	30	35	224	1.31
Odonata	Aeshnidae	*Ashna interrupta*	9	22	22	35	38	0	0	32	158	0.92
		Sub-total	24	116	122	134	82	95	106	93	772	
Diptera	Culicidae	*Aedes* sp.	2	8	34	19	37	28	27	0	155	0.91
Diptera	Culicidae	*Culex* sp.	8	79	17	34	21	35	38	58	290	1.69
		Sub-total	10	86	51	53	58	63	65	59	445	
Plecoptera	Perlidae	*Perlids* sp.	24	0	37	28	201	0	31	27	348	2.03
Plecoptera	Leuctridae	*Latelmis* sp.	37	0	35	20	32	22	28	8	182	1.06
		Sub-total	61	0	72	38	233	59	52	15	530	
Coleopteran	Gyrinidae	*Gyrinus* sp.	7	28	29	22	16	24	20	5	151	0.88
		Sub-total	7	28	29	22	16	24	20	5	151	

February	Hemiptera	Corixidae	*Hesperocorixa castanea*	0	11	47	77	81	59	1	119	395	2.31
	Hemiptera	Gerridae	*Gerris remigis*	0	15	32	27	35	23	3	6	141	0.82
	Hemiptera	Vellidae	*Velia sp*	0	18	26	32	36	32	5	3	152	0.89
	Hemiptera	Belostomidae	*Belostoma sp.*	0	23	7	36	28	21	2	78	195	1.14
	Hemiptera	Nepidae	*Nepa sp.*	0	18	28	21	27	33	7	3	137	0.80
			Sub-total	0	85	140	193	207	168	18	209	1020	
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	15	0	10	28	14	23	25	0	115	0.67
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	189	0	0	22	3	29	22	9	274	1.60
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	76	0	2	19	26	31	34	7	195	1.14
	Ephemeroptera	Isonychiidae	*Isonychia arida*	112	0	8	21	23	19	23	9	215	1.26
	Ephemeroptera	Leptophlebiidae	*Leptophlebia* sp.	237	0	11	11	27	19	21	3	329	1.92
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	21	0	9	21	16	18	18	4	107	0.63
	Ephemeroptera	Potamanthidae	*Potamanthus* sp.	28	0	10	31	23	32	37	8	169	0.99
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	18	0	6	24	31	22	33	9	143	0.84
			Sub-total	696	0	52	177	161	193	213	55	1547	
	Trichoptera	Hydropsychidae	*Hydropsychids* sp.	22	0	2	34	31	36	24	7	156	0.91
			Sub-total	22	0	2	34	31	36	24	7	156	
	Odonata	Libelluidae	*Hemistigma* sp	14	36	30	27	31	31	19	8	196	1.15
	Odonata	Aeshnidae	*Helocordulia selysii*	27	35	23	19	21	25	17	3	170	0.99
	Odonata	Libelluidae	*Pantata flarescens*	10	21	28	27	29	22	29	4	170	0.99
	Odonata	Aeshnidae	*Ashna interrupta*	16	30	26	16	24	19	36	3	170	0.99
			Sub-total	67	122	107	89	105	97	101	18	706	

Diptera	Culicidae	*Aedes* sp.	17	22	38	25	0	23	26	0	151	0.88
Diptera	Culicidae	*Culex* sp.	35	23	16	37	16	21	31	32	211	1.23
		Sub-total	52	45	47	62	21	44	57	34	362	
Plecoptera	Perlidae	*Perlids* sp.	172	0	0	28	23	3	28	2	256	1.50
Plecoptera	Leuctridae	*Latelmis* sp.	103	0	20	21	0	28	34	19	225	1.31
		Sub-total	275	0	21	49	30	31	62	13	481	
Coleopteran	Gyrinidae	*Gyrinus* sp.	1	6	22	1	32	21	0	34	117	0.68
		Sub-total	1	6	22	1	32	21	0	34	117	
		Grand total	2514	1291	1724	2451	2494	2334	2313	1737	**16,858**	
		% Abundance	14.69	7.54	10.07	14.32	14.57	13.64	13.51	10.15		

Appendix 13. Checklist of Sediment macro-invertebrate abundance

Months	Orders	Families	*Genus and Species*	Numbers of sediment macroinvertebrates collected per stations							
				1	2	3	4	5	6	7	8
March	Hemiptera	Corixidae	*Hesperocorixa castanea*	-	+	+	+	+	+	+	+
	Hemiptera	Gerridae	*Gerris remigis*	-	+	+	+	+	+	+	+
	Hemiptera	Cicadellidae	*Lonatura megalopa*	-	+	+	+	+	+	+	+
	Hemiptera	Belostomidae	*Belostoma sp.*	-	+	+	+	+	+	+	+
	Hemiptera	Nepidae	*Nepa sp.*	-	+	+	+	+	+	+	+
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	+	-	+	+	+	+	+	+
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	+	-	+	+	+	+	+	+
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	+	-	+	+	+	+	+	+
	Ephemeroptera	Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	+	-	+	+	+	+	+	+
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	+	-	+	+	+	+	+	+
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	+	-	+	+	+	+	+	+
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+
	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	+	-	+	+	+	+	+	+
	Odonata	Libelluidae	*Hemistigma sp*	+	+	+	+	+	+	+	+
	Odonata	Aeshnidae	*Helocordulia selysii*	-	+	+	+	+	+	+	+
April	Odonata	Libelluidae	*Pantata flarescens*	-	+	+	+	+	+	+	+

	Odonata	Aeshn idea	*Ashna interrupta*	-	+	+	+	+	+	+	+
	Diptera	Culicidae	*Aedes sp.*	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Culex sp.*	+	+	+	+	+	+	+	+
	Plecoptera	Perlidae	*Perlids sp.*	+	-	-	+	+	+	+	+
	Plecoptera	Leuctridae	*Latelmis sp.*	+	-	+	+	+	+	+	+
	Coleoptera	Gyrinidae	*Gyrinus sp.*	+	+	+	+	+	+	+	+
	Hemiptera	Corixidae	*Hesperocorixa castanea*	+	-	+	+	+	+	+	+
	Hemiptera	Gerridae	*Gerris remigis*	-	+	+	+	+	+	+	+
	Hemiptera	Vellidae	*Velia sp*	-	+	+	+	+	+	+	+
	Hemiptera	Belostomidae	*Belostoma sp.*	-	+	+	+	+	+	+	+
	Hemiptera	Nepidae	*Nepa sp.*	-	+	+	+	+	-	+	+
May	Ephemeroptera	Epemerellidae	*Ephemerella doris*	-	+	+	+	+	+	+	+
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	+	-	+	+	+	+	+	+
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	+	-	+	+	+	-	+	+
	Ephemeroptera	Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	+-	-	+	+	+	+	+	+
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	+	-	+	+	+	+	+	+
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	+	+	+	+	+	+	+	+
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+
	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	+	-	+	+	+	+	+	+
	Odonata	Libelluidae	*Hemistigma sp*	-	+	+	+	+	+	+	+
	Odonata	Aeshnidae	*Helocordulia selysii*	-	+	+	+	+	+	+	+

	Odonata	Libelluidae	*Pantata flarescens*	-	+	+	+	+	+	+	+
June	Odonata	Aeshnidae	*Ashna interrupta*	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Aedes sp.*	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Culex sp.*	+	+	+	+	+	+	+	+
	Plecoptera	Perlidae	*Perlids sp.*	+	-	+	+	+	+	+	+
	Plecoptera	Leuctridae	*Latelmis sp.*	+	-	+	+	+	+	+	+
	Coleoptera	Gyrinidae	*Gyrinus sp.*	+	+	+	+	+	+	+	+
	Hemiptera	Corixidae	*Hesperocorixa castanea*	-	+	+	+	+	+	+	+
	Hemiptera	Gerridae	*Gerris remigis*	-	+	-	+	+	+	+	-
	Hemiptera	Vellidae	*Velia sp*	-	+	+	+	+	+	+	-
	Hemiptera	Belostomidae	*Belostoma sp.*	-	+	+	+	+	+	+	-
	Hemiptera	Nepidae	*Nepa sp.*	-	+	+	+	+	+	+	+
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	+	-	+	+	+	+	+	+
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	+	-	+	+	+	+	+	+
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	+	-	+	+	+	+	+	+
	Ephemeroptera	Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	+	-	-	+	+	+	+	+
	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	+	-	+	+	+	+	+	+
July	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	+	-	+	+	+	+	+-	+
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+
	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	+	-	+	+	+	+	+	+
	Odonata	Libelluidae	*Hemistigma sp*	+	+	+	+	+	+	+	+

	Odonata	Aeshnidae	*Helocordulia selysii*	+	+	+	+	+	+	+	+
	Odonata	Libelluidae	*Pantata flarescens*	+	+	+	+	+	+	+	+
	Odonata	Aeshnidae	*Ashna interrupta*	+	+	+	+	+	+	+	-
	Diptera	Culicidae	*Aedes* sp.	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Culex* sp.	+	+	+	+	+	+	+	+
			Sub-total	+	+	+	+	+	+	+	+
	Plecoptera	Perlidae	*Perlids* sp.	+	-	-	+	+	+	+	+
August	Plecoptera	Leuctridae	*Latelmis* sp.	+	-	+	+	+	+	+	+
	Coleopteran	Gyrinidae	*Gyrinus* sp.	+	+	+	+	+	+	+	+
	Hemiptera	Corixidae	*Hesperocorixa castanea*	-	+	+	+	+	+	+	+
	Hemiptera	Gerridae	*Gerris remigis*	-	+	+	+	+	+	+	+
	Hemiptera	Vellidae	*Velia* sp	-	+	+	+	+	+	+	+
	Hemiptera	Belostomidae	*Belostoma* sp.	-	+	+	+	+	+	+	+
	Hemiptera	Nepidae	*Nepa* sp.	-	+	+	+	+	+	+	+
	Ephemeroptera	Epemerellidae	*Ephemerella doris*	+	-	+	+	+	+	+	+
	Ephemeroptera	Ephemeridae	*Hexagenia limbata*	+	-	+	+	+	+	+	+
	Ephemeroptera	Heptageniidae	*Stenonema exiguum*	+	-	+	+	+	+	+	+
	Ephemeroptera	Isonychiidae	*Isonychia arida*	+	-	+	+	+	+	+	+
	Ephemeroptera	Leptophlebiidae	*Leptophlebia sp.*	+	-	+	+	+	+	+	+
September	Ephemeroptera	Polymitarcyidae	*Tortopus incertus*	+	-	+	+	+	+	+	+
	Ephemeroptera	Potamanthidae	*Potamanthus sp.*	+	-	+	+	+	+	+	+
	Ephemeroptera	Tricorythidae	*Tricorythodes albilineatus*	+	-	+	+	+	+	+	+

	Trichoptera	Hydropsychidae	*Hydropsychids sp.*	+	-	+	+	+	+	+	+
October	Odonata	Libelluidae	*Hemistigma sp*	+	+	+	+	+	+	+	+
	Odonata	Aeshnidae	*Helocordulia selysii*	+	+	+	+	+	+	+	+
	Odonata	Libelluidae	*Pantata flarescens*	+	+	+	+	+	+	+	+
	Odonata	Aeshnidae	*Ashna interrupta*	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Aedes sp.*	+	+	+	+	+	+	+	+
	Diptera	Culicidae	*Culex sp.*	+	+	-	+	+	+	+	+
	Plecoptera	Perlidae	*Perlids sp.*	+	-	+	+	+	+	+	+
	Plecoptera	Leuctridae	*Latelmis sp.*	+	-	+	+	+	+	+	+
	Coleopteran	Gyrinidae	*Gyrinus sp.*	+	+	+	+	+	+	+	+

Appendix 14. Monthly fish abundance (wet season)

Months	Families	Orders	Genus and Species	Numbers of fish collected per Station								Total	% Abundance
				1	2	3	4	5	6	7	8		
March	Clariidae	Siluriformes	*Clarias gariepinus*	123	78	391	319	156	232	190	56	1545	5.96
		Siluriformes	*C. anguillaris*	672	22	429	250	289	266	521	32	2481	9.58
		Siluriformes	*Heterobranchus bidorsalis*	56	128	114	144	184	154	174	45	999	3.86
			Sub-total	851	228	934	713	629	652	885	133	5025	
	Centropomidae	Ophiocephaliformes	*Lates niloticus*	98	33	0	54	31	50	43	67	376	1.45
	Channidae	Ophiocephaliformes	*Parachanna africana*	453	0	11	41	343	99	75	237	1259	4.86
		Ophiocephaliformes	*P. obscura*	213	69	56	50	39	26	97	120	670	2.59
			Sub-total	764	102	67	145	413	175	215	424	2305	
	Cichlidae	Perciformes	*Coptodon zilli*	189	74	3	0	498	561	574	178	2077	8.02
		Perciformes	*Oreochromis niloticus*	235	76	0	433	54	87	54	165	1104	4.26
April		Perciformes	*Hemichromis fasciatus*	207	69	0	87	147	192	301	100	1103	4.26
			Sub-total	631	219	3	520	699	840	929	443	4284	
	Protopteridae	Lepidosereniformes	*Protopterus annectens*	113	26	13	31	118	233	245	120	899	3.47
			Sub-total	113	26	13	31	118	233	245	120	899	
	Osteoglossidae	Osteoglossiformes	*Heterotis niloticus*	198	108	23	111	30	170	91	378	1109	4.28
			Sub-total	198	108	23	111	30	170	91	378	1109	
May	Pantodontidae		*Pantodon bucholzi*	245	16	0	34	27	117	3	150	592	2.29
			Sub-total	245	16	0	34	27	117	3	150	592	
	Notopteridae		*Papyrocranus afer*	383	23	5	5	7	3	3	174	603	2.33
			Xenomystus nigri	19	2	13	6	3	0	17	47	107	0.41
			Sub-total	402	25	18	7	10	7	20	221	710	

	Clariidae	Siluriformes	*Clarias gariepinus*	18	7	63	9	5	9	413	211	735	2.84
			C. anguillaris	21	59	156	45	88	79	1110	141	1699	6.56
June			*Heterobranchus bidorsalis*	156	4	134	3	6	0	9	34	346	1.34
			Sub-total	195	70	353	57	99	95	1525	386	2780	
	Cichlidae	Perciformes	*Tilapia guineensis*	108	8	121	3	9	6	4	67	326	1.26
			Sub-total	108	8	121	3	9	6	4	67	326	
	Anabantidae		*Ctenopoma kingsleyae*	77	0	0	19	76	68	0	53	293	1.13
			Sub-total	77	0	0	19	76	68	0	53	293	
July	Mochokidae	Siluriformes	*Synodontis clarias*	123	67	21	49	83	87	109	78	617	2.38
			Hemisynodontis membranaceous	45	60	12	59	83	58	73	140	530	2.05
			Sub-total	168	127	33	108	166	145	182	218	1147	
	Clariidae		*Clarias gariepinus*	78	70	65	97	76	86	88	57	617	2.38
			C. anguillaris	56	105	59	101	301	99	204	35	960	3.71
			Heterobranchus bidorsalis	95	45	23	42	17	36	65	137	460	1.78
			Sub-total	229	220	147	240	394	221	357	229	2037	
August	Malapteruridae		*Malapterurus electricus*	46	0	0	0	6	11	10	0	76	0.29
			Sub-total	46	0	0	0	6	11	10	0	76	
	Bagridae		*Bagrus filamentosus*	53	1	62	7	4	3	9	87	226	0.87
			Sub-total	53	1	62	7	4	3	9	87	226	
	Ariidae		*Arius gigas*	34	8	2	9	8	5	9	118	193	0.75
			Sub-total	34	8	2	9	8	5	9	118	193	
	Ichthyboridae	Characiformes	*Phago loricatus*	76	0	0	0	4	2	4	197	283	1.09
			Sub-total	76	0	0	0	4	2	4	197	283	
September	Mastacembelidae	Mastacembeliformes	*Mastacembelus loennbergii*	39	0	0	0	0	0	4	56	99	0.38

			Sub-total	39	0	0	0	0	0	4	56	99	
	Cichlidae	Perciformes	*Oreochromis aureus*	45	7	23	8	4	2	9	181	279	1.08
			Sub-total	45	7	23	8	4	2	9	181	279	
	Mormyridae	Mormyriformes	*Gnathonemus petersii*	86	14	4	16	21	13	26	69	249	0.96
			G. deboensis	85	43	6	8	2	1	0	103	248	0.96
			G. niger	19	45	0	2	9	6	10	143	234	0.90
October			*G. senegalensis*	6	0	0	0	0	0	4	142	152	0.59
			G. cyprinoides	34	5	0	0	4	9	7	271	330	1.27
			G. tamadua	90	12	41	11	18	25	21	57	275	1.06
			Sub-total	320	119	51	37	54	54	68	785	1488	
	Clariidae	Siluriformes	*C. gariepinus*	38	23	987	26	9	8	4	67	1162	4.49
			Sub-total	38	23	987	26	9	8	4	67	1162	
	Cichlidae		*Sarotherodon galilaeus*	98	38	110	85	43	23	12	51	460	1.78
			Sub-total	98	38	110	85	43	23	12	51	460	
	Polyteridae	Polypteriformes	*Calamoichthys calabaricus*	20	2	3	1	7	4	3	57	97	0.37
			Sub-total	20	2	3	1	7	4	3	57	97	
			Total	4751	1349	2953	2165	2811	2838	4587	4452	25906	
			% Abundance	18.34	5.21	11.40	8.36	10.85	10.95	17.71	17.19		

Appendix 15. Monthly fish abundance (dry season)

Months	Families	Orders	Genus and Species	Numbers of fish collected per Station								Total	% Abundance
				1	2	3	4	5	6	7	8		
November	Clariidae	Siluriformes	*C. gariepinus*	23	34	101	21	20	25	19	28	271	7.89
			H. bidorsalis	45	23	1	53	29	61	66	14	292	8.50
			Sub-total	68	57	102	74	49	86	85	42	563	
	Phractolaemidae	Gonorynchiformes	*Phractolaemus ansorgei*	49	6	0	5	8	4	3	17	92	2.68
			Sub-total	49	6	0	5	8	4	3	17	92	
	Cichlidae	Perciformes	*Coptodon zilli*	43	9	11	6	23	17	7	25	141	4.11
			Oreochromis niloticus	34	7	0	21	27	31	8	12	140	4.08
			Sub-total	77	16	11	27	50	48	15	37	281	
	Schilbeidae	Siluriformes	*Schilbe uronoscopus*	31	7	32	5	4	0	2	10	91	2.65
			Siluranodon auritus	44	5	2	0	0	0	0	27	78	2.27
			Sub-total	75	12	34	5	4	0	2	37	169	
December	Polyteridae	Polypteriformes	*Calamoichthys calabaricus*	36	0	0	0	0	7	1	65	109	3.17
			Sub-total	36	0	0	0	0	7	1	65	109	
	Clariidae	Siluriformes	*C. gariepinus*	34	8	45	9	7	4	9	23	139	4.05
			Sub-total	34	8	45	9	7	4	9	23	139	
	Hepsetidae	Gonorynchiformes	*Hepsetus odoe*	55	1	10	2	6	5	3	15	97	2.82
			Sub-total	55	1	123	2	6	5	3	15	210	
January	Malapteruridae	Siluriformes	*Malapterurus electricus*	56	4	3	9	2	12	6	39	131	3.81

			Sub-total	56	4	3	26	33	42	59	39	262	
	Cichlidae	Perciformes	*C. zilli*	12	25	13	9	7	12	11	23	112	3.26
			Sub-total	12	25	13	9	7	12	11	23	112	
	Clariidae	Siluriformes	*C. gariepinus*	33	23	15	45	25	23	42	26	232	6.76
			Sub-total	33	23	15	45	25	23	42	26	232	
	Schilbeidae	Siluriformes	*Schilbe uronoscopus*	13	0	0	0	5	2	4	21	45	1.31
			Sub-total	13	0	0	0	5	2	4	21	45	
February	Cichlidae	Perciformes	*C. zilli*	39	6	0	0	54	16	13	15	143	4.16
			Sub-total	39	6	0	0	54	16	13	15	143	
	Clariidae	Siluriformes	*C. gariepinus*	18	41	19	57	8	7	11	35	196	5.71
			Sub-total	18	41	19	57	8	7	11	35	196	
	Malapteruridae	Siluriformes	*Malapterurus electricus*	57	2	0	6	2	1	9	26	103	3.00
			Sub-total	57	2	0	6	2	1	9	26	103	
	Polyteridae	Polypteriformes	*Calamoichthys calabaricus*	41	1	0	4	7	5	4	17	79	2.30
			Sub-total	41	1	0	4	7	5	4	17	79	
	Channidae	Ophiocephaliformes	*Parachanna africana*	29	27	21	6	1	0	4	45	135	3.93
			P. obscura	12	18	7	4	3	29	31	9	113	3.29
			Sub-total	41	45	28	10	4	29	35	54	248	
			Total	620	294	156	297	259	248	323	512	2709	
			% Abundance	18.05	8.56	4.54	8.65	7.54	7.22	9.41	14.91		

Appendix 16. Monthly checklist fish species of Gbalegbe River, Delta State (wet season)

Months	Families	Orders	Genus and Species	Numbers of fish collected per Station							
				1	2	3	4	5	6	7	8
March	Clariidae	Siluriformes	*Clarias gariepinus*	+	+	+	+	+	+	+	+
		Siluriformes	*C. anguillaris*	+	+	+	+	+	+	+	+
		Siluriformes	*Heterobranchus bidorsalis*	+	+	+	+	+	+	+	+
	Centropomidae	Ophiocephaliformes	*Lates niloticus*	+	+	-	+	+	+	+	+
	Channidae	Ophiocephaliformes	*Parachanna africana*	+	-	+	+	+	+	+	+
		Ophiocephaliformes	*P. obscura*	+	+	+	+	+	+	+	+
	Cichlidae	Perciformes	*C. zilli*	+	+	+	-	+	+	+	+
April		Perciformes	*Oreochromis niloticus*	+	+	-	+	+	+	+	+
		Perciformes	*Hemichromis fasciatus*	+	+	-	+	+	+	+	+-
	Protopteridae	Lepidosereniformes	*Protopterus annectens*	+	+	+	+	+	+	+	+
	Osteoglossidae	Osteoglossiformes	*Heterotis niloticus*	+	+	+	+	+	+	+	+
	Pantodontidae		*Pantodon bucholzi*	+	+	-	+	+	+	+	+
May	Notopteridae		*Papyrocranus afer*	+	+	+	+	+	+	+	+
			Xenomystus nigri	+	+	+	+	+	-	+	+
	Clariidae	Siluriformes	*Clarias gariepinus*	+	+	+	+	+	+	+	+
			C. anguillaris	+	+	+	+	+	+	+	+
			Heterobranchus bidorsalis	+	+	+	+	+	-	+	+
June	Cichlidae	Perciformes	*Tilapia guineensis*	+	+	+	+	+	+	+	+
	Anabantidae		*Ctenopoma*	+	-	-	+	+	+	-	+

			kingsleyae								
	Mochokidae	Siluriformes	*Synodontis clarias*	+	+	+	+	+	+	+	+
			Hemisynodontis membranaceous	+	+	+	+	+	+	+	+
	Clariidae		*Clarias gariepinus*	+	+	+	+	+	+	+	+
			C. anguillaris	+	+	+	+	+	+	+	+
July			*Heterobranchus bidorsalis*	+	+	+	+	+	+	+	+
	Malapteruridae		*Malapterurus electricus*	+	-	-	-	+	+	+	-
	Bagridae		*Bagrus filamentosus*	+	+	+	+	+	+	+	+
	Ariidae		*Arius gigas*	+	+	+	+	+	+	+	+
August	Ichthyboridae	Characiformes	*Phago loricatus*	+	-	-	-	+	+	+	+
	Mastacembelidae	Mastacembeliformes	*Mastacembelus loennbergii*	+	-	-	-	-	-	+	+
	Nandidae	Perciformes	*Oreochromis aureus*	+	+	+	+	+	+	+	+
	Mormyridae	Mormyriformes	*Gnathonemus petersii*	+	+	+	+	+	+	+	+
September			*G. deboensis*	+	+	+	+	+	+	-	+
			G. niger	+	+	-	+	+	+	+	+
			G. senegalensis	+	-	-	-	-	-	+	+
			G. cyprinoides	+	+	-	-	+	+	+	+
October			*G. tamadua*	+	+	+	+	+	+	+	+
	Clariidae	Siluriformes	*C. gariepinus*	+	+	+	+	+	+	+	+
	Cichlidae		*Sarotherodon galilaeus*	+	+	+	+	+	+	+	+
	Polyteridae	Polypteriformes	*Calamoichthys calabaricus*	+	+	+	+	+	+	+	+

Appendix 17. Checklist of fish species abundance of Gbalegbe River, Delta State (dry season)

Months	Families	Orders	Genus and Species	Numbers of fish collected per Station							
				1	2	3	4	5	6	7	8
November	Clariidae	Siluriformes	*C. gariepinus*	+	+	+	+	+	+	+	+
			H. bidorsalis	+	+	+	+	+	+	+	+
	Phractolaemidae	Gonorynchiformes	*Phractolaemus ansorgei*	+	+	-	+	+	+	+	+
	Cichlidae	Perciformes	*Coptodon zilli*	+	+	+	+	+	+	+	+
			Oreochromis niloticus	+	+	-	+	+	+	+	+
	Schilbeidae	Siluriformes	*Schilbe uronoscopus*	+	+	+	+	+	-	+	+
			Siluranodon auritus	+	+	+	-	-	-	-	+
December	Polyteridae	Polypteriformes	Calamoichthys calabaricus	+	-	-	-	-	+	+	+
	Clariidae	Siluriformes	*C. gariepinus*	+	+	+	+	+	+	+	+
	Hepsetidae	Gonorynchiformes	*Hepsetus odoe*	+	+	+	+	+	+	+	+
January	Malapteruridae	Siluriformes	*Malapterurus electricus*	+	+	+	+	+	+	+	+
	Cichlidae	Perciformes	*C. zilli*	+	+	+	+	+	+	+	+
	Clariidae	Siluriformes	*C. gariepinus*	+	+	+	+	+	+	+	+
	Schilbeidae	Siluriformes	*Schilbe uronoscopus*	+	-	-	-	+	+	+	+
February	Cichlidae	Perciformes	*C. zilli*	+	+	-	-	+	+	+	+
	Clariidae	Siluriformes	*C. gariepinus*	+	+	+	+	+	+	+	+
	Malapteruridae	Siluriformes	*Malapterurus electricus*	+	+	-	+	+	+	+	+
	Polyteridae	Polypteriformes	*Calamoichthys calabaricus*	+	+	-	+	+	+	+	+
	Channidae	Ophiocephaliformes	*Parachanna africana*	+	+	+	+	+	-	+	+
			P. obscura	+	+	+	+	+	+	+	+

APpendix 18: ANOVA of heavy metal concentrations in water at different stations along Gbalegbe River

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	1.614	8	0.202	13.389	0.076
	Within Groups	7.581	503	0.015		
	Total	9.196	511			
Pb	Between Groups	1.593	8	0.199	13.197	0.16
	Within Groups	7.589	503	0.015		
	Total	9.182	511			
Ni	Between Groups	1.589	8	0.199	12.868	0.43
	Within Groups	7.764	503	0.015		
	Total	9.353	511			
Cd	Between Groups	1.604	8	0.2	13.052	0.32
	Within Groups	7.726	503	0.015		
	Total	9.33	511			
Fe	Between Groups	1.787	8	0.223	14.42	0.11
	Within Groups	7.793	503	0.015		
	Total	9.58	511			
Zn	Between Groups	0.075	8	0.009	0.508	0.851
	Within Groups	9.24	503	0.018		
	Total	9.315	511			
Mn	Between Groups	0.096	8	0.012	0.666	0.022
	Within Groups	9.046	503	0.018		
	Total	9.142	511			
Cr	Between Groups	0.136	8	0.017	0.879	0.534
	Within Groups	9.722	503	0.019		
	Total	9.858	511			

Appendix 19.ANOVA of heavy metal concentrations of Gbalegbe River at different seasons

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	2.876	4	0.719	57.684	0.00
	Within Groups	6.32	507	0.012		
	Total	9.196	511			
Pb	Between Groups	2.729	4	0.682	53.617	0.00
	Within Groups	6.452	507	0.013		
	Total	9.182	511			
Ni	Between Groups	2.813	4	0.703	54.525	0.00
	Within Groups	6.54	507	0.013		
	Total	9.353	511			
Cd	Between Groups	2.745	4	0.686	52.845	0.00
	Within Groups	6.585	507	0.013		
	Total	9.33	511			
Fe	Between Groups	3.32	4	0.83	67.218	0.00
	Within Groups	6.26	507	0.012		
	Total	9.58	511			
Zn	Between Groups	1.104	4	0.276	17.038	0.00
	Within Groups	8.211	507	0.016		
	Total	9.315	511			
Mn	Between Groups	1.259	4	0.315	20.248	0.00
	Within Groups	7.882	507	0.016		
	Total	9.142	511			
Cr	Between Groups	1.372	4	0.343	20.497	0.00
	Within Groups	8.485	507	0.017		
	Total	9.858	511			

Appendix 20: ANOVA of heavy metal concentrations in *C. gariepinus* at different stations along Gbalegbe River

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	1.588	2	0.794	53.103	0.00
	Within Groups	7.608	509	0.015		
	Total	9.196	511			
Pb	Between Groups	1.586	2	0.793	53.135	0.00
	Within Groups	7.596	509	0.015		
	Total	9.182	511			
Ni	Between Groups	1.586	2	0.793	51.969	0.00
	Within Groups	7.767	509	0.015		
	Total	9.353	511			
Cd	Between Groups	1.604	2	0.802	52.835	0.00
	Within Groups	7.726	509	0.015		
	Total	9.33	511			
Fe	Between Groups	1.77	2	0.885	57.659	0.00
	Within Groups	7.811	509	0.015		
	Total	9.58	511			
Zn	Between Groups	0.012	2	0.006	0.318	0.028
	Within Groups	9.303	509	0.018		
	Total	9.315	511			
Mn	Between Groups	0.01	2	0.005	0.268	0.025
	Within Groups	9.132	509	0.018		
	Total	9.142	511			
Cr	Between Groups	0.04	2	0.02	1.039	0.035
	Within Groups	9.818	509	0.019		
	Total	9.858	511			

Appendix 21: ANOVA of heavy metal concentrations in *C. gariepinus* from Gbalegbe River at different seasons

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	5.683	8	0.71	101.698	0.065
	Within Groups	3.513	503	0.007		
	Total	9.196	511			
Pb	Between Groups	5.78	8	0.723	106.838	0.550
	Within Groups	3.402	503	0.007		
	Total	9.182	511			
Ni	Between Groups	5.696	8	0.712	97.925	0.18
	Within Groups	3.657	503	0.007		
	Total	9.353	511			
Cd	Between Groups	5.74	8	0.717	100.533	0.69
	Within Groups	3.59	503	0.007		
	Total	9.33	511			
Fe	Between Groups	6.041	8	0.755	107.348	0.12
	Within Groups	3.539	503	0.007		
	Total	9.58	511			
Zn	Between Groups	4.201	8	0.525	51.642	0.37
	Within Groups	5.114	503	0.01		
	Total	9.315	511			
Mn	Between Groups	4.258	8	0.532	54.827	0.082
	Within Groups	4.883	503	0.01		
	Total	9.142	511			
Cr	Between Groups	3.954	8	0.494	42.105	0.278
	Within Groups	5.904	503	0.012		
	Total	9.858	511			

Appendix 22: ANOVA of heavy metal concentrations in sediment at different stations along Gbalegbe River.

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	2.181	4	0.545	39.401	0.00
	Within Groups	7.015	507	0.014		
	Total	9.196	511			
Pb	Between Groups	2.028	4	0.507	35.94	0.076
	Within Groups	7.154	507	0.014		
	Total	9.182	511			
Ni	Between Groups	2.223	4	0.556	39.521	0.00
	Within Groups	7.13	507	0.014		
	Total	9.353	511			
Cd	Between Groups	2.213	4	0.553	39.407	0.372
	Within Groups	7.117	507	0.014		
	Total	9.33	511			
Fe	Between Groups	2.206	4	0.551	37.916	0.02
	Within Groups	7.374	507	0.015		
	Total	9.58	511			
Zn	Between Groups	0.32	4	0.08	4.505	0.094
	Within Groups	8.995	507	0.018		
	Total	9.315	511			
Mn	Between Groups	0.403	4	0.101	5.843	0.00
	Within Groups	8.739	507	0.017		
	Total	9.142	511			
Cr	Between Groups	0.229	4	0.057	3.009	0.018
	Within Groups	9.629	507	0.019		
	Total	9.858	511			

Appendix 23: ANOVA of heavy metal concentrations in sediment of Gbalegbe River at different seasons

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	0.029	7	0.004	0.261	0.968
	Within Groups	8.006	504	0.016		
	Total	8.035	511			
Pb	Between Groups	0.009	7	0.001	0.085	0.999
	Within Groups	7.767	504	0.015		
	Total	7.777	511			
Ni	Between Groups	0.013	7	0.002	0.111	0.048
	Within Groups	8.478	504	0.017		
	Total	8.491	511			
Cd	Between Groups	0.016	7	0.002	0.14	0.995
	Within Groups	8.322	504	0.017		
	Total	8.338	511			
Fe	Between Groups	0.024	7	0.003	0.217	0.982
	Within Groups	8.11	504	0.016		
	Total	8.135	511			
Zn	Between Groups	0.006	7	0.001	0.053	1.00
	Within Groups	8.441	504	0.017		
	Total	8.447	511			
Mn	Between Groups	0.021	7	0.003	0.183	0.989
	Within Groups	8.224	504	0.016		
	Total	8.245	511			
Cr	Between Groups	0.027	7	0.004	0.247	0.973
	Within Groups	7.941	504	0.016		
	Total	7.969	511			

Appendix 24.ANOVA of sediment composition at different stations along Gbalegbe River

				Sum of Squares	df	Mean Square	F	Sig.
EC	Between Groups	(Combined)		14435	1	14435	8.322	0.005
		Linear Term	Contrast	14435	1	14435	8.322	0.005
	Within Groups			218567	126	1734.659		
	Total			233002	127			
OC	Between Groups	(Combined)		17.942	1	17.942	3.072	0.082
		Linear Term	Contrast	17.942	1	17.942	3.072	0.082
	Within Groups			735.991	126	5.841		
	Total			753.933	127			
TN	Between Groups	(Combined)		880.636	1	880.636	0.709	0.401
		Linear Term	Contrast	880.636	1	880.636	0.709	0.401
	Within Groups			156501.8	126	1242.078		
	Total			157382.4	127			
AP	Between Groups	(Combined)		1053.405	1	1053.405	5.063	0.026
		Linear Term	Contrast	1053.405	1	1053.405	5.063	0.026
	Within Groups			26216.06	126	208.064		
	Total			27269.47	127			

K	Between Groups	(Combined)		338.13	1	338.13	0.878	0.351
		Linear Term	Contrast	338.13	1	338.13	0.878	0.351
	Within Groups			48537.96	126	385.222		
	Total			48876.09	127			
Na	Between Groups	(Combined)		499.32	1	499.32	15.803	0
		Linear Term	Contrast	499.32	1	499.32	15.803	0
	Within Groups			3981.263	126	31.597		
	Total			4480.582	127			
Ca	Between Groups	(Combined)		426.174	1	426.174	3.649	0.058
		Linear Term	Contrast	426.174	1	426.174	3.649	0.058
	Within Groups			14716.1	126	116.794		
	Total			15142.28	127			
Mg	Between Groups	(Combined)		285.276	1	285.276	6.509	0.012
		Linear Term	Contrast	285.276	1	285.276	6.509	0.012
	Within Groups			5522.396	126	43.829		
	Total			5807.673	127			
pH	Between Groups	(Combined)		9.99	1	9.99	6.981	0.009

		Linear Term	Contrast	9.99	1	9.99	6.981	0.009
	Within Groups			180.33	126	1.431		
	Total			190.321	127			
EA	Between Groups	(Combined)		7.976	1	7.976	2.22	0.139
		Linear Term	Contrast	7.976	1	7.976	2.22	0.139
	Within Groups			452.735	126	3.593		
	Total			460.711	127			
CEC	Between Groups	(Combined)		7959.277	1	7959.277	6.639	0.011
		Linear Term	Contrast	7959.277	1	7959.277	6.639	0.011
	Within Groups			151053.9	126	1198.84		
	Total			159013.2	127			

Appendix 25.ANOVA of sediment composition of Gbalegbe River at different seasons

				Sum of Squares	df	Mean Square	F	Sig.
EC	Between Groups	(Combined)		68437.53	3	22812.51	17.189	0.00
		Linear Term	Contrast	8544.996	1	8544.996	6.439	0.012
			Deviation	59892.53	2	29946.27	22.565	0.00
	Within Groups			164564.5	124	1327.133		
	Total			233002	127			
OC	Between Groups	(Combined)		47.555	3	15.852	2.783	0.044
		Linear Term	Contrast	47.242	1	47.242	8.293	0.005
			Deviation	0.313	2	0.157	0.027	0.973
	Within Groups			706.377	124	5.697		
	Total			753.933	127			
TN	Between Groups	(Combined)		17465.96	3	5821.985	5.16	0.002
		Linear Term	Contrast	3117.343	1	3117.343	2.763	0.099
			Deviation	14348.61	2	7174.306	6.358	0.002
	Within Groups			139916.5	124	1128.359		
	Total			157382.4	127			
AP	Between Groups	(Combined)		3027.33	3	1009.11	5.162	0.002

		Linear Term	Contrast	2773.141	1	2773.141	14.185	0.00
			Deviation	254.19	2	127.095	0.65	0.524
	Within Groups			24242.14	124	195.501		
	Total			27269.47	127			
Mg	Between Groups	(Combined)		87.828	3	29.276	0.635	0.594
		Linear Term	Contrast	32.883	1	32.883	0.713	0.40
			Deviation	54.945	2	27.473	0.596	0.553
	Within Groups			5719.844	124	46.128		
	Total			5807.673	127			
Na	Between Groups	(Combined)		351.662	3	117.221	3.52	0.017
		Linear Term	Contrast	0.375	1	0.375	0.011	0.916
			Deviation	351.287	2	175.644	5.275	0.006
	Within Groups			4128.92	124	33.298		
	Total			4480.582	127			
Ca	Between Groups	(Combined)		1246.879	3	415.626	3.709	0.013
		Linear Term	Contrast	100.156	1	100.156	0.894	0.346
			Deviation	1146.723	2	573.362	5.117	0.007

	Within Groups			13895.4	124	112.06		
	Total			15142.28	127			
K	Between Groups	(Combined)		761.239	3	253.746	0.654	0.582
		Linear Term	Contrast	82.226	1	82.226	0.212	0.646
			Deviation	679.014	2	339.507	0.875	0.419
	Within Groups			48114.85	124	388.023		
	Total			48876.09	127			
pH	Between Groups	(Combined)		2.043	3	0.681	0.449	0.719
		Linear Term	Contrast	0.992	1	0.992	0.653	0.42
			Deviation	1.051	2	0.525	0.346	0.708
	Within Groups			188.277	124	1.518		
	Total			190.321	127			
EA	Between Groups	(Combined)		93.631	3	31.21	10.543	0.00
		Linear Term	Contrast	12.53	1	12.53	4.233	0.042
			Deviation	81.101	2	40.55	13.698	0.00
	Within Groups			367.08	124	2.96		
	Total			460.711	127			
CEC	Between Groups	(Combined)		7767.98	3	2589.327	2.123	0.101
		Linear	Contrast	19.548	1	19.548	0.016	0.899

Term						
	Deviation	7748.432	2	3874.216	3.176	0.045
Within Groups		151245.2	124	1219.719		
Total		159013.2	127			

Appendix 26: ANOVA of heavy metal concentrations in *H. castanea* at different stations along Gbalegbe River

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	3.179	3	1.06	110.887	0.05
	Within Groups	4.855	508	0.01		
	Total	8.035	511			
Pb	Between Groups	3.18	3	1.06	117.144	0.89
	Within Groups	4.597	508	0.009		
	Total	7.777	511			
Ni	Between Groups	2.847	3	0.949	85.431	0.00
	Within Groups	5.644	508	0.011		
	Total	8.491	511			
Cd	Between Groups	3.258	3	1.086	108.611	0.083
	Within Groups	5.08	508	0.01		
	Total	8.338	511			
Fe	Between Groups	2.424	3	0.808	71.895	0.06
	Within Groups	5.71	508	0.011		
	Total	8.135	511			
Zn	Between Groups	3.202	3	1.067	103.355	0.078
	Within Groups	5.245	508	0.01		
	Total	8.447	511			
Mn	Between Groups	3.101	3	1.034	102.114	0.05
	Within Groups	5.143	508	0.01		
	Total	8.245	511			
Cr	Between Groups	2.541	3	0.847	79.288	0.09
	Within Groups	5.427	508	0.011		
	Total	7.969	511			

Appendix 27: ANOVA of heavy metal concentrations in *H. castanea* at different seasons along Gbalegbe River

		Sum of Squares	df	Mean Square	F	Sig.
Cu	Between Groups	0.344	3	0.115	7.584	0.54
	Within Groups	7.69	508	0.015		
	Total	8.035	511			
Pb	Between Groups	0.304	3	0.101	6.884	0.13
	Within Groups	7.473	508	0.015		
	Total	7.777	511			
Ni	Between Groups	0.397	3	0.132	8.313	0.86
	Within Groups	8.094	508	0.016		
	Total	8.491	511			
Cd	Between Groups	0.372	3	0.124	7.917	0.25
	Within Groups	7.966	508	0.016		
	Total	8.338	511			
Fe	Between Groups	0.27	3	0.09	5.803	0.71
	Within Groups	7.865	508	0.015		
	Total	8.135	511			
Zn	Between Groups	0.442	3	0.147	9.344	0.09
	Within Groups	8.005	508	0.016		
	Total	8.447	511			
Mn	Between Groups	0.473	3	0.158	10.299	0.52
	Within Groups	7.772	508	0.015		
	Total	8.245	511			
Cr	Between Groups	0.162	3	0.054	3.523	0.45
	Within Groups	7.806	508	0.015		
	Total	7.969	511			

Appendix 28: ANOVA of TPH concentrations in biota of Gbalegbe River at different stations

				Sum of Squares	df	Mean Square	F	Sig.
TPHWATER	Between Groups	(Combined)		102.789	7	14.684	3.096	0.45
		Linear Term	Contrast	0.251	1	0.251	0.053	0.818
			Deviation	102.538	6	17.09	3.604	0.003
	Within Groups			569.098	120	4.742		
	Total			671.887	127			
TPHFISH	Between Groups	(Combined)		0.444	7	0.063	1.241	0.286
		Linear Term	Contrast	0.183	1	0.183	3.581	0.061
			Deviation	0.261	6	0.043	0.851	0.533
	Within Groups			6.128	120	0.051		
	Total			6.572	127			
TPHSEDIMT	Between Groups	(Combined)		0.576	7	0.082	1.066	0.389
		Linear Term	Contrast	0.144	1	0.144	1.866	0.175
			Deviation	0.432	6	0.072	0.933	0.474
	Within Groups			9.266	120	0.077		
	Total			9.843	127			
TPHINVERTB	Between Groups	(Combined)		0.052	7	0.007	0.305	0.045
		Linear Term	Contrast	0.003	1	0.003	0.123	0.726
			Deviation	0.049	6	0.008	0.336	0.917
	Within Groups			2.914	120	0.024		
	Total			2.966	127			

Appendix 29: ANOVA of TPH concentrations in biota of Gbalegbe River at different seasons

				Sum of Squares	df	Mean Square	F	Sig.
TPHWATER	Between Groups	(Combined)		186.047	1	186.047	48.25	0.53
		Linear Term	Contrast	186.047	1	186.047	48.25	0.12
	Within Groups			485.84	126	3.856		
	Total			671.887	127			
TPHFISH	Between Groups	(Combined)		0.014	1	0.014	0.261	0.04
		Linear Term	Contrast	0.014	1	0.014	0.261	0.61
	Within Groups			6.558	126	0.052		
	Total			6.572	127			
TPHSEDIMT	Between Groups	(Combined)		2.299	1	2.299	38.403	0.00
		Linear Term	Contrast	2.299	1	2.299	38.403	0.04
	Within Groups			7.544	126	0.06		
	Total			9.843	127			
TPHINVERTB	Between Groups	(Combined)		0.036	1	0.036	1.543	0.22
		Linear Term	Contrast	0.036	1	0.036	1.543	0.22
	Within Groups			2.93	126	0.023		
	Total			2.966	127			