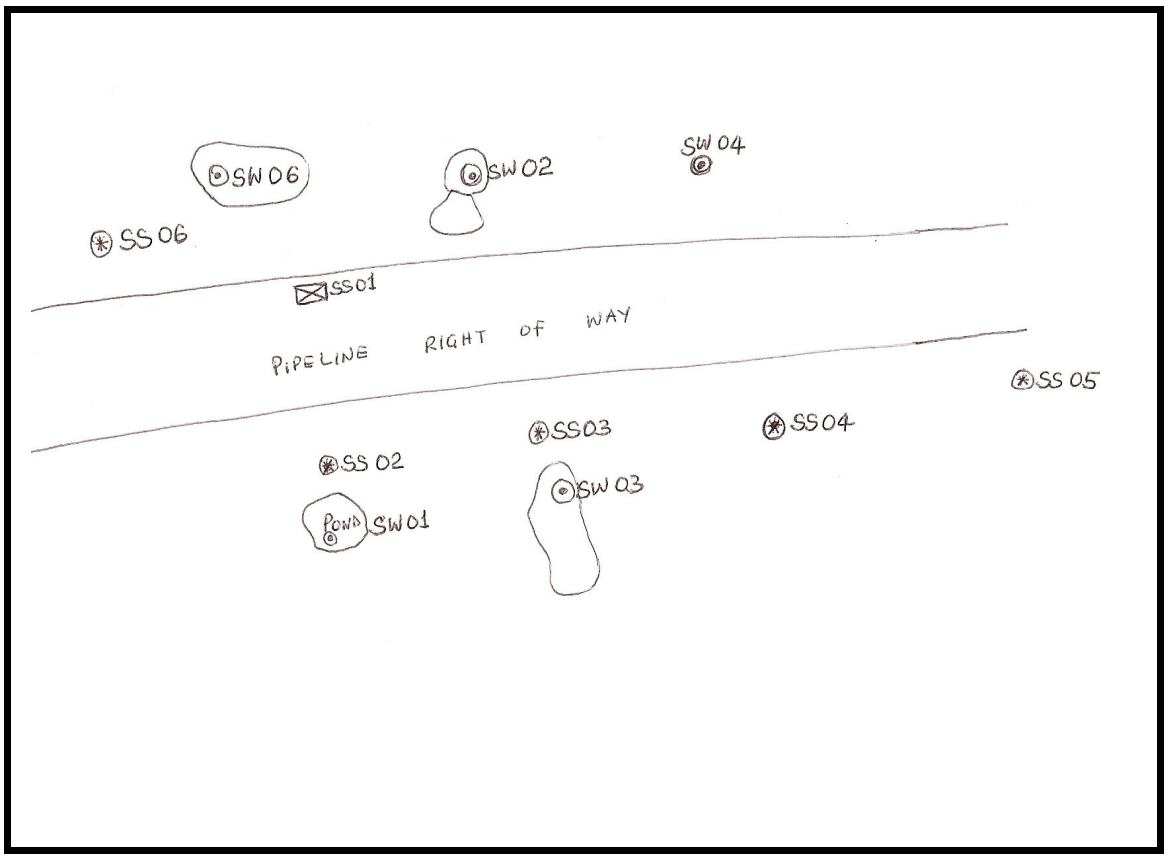
THE FEDERAL REPUBLIC OF NIGERIA

POST IMPACT ASSESSMENT STUDY OF THE OIL SPILLAGE IN ORUMA, BAYELSA STATE

REPORT



By

BRYJARK ENVIRONMENTAL SERVICES LIMITED
PORT HARCOURT, NIGERIA

February 2008

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POST IMPACT ASSESSMENT STUDY OF THE OIL SPILLAGE IN ORUMA, BAYELSA STATE

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In June 2005 there was an oil spill in Oruma, now called Yiba – Ama, along a Shell Petroleum Development Company of Nigeria (SPDC) pipeline route at Olumogbogbo-Gbara, where pipelines cross farmlands. The site is located in a gallopy fresh water swamp forest. The oil spill occurred in the wet season. The flood of the wet season therefore aided the spread of the oil further into the forest. Aquatic life in several fish ponds died. During the cleaning up operations some of the recovered oil was incinerated in open dumps in the forest. The flames and the heat generated from the cleaning up activities also burnt the forest and farm resources in the area, leading to huge economic losses.

Concerned with the need to establish economical damage caused by the spill, Environmental Rights Action (ERA) commissioned a team of Scientists Bryjark Environmental Services Limited, Nigeria to carry out post impact assessment studies of the oil spillage.

The main objectives of the study include:
- establishing the existing quality of surface water within the study area;
- obtaining scientific identification, qualification and characterization of existing micro and macro flora and fauna;
- establishing existing soil quality, identifying vegetation and assessing diseases and state of plant health within the study area;
- assessing the environmental impact of the spillage;
- making necessary recommendations on the remediation of the area.

The objectives were achieved through detailed field and laboratory studies in June 2007, using standard acceptable international methods.

The study has shown that the Oruma study area is impacted by hydrocarbon from either the spill source or previous incidents of existing SPDC-activities in the area.

Since the post impact assessment study has been undertaken twenty four months after the spill, there has been a significant decrease in the hydrocarbon concentration especially in the surface water based on the relatively dynamic nature of the water system in the area. However, the concentration range of 0.17 – 1.35 milligram/liter of Total Petroleum Hydrocarbon (TPH) recorded in the surface water can exert negative impact on the resources of the area and the recruitment potential of the system.

The study also showed high levels of hydrocarbon retained in sediments and soils of the area. This is partly responsible for the stress observed in the ecology of the environment. This is based on the results of field observation, epipelic algae (algae that grow on the surface of intertidal mudflats or substrates) and benthos (sediment organisms) where the presence of oil appears to have affected the abundance and distribution of the organisms.

In Oruma, the clean up operations also involved burning of recovered oil in open dumps within the vicinity of the spill area. This caused more damage to the environment as several timber and non-timber forest products such as plantains, cassava, snails etc. were destroyed. The ecological implication is difficult to quantify.

Previous studies have shown that oil trapped in soils and sediment persists much longer and is likely to cause more environmental problems than oil in water. It is therefore likely that the ecological problems associated with the hydrocarbon concentration in the sediment of the study area persist for a much longer period since cleansing mechanism is slower.

CHAPTER 1: INTRODUCTION

In June 2005 there was an oil spill in Oruma, now called Yiba – Ama, along a Shell Petroleum Development Company of Nigeria (SPDC) pipeline route at Olumogbogbo-Gbara, where pipelines cross farmlands. The site is located in a gallopy fresh water swamp forest. The oil spill occurred in the wet season. The flood of the wet season therefore aided the spread of the oil further into the forest. Aquatic life in several fish ponds died. During the cleaning up operations some of the recovered oil was incinerated in open dumps in the forest. The flames and the heat generated from the cleaning up activities also burnt the forest and farm resources in the area, leading to huge economic losses.

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1.1 **OBJECTIVES**

The main objectives of the study include:
- establishing the existing quality of surface water within the study area;
- obtaining scientific identification, qualification and characterization of existing micro and macro flora and fauna;
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- assessing the environmental impact of the spillage;
- making necessary recommendations on the remediation of the area.

These included the impact or the cleaning rate of the environment and qualifying and quantifying the impact of the spill on the environment.

The objectives were achieved through detailed field and laboratory studies.

1.2 **SCOPE**

The scope involved collection of water, sediment and soil samples from impacted and control study stations to investigate the existing characteristics of the study area for the determination of the water, sediment and soil quality in the study area three years after the oil spill.

1.3 **STUDY STRATEGY**

Based on the observations made during the reconnaissance visit to the study area, hydrodynamics of the water system, and information obtained from informed members of the community, study stations were established (Fig. 1.3.1). The study stations were established in such a manner that impacted and control areas were covered.

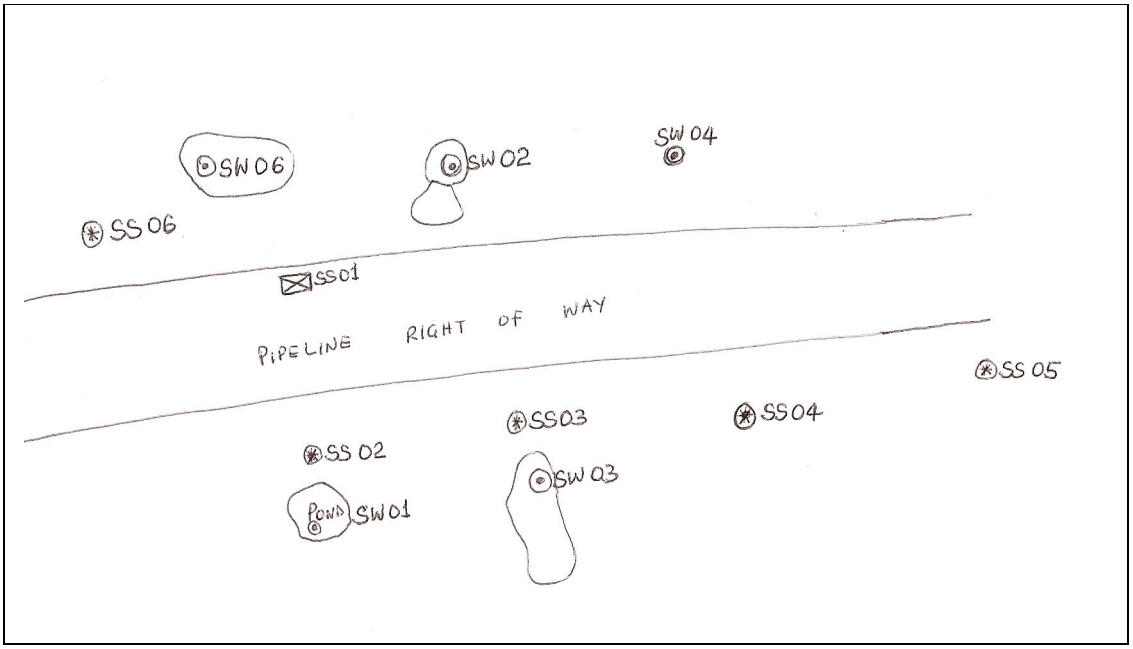

Fig. 1.3.1: Study Stations in Oruma Study Area

CHAPTER TWO: DETAILED METHODOLOGY

2.1 SOIL STUDIES

The soil studies involved assessing existing literature and on-ground status of soil physio-chemical parameters, soil microfloristic composition and oil content. Soil study stations were established as indicated in Fig. 1.3.1.
Representative samples from five random grab samples per study station were composited, air dried and sieved through 2 μm mesh sieve prior to analysis in the laboratory.

2.1.1 Soil Physiochemistry

The following analyses were carried out:
All samples were subjected to complete analyses for total hydrocarbon content, pH, E.C., organic carbon, total nitrogen, mineral nitrogen (NH_4, $N0_2$, $N0_3$) exchangeable cations (Na, K, Ca, Mg), available phosphorus and mechanical analysis for soil/sediment texture.
Samples collected from the different study areas were air-dried and sieved using a 2 ptm sieve. The fine earth was then used for the analyses. The followings describe the methods used for the different analyses carried out on soils and plant samples:

pH
The pH values of the soils and sediment samples were determined in the laboratory using an EIL Model 720 pH meter. The pH was determined by dipping the electrode into a 1:25 soil/ water suspension that had been stirred and allowed to equilibrate for about I hour.

Electrical Conductivity (E.C.)
The E.C. of soil and sediment samples were determined on the filtrate obtained after filtering; the suspension used for the pH determination. The conductivity bridge used for the measurement was the Griffin Conductance bridge. Conductivity was expressed as ps/cm-

Hydrocarbon Content
The hydrocarbon contents of the samples were determined by shaking 5g of a representative sample with 10 ml of toluene and the concentration of hydrocarbon extracted determined by the absorbance of the extract at 420nm in a Spectronic 20 Spectrophotometer. Hydrocarbon concentrations in the samples were then calculated after reading the concentration of the hydrocarbons in the extract from the spectrophotometer.

Exchangeable Cations
Two and half grams portions of a finely ground representative sample were shaken in a conical flask with 25 ml of IM ammonium acetate for about I hour and filtered into plastic cups. The filtrate was used for the determination of sodium (Na^+), potassium (K^+) and calcium (Ca^{++}) by flame photometry, and magnesium (Mg++) manganese (Mn^{++}) and iron (Fe^{++}), by Perkin Elmer Atomic Absorption Spectrophotometer. The concentrations of the cations were calculated after taking due note of the dilution factors and expressed in milligram equivalent per 100g soil (meq/100g soil).

Total Nitrogen
Two and half grams of a representative air dried sample were accurately weighed into Tecator digestion flasks and a catalyst mixture containing selenium, $CuS0_4$ and Na_2SO_4 was added followed by 10 ml of concentrated analytical grade sulphuric acid. The contents of the flask

were mixed by gentle swirling and digested on a Tecator block until the digest cleared (light green or grey colour). Heating was continued for another one hour and the digest allowed to cool. The digest was transferred quantitatively with distilled water to a 150 ml volumetric flask and made up to mark with distilled water. Aliquots of this were then taken and used for the determination of ammonium-nitrogen using an auto-analyser. The percentage nitrogen contents of the soil was then calculated after taking into account the different dilution factors.

NH_4+. NO_2- and $N0_3^-$
Ammonium, nitrite and nitrate-nitrogen were determined in the extracts by shaking 5g of a representative sample with 50ml of IM K_2SO_4. Aliquots of this extract were used for ammonium - nitrogen determination by nesslerization.

Nitrite-nitrogen was determined by the Greiss-Ilosvay method using alpha-napthylamine and sulphanilic acid and nitrate-nitrogen was determined by the phenoldisulphonic acid method. Nitrite concentrations were generally low and so did not require removal by decomposition with sulphamic acid before nitrate determination.

Organic Carbon
Carbon was determined by the wet combustion method of Wakely and Black (1934). One gram of finely ground representative sample was weighed in duplicate into beakers. 10 ml of potassium dichromate solution was accurately pipetted into each beaker and rotated gently to wet the soil sample completely. This was followed by the addition of 20 ml of concentrated H_2SO_4 using a graduated cylinder, taking a few seconds only in the operation. The beaker was rotated again to effect more complete oxidation and allowed to stand for 10 minutes before dilution with distilled water to about 200-250 ml. 25 ml of 0.5M ferrous ammonium sulphate was then added and titrated with OAM potassium permanganate under a strong light.

Available Phosphorus (Bray P-1)
Available phosphor-us in the samples was determined by weighing Ig of a representative sample into extraction flask. This was followed by the addition of 10 ml of Bray P-1 extracting solution (0.25M HCI & 0.03M NH4F) and shaking immediately for 1 minute and filtered. 5 ml of the filtrate was then pipetted into 25 ml volumetric flask and diluted with distilled water followed by 4 ml of ascorbic acid solution (0.056g ascorbic acid in 200 ml molybdate-tartarate solution) and diluted to volume. This was allowed to wait for at least 30 minutes for full colour development before reading from the spectronic 20 at 730 nm. Phosphorus ($P0_4^{3-}$) concentrations were then calculated after reference to a standard curve.

2.1.2 Soil Microbiology
Soil microorganisms were estimated by the soil dilution plate method in which serial dilutions of a soil sample in sterile distilled water were plated on a suitable agar medium. One gram of each sample of previously air-dried soil was added to and shaken with 10 ml sterile distilled water in a McCartney bottle, to give soil suspension at a dilution of 10^{-1}. A clean sterile pipette was used to transfer 1 ml of the soil suspension to another McCartney bottle containing 9ml sterile distilled water; the contents of the bottle were gently shaken together to give a soil suspension dilution of 10^{-2}. Further series of dilutions were carried out to give a dilution of 10^{-4} to 10^{-6}. Details of the media composition are presented in the aquatic microbiology section of this report.

2.2 AQUATIC STUDIES

2.2.1 Water Physiochemistry

The aquatic physiochemical studies were designed to describe the existing characteristics of the study environment that constitute reliable measurable indices in natural environmental status. Thus, any change caused by the oil spill and related activities in the study area can be effectively determined.

To achieve these objectives, seven aquatic sampling stations were established as shown in Fig 1.1. The stations, therefore, included areas likely to be impacted in case of any accidents and those not likely to be affected, i.e. control areas. The coordinates of the study stations are presented in the Table 2.2. 1.

Table 2.2.1: Coordinates for Oruma Study Stations

S/No.	Station No.	N	E
1	Oruma 01	04º55'33.3"	006º25'22.0"
2	Oruma 02	04º55'33.2"	006º25'22.1"
3	Oruma 03	04º55'34.4"	006º25'23.7"
4*	Oruma 04		
5*	Oruma 05		
6*	Oruma 06		
7*	Oruma 07		

*** Heavy rains disturbed geolocation of study stations**

2.2.1.1 Sample Collection

All water samples were collected subsurface (15-25 cm) and below the surface (with the depths recorded). The containers were opened to fill and closed below the water. All containers were always rinsed at least three times with the water being sampled before sample collection. The samples were then transported to the laboratory for analyses.

Samples for metal analyses were preserved by adding $HN0_3$ to the samples until the pH was 2. Glass containers were used for the collection of samples for hydrocarbon analysis. These were immediately preserved in ice-cooled boxes and transported to the laboratory.

2.2.1.2 Field Measurements

The following parameters were measured in the field using appropriate field meters:
The pH, conductivity and Dissolved solids, Temperature and Salinity of water were measured with Horiba Multi probe field meter.
The field meter was always properly checked and calibrated before and after sampling. Date and time of sampling were also recorded.

2.2.1.3 Laboratory Measurements

The parameters measured in the laboratory include: alkalinity, suspended solids, $P0_4^{-3}$, $N0_3^-$, NH_4^+, $N0_2^-$, $S0_4^{2-}$ and total hydrocarbon content. Details and principles of the methods used are as follows:

Phosphate

Phosphate was determined by the stannous chloride method (APHA 1998, Galley et al., 1975). Phosphate in water reacted with ammonium molybdate in acidic medium to form molybdophosphuric acid which was reduced to molybdenum blue complex by stannous chloride. The intensity of colour was measured at 690 nm using a Spectronic 20.

Sulphate

Sulphate was determined by the turbidimetric method (APHA 1998). The sulphate was reacted with barium ion in the presence of sodium chloride-hydrochloric acid solution containing glycerol and ethyl alcohol. This resulted in the formation of colloidal barium sulfate which was measured at 420 nm.

Total Alkalinity

Total Alkalinity was determined by titrating water samples (100 ml) with 0.02N sulphuric acid solution using methyl orange as the indicator (APHA, 1998).

Ammonium Nitrogen

This was determined by the phenol-hypochlorite method (APHA, 1998). Alkaline phenol and hypochlorite catalysed by sodium nitropruside, reacted with ammonia to form indophenol blue complex. The intensity of the colour was measured at 630 nm.

Suspended Solids

This parameter was measured by the gravimetric method (APHA, 1998). Water samples, 200 ml were filtered through pre-weighed 0.5 u membrane filters. The filters were then dried to constant weight in an oven at 103 - 1050C.

Chloride

Chloride was measured titrimetrically (Argentometric Method) in slightly alkaline solution with silver nitrate (AgN03), solution in the presence of potassium chromate as indicator (APHA, 1998).

Biochemical Oxygen Demand (BOD)

The BOD of water samples collected was determined using the modified oxygen depletion/Winkler's method (APHA, 1998). This is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements in waste water, effluents and polluted waters. It is a titrimetric procedure based on the oxidizing property of dissolved oxygen.

Two sets of samples were collected; one set for immediate dissolved oxygen (DO) determination and the other for incubation for 5 days at 200C. Prior to titration, each of the samples (250 ml) was fixed, and 2 ml of concentrated F12SO4 also added to aid liberation of iodine equivalent to the original DO content in the sample. The samples were then titrated with a standard solution of thiosulphate. Waste water samples were diluted with dilution water. The difference between initial and 5 day DO gives the BOD mgL^{-1}.

2.2.1.4 Determination of Total Petroleum Hydrocarbon by GC

This standard operating procedure (USEPA 8270B) was adopted. This provides an accurate and precise method for extraction, isolation, and concentration of selected organic compounds from soil and sediment samples. It achieves analyte recoveries using less solvent and taking significantly less time. Final extracts were used in the quantitative determination of polycyclic aromatic hydrocarbons (PAHs), aliphatic hydrocarbons and total petroleum hydrocarbon (TPH) by chromatographic procedures. This procedure was used to extract soil and sediment samples for gravimetric determination of extractable organic material (EOM)

Total Petroleum Hydrocarbons (TPH) concentrations were determined using Gas Chromatography Agilent 6890N Gas Chromatographs with flame ionisation detector (USEPA 8270B). The hydrocarbons in the samples were determined by comparing the areas and retention times of all identified peaks based on standards used.

2.2.1.5 Determination of Polyaromatic Hydrocarbon by GC

Polyaromatic Hydrocarbons (PAH) concentrations were determined using Gas Chromatography Agilent 6890N Gas Chromatographs with flame ionisation detector (USEPA 8270B). The hydrocarbons in the samples were determined by comparing the areas and retention times of all identified peaks based on standards used.

2.2.2 Microbiology

Microorganism (bacteria, fungi, etc.) respond quickly to changes in the physiochemical status of their environments (terrestrial or aquatic). Such effects may be reflected in changes in their numbers and/or diversity. By a combination of various data analytical methods, the relationship between such changes in diversity/numbers (and even distribution) and biophysiochemical factors could be established. Also, apart from their use in assessing change in the environment, a knowledge of the numbers of microbes in any ecosystem is required especially in petroleum exploitation since they constitute the first line of defense against oil contamination or pollution. The numbers and proportions of such microorganisms that are capable of degrading petroleum hydrocarbon could provide an index of measuring the recovery potential or pollution status of the system.

Sample Collection

Subsurface and bottom water, and sediment samples in the case of aquatic studies and soil samples in the case of terrestrial studies were collected at sites identical to those of chemical studies. This was to enhance correlation (by statistics) of microbiological and chemical data for effective interpretation of results.

Water samples were collected in 250-ml pre-sterilized glass bottles with stoppers and analysed within 4 hours of collection. Sediment samples were also similarly collected using a bottom sampler (where applicable). Handling conditions were as applied for water samples.

Soil samples were collected at two depths (0-15 and 15 - 30cm) using an auger of 9cm diameter.

Sample Analysis

Subsurface water samples were analysed for total aerobic, heterotrophic and petroleum-utilizing bacteria, total fungi and petroleum-utilizing fungi. These parameters were screened by plating out (spread plate method) Iml of diluted sample on each of the appropriate media described below, using sterile 1-ml pipettes. Sediment and soil samples were also similarly

treated except that Ig portions were suspended in 9 ml of sterile dilution blank and diluted appropriately.

Media for Cultivation and Enumeration of Microorganisms

Total Aerobic Heterotrophic Bacteria
Total aerobic heterotrophic bacteria were cultivated and enumerated on nutrient again in plates. All samples were incubated after inoculation at 28-300C and counted after 24h.

Petroleum-utilizing bacteria
Petroleum-utilizing heterotrophic bacteria were cultivated at 250C on petroleum agar with the following composition:

Difco agar - 15g
Ammonium Chloride, NH_4Cl - 0.5g
Dipotassium hydrogen phosphate, K_2HP0_4 - 0.5g
Disodium hydrogen phosphate, Na_2HP0_4-$12H_20$ - 2.5g
(or 7. 1 g of anhydrous salt)
Engine oil/diesel mixture (1 : 3 ratio) - 0.5%.
Estuarine salt solution - 750 ml
Distilled water - 250 ml
pH - 7.6.

The estuarine salt solution (artificial seawater) was prepared by dissolving in 1000ml of distilled water the following:
Sodium Chloride, NaCl - 10g.
Magnesium Chloride, $MgCl_2$ - 2.3g.
Potassium Chloride, KCI - 0.3g.

2.2.3 Phytoplankton
Phytoplanktons occupy the lowest trophic level which other life forms in the aquatic ecosystem depend directly or indirectly on as a primary food source. Their utilization of inorganic and/or organic elements in the environment and species richness, species diversity, density and distribution which reflect the nutrient status and any fouling compound introduced into the ecosystem, justify their study. Therefore, the following were considered during the study:

(i) the assessment of the taxa and the abundance of the species;
(ii) the evaluation of the distribution; and
(iii) evaluation of the relationship of abundance, composition and distribution to physiochemical parameters.

Phytoplankton samples were collected using a one litre translucent plastic bottle to collect the subsurface water sample and immediately fixed with Iml of laboratory prepared Lugol's iodine solution. This was later transferred to the laboratory.

In the laboratory, the samples were allowed to stand for a minimum of 24 hours before the supernatant were pipetted off until a 50ml concentration volume was achieved. From the 50 ml concentrated sample, I ml of properly homogenised sub-sample was transferred into a Sedgewick Rafter counting chamber using Starnple pipette. The organisms were identified and enumerated under a binocular microscope (140 - 144 x).

2.2.4 Zooplankton

Zooplankton organisms comprise the juvenile and larval stages of larger animals such as crab zoea, shrimp zoea, fish larvae/embryo, vegiller larvae of molluscs, and the permanent zooplankton (Holoplankton) such as copepods, euphausids, jelly fish and chaetognaths. These organisms mostly feed on particles in the water, and therefore, concentrate smaller phytoplankton, some other zooplankton and debris. By their feeding process they may ingest oil particles in places where there is oil pollution.

Some of them have been shown to concentrate the oil particles, others metabolize and break them down (Gardner et al. 1979). At some concentrations of the oil, some of these organisms die. Mironov (1972) showed that the young *Acartia clausii* and *Oithona nana* died after 3 to 4 days immersion in seawater containing up to 10 ml/L of oil, while their adults and some other copepod species suffered accelerated death after longer exposure. Mironov also observed that planula larvae of coelenterates, larvae of fish, polychaete and crustaceans have all been very sensitive, and at concentrations of 10-100 ppm in seawater, may not metamorphose. These zooplankton have been found to make up the bulk of food material for most juvenile and pelagic fish species (Fagade and Olaniyan, 1972). Thus, zooplankton not only indicate the effect of low levels of oil and chemical pollution in the water body, which might not be lethal to the higher organisms, they also play very important role in the food chain and energy flow within the water bodies.

Zooplankton sampling was carried out with the aim of identifying the various taxa of the zooplankton. The various taxa at several chosen stations would be enumerated, with which an index of their abundance in relationship to the level of pollutants, (mainly petroleum and chemical) could be established.

Subsurface water samples were collected in 101itre plastic buckets and poured through a 55 mesh size plankton net fifty times. The net samples (representing 5001itres of water) were washed into 20ml sample collecting bottles and immediately fixed in 10 percent formalin.

In the laboratory, samples were made up to a uniform volume of 100ml using distilled water. Following a thorough agitation and homogenisation, 1ml sub-samples were taken using a Stampel Pipette and transferred to a graded 1 ml counting chamber for observation under a binocular microscope with magnification of 40 to 400x. The organisms were simultaneously identified and enumerated and results entered on analysis sheets.

2.2.5 Epipelic Algae

Epipelic algae are used as biological indicator organisms in various pollution related studies. Their consideration for such studies is related to their being sessile, always present in water column; some are associated with specific pollutants and are comparably more predictable than the plankton (Pudo 1985 & 1989).

The species list and taxa abundance will be used to indicate any change in the aquatic environment caused by stressed conditions.

Epipelic community were sampled by scrapping artificial and/or natural substrates which are permanently or occasionally submerged in water. The scrapping was restricted to a quadrant of $2cm^2$. The scrapped content from substratum, was emptied into a vial bottle. The aggregate sample was then fixed with 5 percent formalin.

In the laboratory, the samples were made up to 50mls, out of which Iml sub-sample was analysed under a microscope. All organisms encountered within the counting chamber were identified and enumerated. This procedure was repeated twice for each sample. The results obtained were expressed as organism per unit area.

2.2.6 Benthic Macrofauna

Macrofaunal grab samples were sieved immediately after retrieval and the grab contents emptied on to the sieving table and screened through a 0.5 mm mesh sieve using seawater. The sediment and faunal material retained by the sieve were then transferred to a sealed plastic container, labeled and fixed in 10% buffered formalin solution for transport to the laboratory.

In the laboratory samples were sorted and all stained fauna removed and further preserved in 50% propyl alcohol or formalin. These were identified to the lowest possible taxonomic level under a stereo and/or compound microscope and individuals of each taxonomic group were counted and recorded.

2.3 QUALITY CONTROL

The methodology and procedures for sample collection, storage/handling and analysis were such that dependability and reproducibility are assured.

Field Data
To assure the accuracy and reliability of in situ field measurements, field instruments were calibrated prior to use and cross-checked from time to time. Field portable pH meter was calibrated using pH4, pH7 and pH9 buffer solutions. The conductivity and dissolved solids meter were checked against solutions of known conductivity and dissolved solids provided by the manufacturers. The sound level meter was calibrated with a pistonphone prior to commencement of measurements. Water sample containers were washed with detergent and thoroughly rinsed, first with clean water and, finally, with distilled water. Water and soil samples for special analysis were kept frozen or refrigerated before the time for analysis. Biological specimens for tissue analysis were wrapped in clean aluminium foils and stored in portable ice coolers.

Laboratory Data
Samples for wet chemical analysis were refrigerated and immediately analysed for nitrate and phosphate contents. Standard laboratory quality control procedures were adhered to for wet chemical analysis of water samples. These included determination of reagent blanks, use of fresh standards and replicate analysis for confidence limit, and cleaning of glass wares and other containers. The same procedures were used on water samples for hydrocarbon determinations.

Data Verification
Data Verification was done at several points of the collection and analysis process. Field data sheets were carefully kept and inspected daily. Data which did not fall within the expected range (especially in relation to water samples) were noted, and when possible the stations in question were resampled. Laboratory data for wet chemistry were subjected to analysis to draw attention to the stations whose values fell outside the observed range. Such stations were subjected to further scrutiny during data analysis so as to provide explanation for the values. If no reason was found from the anomalous values, the conclusion was that the values were in error. Such erroneous values were detected and deleted through this method.

Quality Assurance Plan
A quality control program was established from the onset of the project to ensure the validity and comparability of data. Every effort was made to adhere to the goals of this program throughout the course of the study.

Detailed procedural guidelines for sampling and analysis were made available to each member of the study group. Field data sheets were not only be used to record pertinent environmental and ecological observations but also serve as checklists for detailing each step in sample collection, preservation, and sample storage. This assisted in recording the exact number of samples collected at each station, ensured proper labelling and preservation. These data sheets were used for sample analysis, data verification and data analysis.

A logbook was also maintained throughout the field and laboratory-based studies for recording movements, handling, types of samples, laboratory procedure, date of collection, starting and completion dates of analysis and the personnel.

CHAPTER THREE: RESULTS

3.1 SOIL STUDIES

3.1.1 General Soil Description

The study area consists of a typical Deltaic Plain with a monotonous and essentially flat topography linked with abundant swamp zones. It is within the Quaternary Meander Belt of recent alluvial deposits with prominent freshwater swamps that overlie the Tertiary Benin Formation (Anderson, 1966). The entire area is low-lying stretches of land bounded by levees. When the flood waters rise, they pass through several breaks through the levees to fill the floodplain and drain away when the river water falls. The soils of the area generally consist of grey-brown or yellowish brown in colour and fine sandy loams and clay loams with clay skin increasing in subsoil. It is associated with luxuriant freshwater vegetation typical of a tropical rainforest belt.

3.1.2 Soil Microbiology

Heterotrophic bacterial counts for Oruma soil samples ranged from 3.74×10^4 to 3.75×10^5 cfu/g. Petroleum degrading bacterial counts in Oruma were low presenting % PDB/HB values that ranged from less than 0.01 % to 7.31 %. Figure 3.1.1 shows the logarithmic values. The low levels of petroleum degrading bacteria do not really reflect the concentration of petroleum hydrocarbon in the study area. The reason could be related the flushing of the environment by the dynamic water system and the delay in carrying out this assessment; some years after the spill. However, the high heterotrophic counts recorded in the study could also be related to the cleaning mode or method adopted for the area.

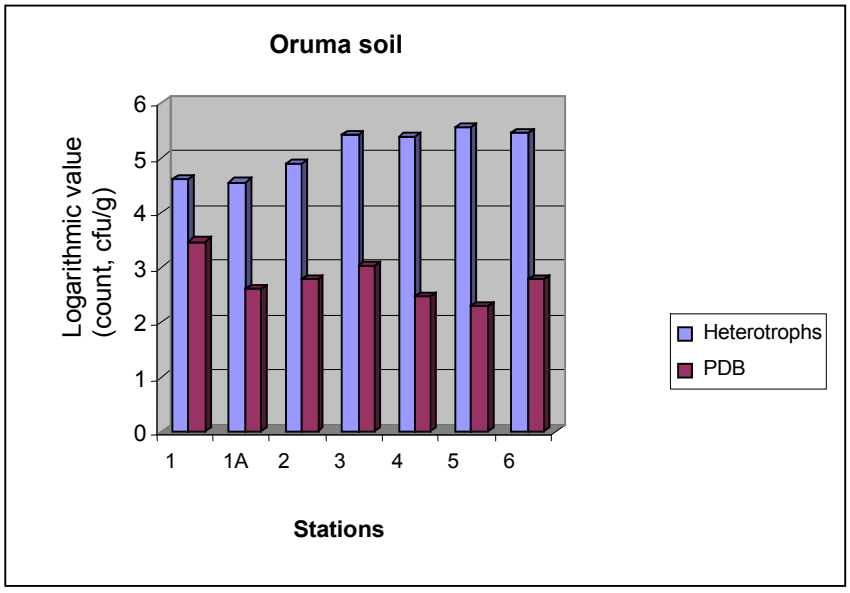

Figure 3.1.1: Logarithmic count of heterotrophic and petroleum-degrading bacteria by site for the Oruma soil samples.

3.1.3 Soil Physiochemistry

Physiochemical properties of the soils collected around Oruma town are presented in Appendix 3.1.1. The soils are moderately acid in reaction with pH in the range of 4.94 to 5.67. Electrical conductivity values are below 100µS/cm indicating very low salinity content (0.0 – 0.2‰) as such no salt deposits in the area. The organic carbons in the soils are between

2.38 to 3.85%, which is quite high for Nigerian Soils (Anderson 1966, Odu et al. 1985). Carbon/nitrogen ratio ranged from 6 to 7 showing that rate of humification is quite high. Mineral nitrogen occur in the order of $NH_4^+ > NO_3^- > NO_2^-$ due probably to wetness of the soils showing nitrification process in the soils. However, the nitrate values (11.3 – 20.5µg/g) are satisfactory, whereas the nitrite content (5.9 – 8.0 µg/g) indicates no adverse reactions occurring in the soil at the time of the study. Available phosphorus are moderate. Exchangeable cations are high while the cation exchangeable capacity is moderate indicating moderate soil fertility.

3.1.4 Pollution Status

Figure 3.1.2 shows total hydrocarbon (oil and grease) concentrations in the soil. The values showed gradual reduction of hydrocarbons around stations ORU 01 (spill point) 04, 06 and 07. However, oil and grease concentrations were still moderately high in stations 02, 03 and 05. This uneven distribution of hydrocarbons in the study area could be attributed to the poor cleaning up method adopted and the difficult nature of the study area. Although, the low carbon-nitrogen ratio (6 – 7) should suggest high population of microbial oil degraders in the area but microbiological studies the reverse. This could also be as a result of adaptation of the microorganisms to the environment or the method used for the cleaning up. The reason for this suggestion is the unusually high heterotrophic counts recorded in the area.

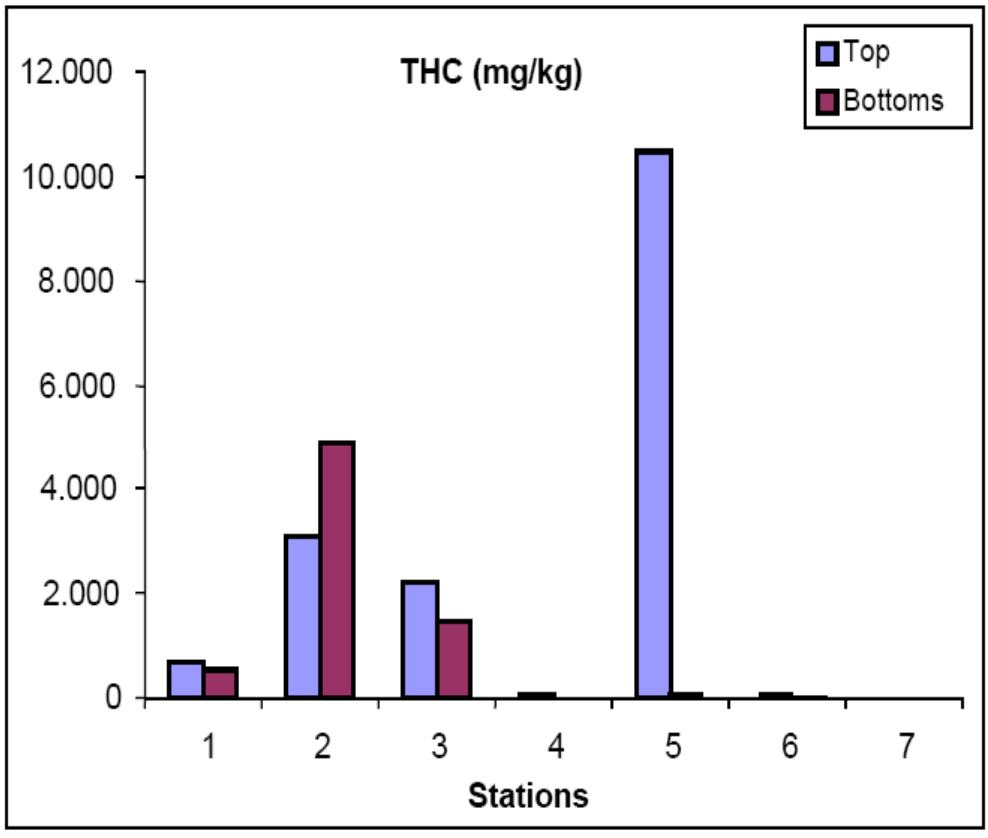

Fig. 3.1.2: Total Hydrocarbon Concentrations around the Study Stations.

3.2 AQUATIC STUDIES

3.2.1 Surface Water Physiochemistry

Physiochemical properties of surface water collected around oil spilled site at Oruma Community in Bayelsa State are presented in Appendix 3.2.1. Total dissolved solids ranged from 41µS/cm at Station 03 to 76µS/cm at station 05 with the exception of Station 04 with 225µS/cm. The EC values indicate that the water system is soft and fresh with very low salinity content (0.0‰). The water pH ranged from slightly acid 6.1 to neutral 7.1 which could be attributed to the nature of the study area rich in basic cations and clay (Appendix 3.3.1). The rich clay contents of the land area may also be responsible for the appreciable high turbidity levels (3 – 13 NTU). Dissolved oxygen levels ranged from very low (0.81mg/l) at Station 03 to high (8.53mg/l) at Kolo Creek and Station 06 enough to support aquatic life. However, the biochemical oxygen demand values are very high (30.45 – 384.38mg/l) indicating water of low quality with high organic load. This further suggests that some adverse reactions might be occurring within the water bodies.

The nutrient levels are low nitrate, (0.12 – 0.31mg/l) and phosphate (<0.05 – 0.07mg/l).This is because nitrates are mobile, easily lost in the flood waters whereas the phosphate ions are strongly adsorbed on clay particles and not easily leached into the receiving waters (Kiel, 1997). The chloride and sulphate contents are low which could be attributed to the rainfall regime and geology of the parent materials. Total alkalinity is high (26.0 – 19.54mg/l $CaCO_3$) suggesting that the waters of the area of study may have slight buffering capacity to resist sudden changes in the ecosystem, but could not withstand high concentration of pollutant introduced.

3.2.2 Surface Water Microbiology

Heterotrophic counts for Oruma ranged from 2.83 x10^3cfu/ml to 4.88 x 10^4cfu/ml real count. The proportions of petroleum-degrading bacteria in the Oruma samples were also low with values generally less than proportion was 0.01%. Figure 3.2.1 shows the logarithmic values.

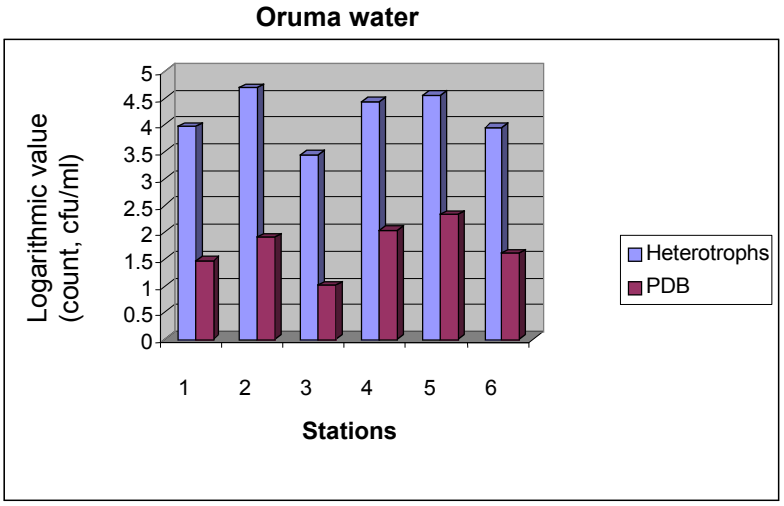

Figure 3.2.1: Logarithmic counts of heterotrophic and petroleum-degrading bacteria by site for the Oruma water samples.

3.2.3 Drinking Water Quality

The physiochemical characteristics of a sample of Kolo Creek, a source of potable water for the community are presented in Table 3.2.1. The parameters show that the characteristics of the water sample are very similar to the features reported for other surface water samples

from the studyarea. The water samples are generally acidic; the drinking water is not within the limits recommended for potable water by WHO (as described in EGASPIN, environmental guidelines and standards for the petroleum industry in Nigeria, page 109, 2002).

Table 3.2.1: Comparison of Drinking Water quality with WHO recommended limits for potable water

S/No.	Parameter	Drinking Water	WHO Standard (maximum permissible level)
1.	pH	6.2	6.5 to 9.2
2.	Conductivity (µS/cm)	43.0	-
3.	Turbidity (NTU)	3.0	-
4.	TDS (mg/l)	30.10	1500
5.	Chloride (mg/l)	0.25	600
6.	Sulphate (mg/l)	5.3	400
7.	Phosphate (mg/l)	<0.05	-
8.	Nitrogen-Nitrate (mg/l)	0.18	-
9.	Hardness ((mg/l)as CaC03)	8.62	500
10.	Calcium (mg/l)	1.38	200
11.	Magnesium (mg/l)	1.26	150
12.	Total Hydrocarbon Conc.	<0.02	-

Water borne diseases (associated with poor water supply) include diarrhoea, cholera, typhoid, hook worm and hepatitis. In the study area the people lack potable water supply and are therefore exposed to these ailments, which can lead to potentially fatal complications in sufferers. The lack of potable water in the area predisposes the people to water-borne disease vectors and thus poor health conditions as reported by the community representatives during the field study. This situation is normally aggravated when oil is introduced to such a system because the presence of the oil adds to poor quality of the water.

The major sources of water supply in the study area are the Kolo Creek, streams and harvesting of rain. Although the water quality of the Kolo Creek appeared to have recovered from the impact of the spill at the time of the study, the hydrodynamics of the study area suggest that the oil introduced into the environment at the spill site, would have been flushed down the Kolo Creek and made the water unsuitable for the various desired purposes thus causing water related health problems in the community as indicated earlier.

3.2.4 Phytoplankton

Phytoplanktons occupy the lowest trophic level which other life forms in the aquatic ecosystem depend directly or indirectly on as a primary food source. Their utilization of inorganic and/or organic elements in the environment and species richness, species diversity, density and distribution which reflect the nutrient status and any fouling compound introduced into the ecosystem, justify their study.

A total of 144 phytoplankton species were observed in the study area. Of these 60 species (41%) were Bacillariophyceae, 37 Cyanophyceae (26%), 26 species Euglenophyceae (18%) and Chorophyceae were represented by 21 species (15%) (Appendix 3.2.2 and Fig 3.2.2). Thirty eight (38.3%) percent of these species exhibited wide distribution amongst the stations

(Appendix 3.2.3). The species richness varied between station ranging from a minimum of 68 species to a maximum of 105 species but the affinity between stations were not significant (R2 = 0.44) (Fig. 3.2.3).

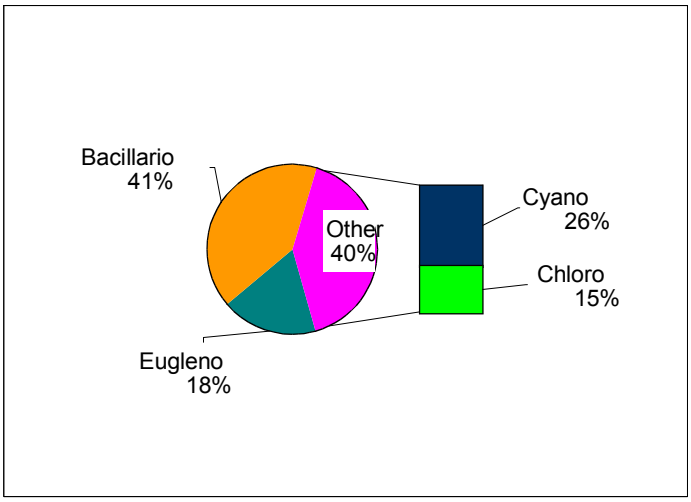

Fig. 3.2.2: The relative contribution of species by different phytoplankton taxonomic groups

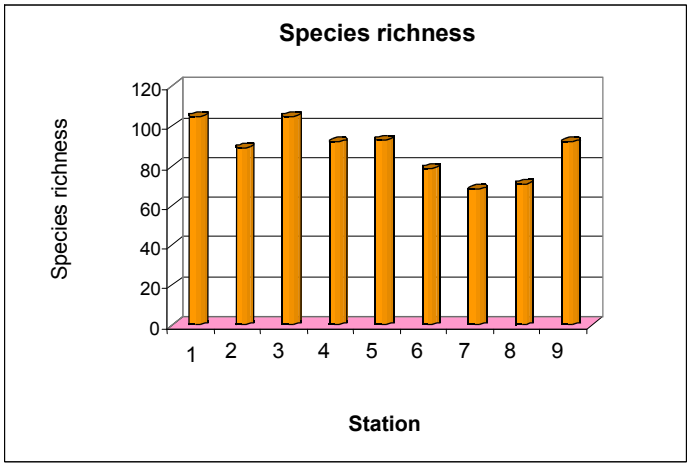

Fig. 3.2.3: The distribution of species richness at the different study stations

The relative composition of the major family groups indicated a pattern of Cyanophyceae (39.3 - 88.5%) > Bacillariophyceae (7.0- 39.4%).> Euglenophyceae (4.0 - 16.2% > Chlorophyceae (0.5 - 14.4%) in that decreasing order of importance in the phytoplankton community (Fig. 3.2.4). The prominence in the community structure by cyanophyceae is high scores recorded at stations 6 -9 contributed by *Microcoleus sociatus, Microcystis aeruginosa* and *Synechococcusaquatilis.*

The phytoplankton densities had values ranging from 881 – 3104 x 10^3 indiv/L^{-1} and the distribution of species. The distribution of densities correlated significantly (R^2 = 0.84)

The comparative analysis of Cyanophyceae and total phytoplankton ratio showed values close to unity at 4 stations (stations 6-9) Fig 3.2.5.

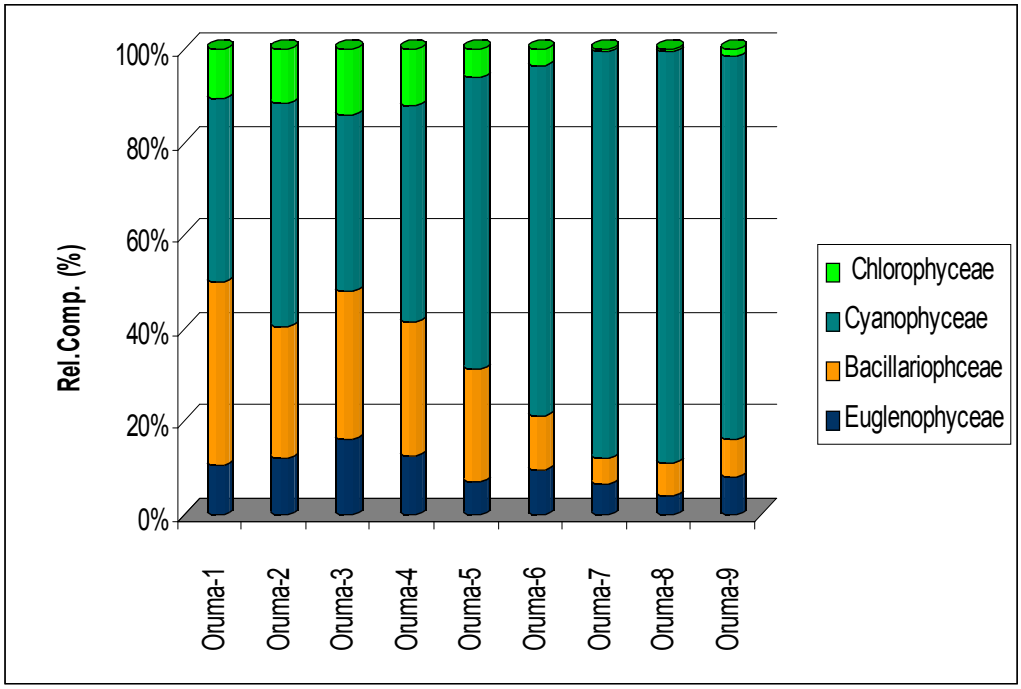

Fig. 3.2.4: The relative proportion of major taxonomic groups to the phytoplankton population

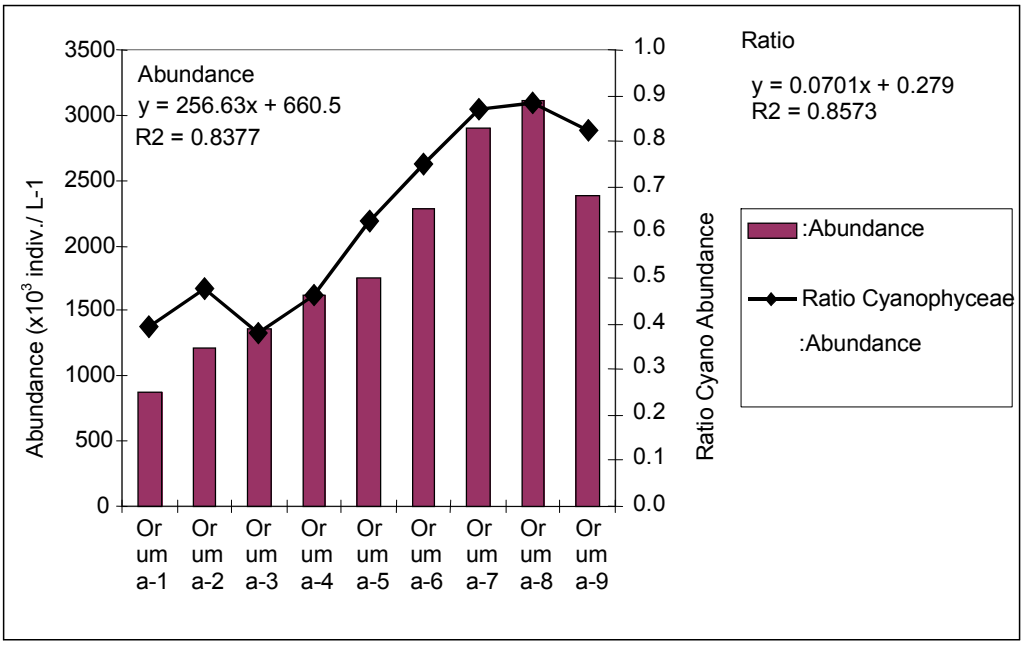

Fig. 3.2.5: The distribution of phytoplankton densities and ratio of Cyanophyceae to phytoplankton abundance at the study stations

3.2.5 Zooplankton.

Zooplankton organisms comprise the juvenile and larval stages of larger animals such as crab zoea, shrimp zoea, fish larvae/embryo, vegiller larvae of molluscs, and the permanent

zooplankton (Holoplankton) such as copepods, euphausids, jelly fish and chaetognaths. These organisms mostly feed on particles in the water, and therefore, concentrate smaller phytoplankton, some other zooplankton and debris. By their feeding process they may ingest oil particles in places where there is oil pollution.

Some of them have been shown to concentrate the oil particles, others metabolize and break them down (Gardner et al. 1979). At some concentrations of the oil, some of these organisms die. Mironov (1972) showed that the young *Acartia clausii* and *Oithona nana* died after 3 to 4 days immersion in seawater containing up to 10 ml/L of oil, while their adults and some other copepod species suffered accelerated death after longer exposure to 10ml/L or after 5 to 6 minutes in 10 ml/L. Mironov, (1972) observed that planula larvae of coelenterates, larvae of fish, polychaete and crustaceans have all been very sensitive, and at concentrations of 10-100 ppm in seawater, may not metamorphose. These zooplankton have been found to make up the bulk of food material for most juvenile and pelagic fish species, (Fagade and Olaniyan, 1972). Thus, zooplankton not only indicate the effect of low levels of oil and chemical pollution in the water body, which might not be lethal to the higher organisms, they also play very important role in the food chain and energy flow within the water bodies.

In the study period, 73 zooplankton taxa were identified, representing fourbroad taxonomic groups (Appendix 3.2.4 and Fig. 3.2.6).

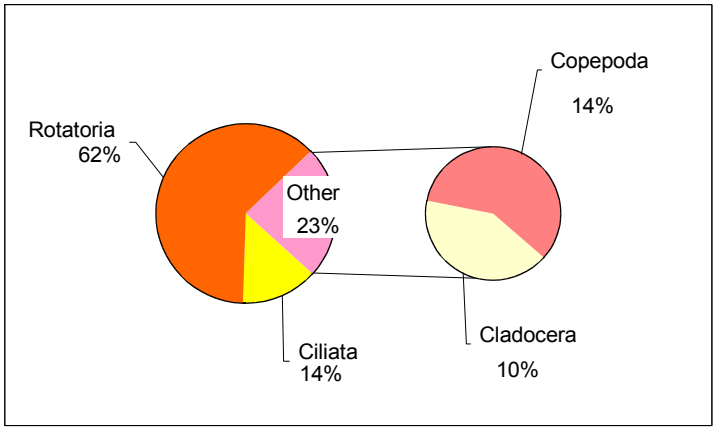

Fig. 3.2.6: The relative contribution of species by different zooplankton taxonomic groups

The dominant group was the rotifers comprising 63% (46 species) of the total number of zooplankton species. 23 of the species werewidely distributed among the stations such as *Asplanchna brightwelli, Brachionus bidentata, Brachionus budapestinneneis, Brachionus caudatus, Brachionus plicatilis, Euchlanis dialatata, Euchlanis lyra, Euchlanis triquetra, Filina passa, Lepadella ovalis, Lepadella triptera, Lucane aquila, Lucane flexilis, Lucane hastata, Lucane kostei, Lucane nana, Lucane rhytida, Lucane signifera, Notholca baioalensis, Notholca cruciformis, Notholca foliacea, Platyias leloupi, and Testudinella elliption* (Table 6). The rotifers was followed by Copepoda and Ciliata that had equal number of species contribution of 14% (10 species) each while Cladocera contributing only 9% of the species number (7 species). The most widely distributed species amongst the copepoda and ciliate were *Oithona nana and Coleps elongatus and Opercularia coarctata* respectively *(*Table 3.2.2).

The distribution of species richness indicated a range with a minimum of 37 species in Station Oruma 6 and maximum of 56 species in Oruma 4 (Fig 3.2.7.).

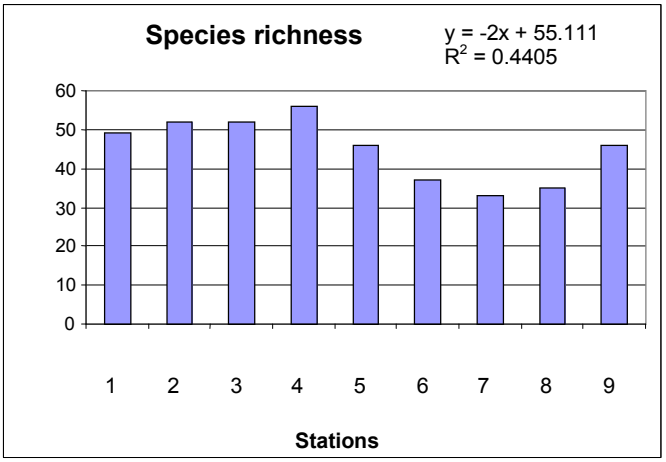

Fig. 3.2.7: The distribution of zooplankton species richness at the different study stations

The relatively wide variability in the distribution of species richness amongst the stations is responsible for the poor relationship between stations ($R^2 = 0.44$).
The community structure demonstrated a distribution pattern of Rotatoria (62.1 - 96.9%) > Copepoda (0 - 24.5%) > Ciliata (3.1 - 12.3%) > Cladocera (0 - 7.2%) decreasing order of contribution by major groups to the zooplankton population.

The zooplankton densities had values ranging from a minimum of 104 in Station Oruma 7 to a maximum of 439 in Station Oruma 2 (Fig. 3.2.8). The densities tended to decline downstream especially with the depressed abundance of copepods and ciliates in the down stream stations where the gradient had visibly concentrated oil, this may be responsible for the non significant relationship between stations on copepod ($R^2 = 0.49$) and Cilates ($R^2 = 0.04$) ratios respective (Table 3.2.3)

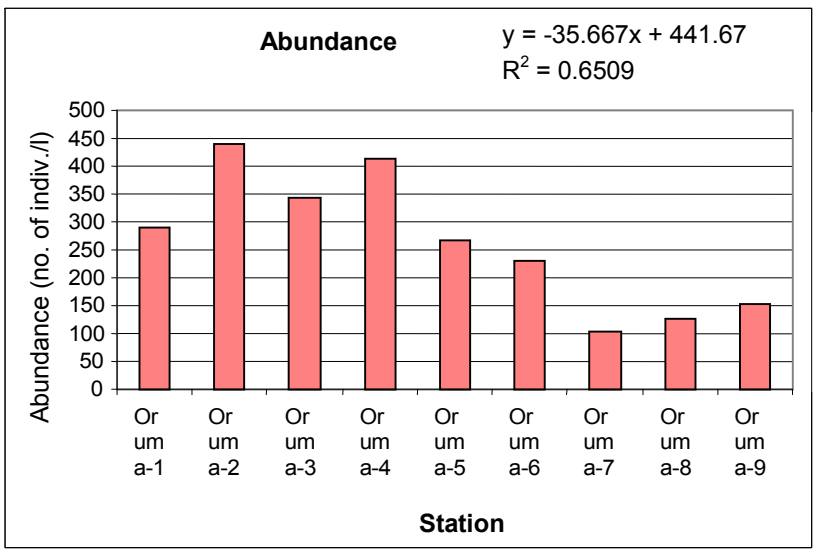

Fig. 3.2.8: The distribution of zooplankton densities at the study stations

Table 3.2.2: The most widely distributed species in the study area for each of the major taxonomic groups.

Rotatoria	***Ciliata***	***Copepoda***
Asplanchna brightwelli	*Coleps elongatus*	*Oithona nana*
Brachionus bidentata	*Opercularia coarctata*	
Brachionus budapestinneneis		
Brachionus caudatus		
Brachionus plicatilis		
Euchlanis dialatata		
Euchlanis lyra		
Euchlanis triquetra		
Filina passa		
Lepadella ovalis		
Lepadella triptera		
Lucane aquila		
Lucane flexilis		
Lucane hastata		
Lucane kostei		
Lucane nana		
Lucane rhytida		
Lucane signifera		
Notholca baioalensis		
Notholca cruciformis		
Notholca foliacea		
Platyias leloupi		
Testudinella elliption		

Table 3.2.3: The regression relationship of Zooplanktton major groups ratio with abundance

Attribute ratio	**Y =**	**R^2**
Rotatoria/Abundance ratio	0.0371x + 0.5875	0.8344
Copepod /Abundance ratio	-0.0058x + 0.071	0.4974
Ciliata /Abundance ratio	-0.0019x + 0.079	0.0377
Cladocera /Abundance ratio	-0.008x + 0.0796	0.8768

3.2.6 Periphyton

Periphytons are used as biological indicator organisms in various pollution related studies. Their consideration for such studies is related to their being sessile, always present in water column; some are associated with specific pollutants and are comparably more predictable than the planktons (Pudo 1985 and 1989).The species list and taxa abundance are used to indicate any change in the aquatic environment caused by stressed conditions.
The periphyton community yielded 106 species representing Bacillariophyceae, cyanophyceae, chlorophyceae and Euglenophyceae each contributing 47 species (45%), 30 species (30%), 15 species (15%) and 14 species (14%) in that decreasing number of species respectively (Appendix 3.2.4 and Fig. 3.2.9), The distribution of species richness showed values ranging from a minimum of 49 species in station Oruma -8 and a maximum at station Oruma -3 (Fig. 3.2.10).

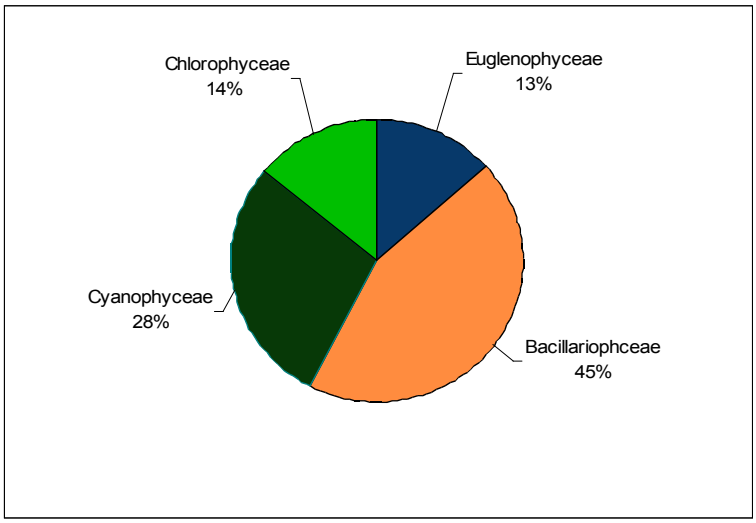

Fig. 3.2.9: The relative contribution of species by different periphyton taxonomic groups

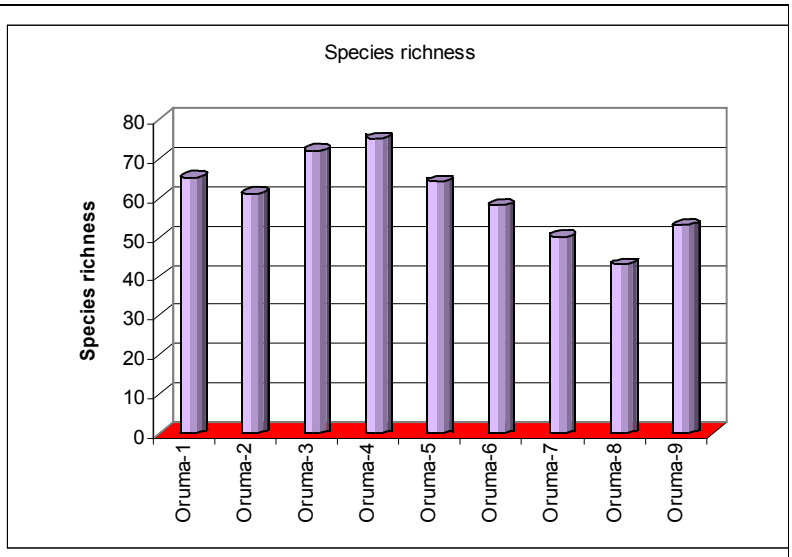

Fig. 3.2.10: The distribution of periphyton species richness at the different study stations

Similarly, the community structure of periphyton for most stations were dominated by Cyanophyceae contributing 51.4-95.5% of the community (Oruma-2 - Oruma-9) largely due to species such as *Gloeocapsa* minima*, Lyngbya epiphytica, Lyngbya limnetica, Microcoleus sociatus, Microcystis aeruginosa, Phormedium uncinatum, Synechococcusaquatilis, Synechococcus cedrorum,*and *Synechococcusmaior* (Fig. 3.2.11)

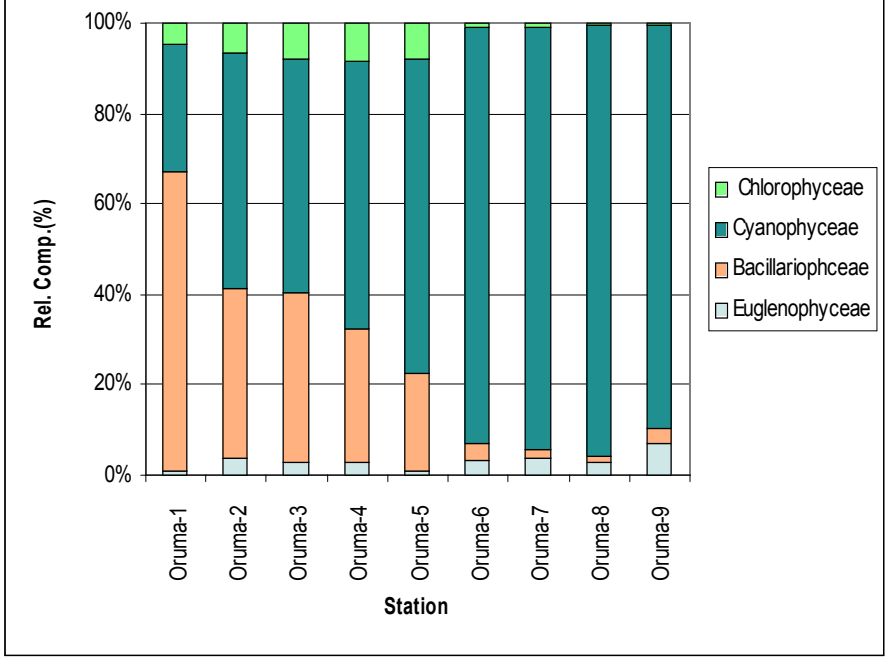

Fig.3.2.11: The relative proportion of major taxonomic groups to the periphyton population

The ratio of the different taxonomic groups with abundance periphyton indicated significant relationship for Bacillariophyceae (R^2 = 0.88) and cyanophyceae (R^2 = 0.88) but that of chlorophyceae (R^2 = 0.54) and Euglenophyceae (R^2 = 0.40) were not significant while that of were significant (Fig. 3.2.12 and Table 3.2.4).

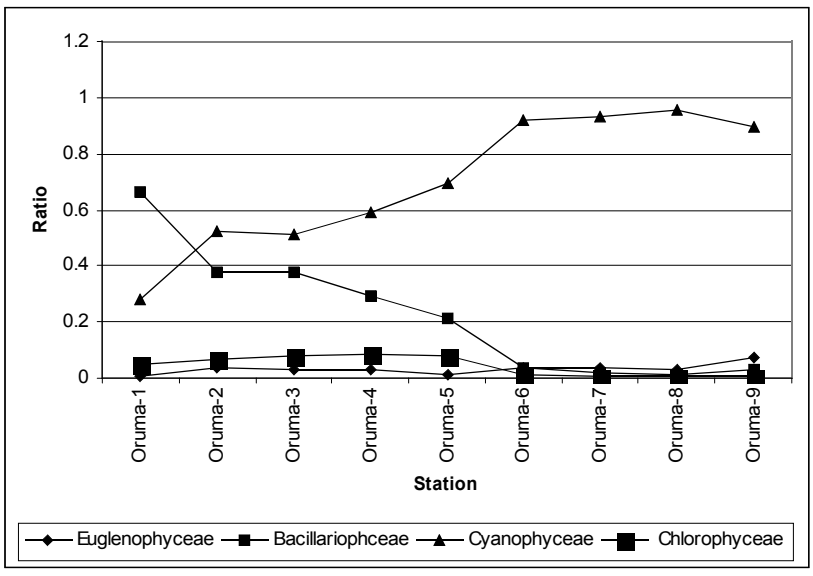

Fig. 3.2.12: Ratio of different taxonomic groups to periphyton abundance at the study stations

Table 3.2.4: The regression relationship of major groups of periphyton ratio with abundance

Families	Y =	R^2
Euglenophyceae	0.0043x + 0.0103	0.4035
Bacillariophceae	-0.0767x + 0.6078	0.8716
Cyanophyceae	0.082x + 0.2906	0.8781
Chlorophyceae	-0.0096x + 0.0913	0.5434

The periphyton densities ranged from 922 – 2933 x10^4 individuals/cm^2 (Fig. 3.2.13) with clear evidence of dominance by blue green algae in some stations where crude oil was visible. This was very obvious in stations Oruma 6 to Oruma 9 with higher abundance against other taxonomic groups. Stations Oruma 1 to Oruma 5 with lower abundance showed about two fold differences in abundance than the other stations.

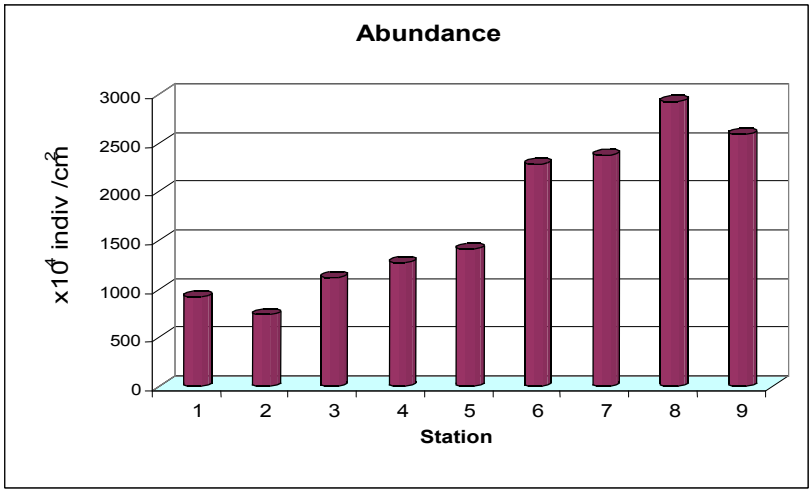

Fig. 3.2.13: The distribution of periphyton densities at the study stations

The number of phytoplankton species occurring in the swamp forest and stream environment are expected in such freshwater systems. The 144 species observed, are higher than values recorded for similar freshwater swamp forest streams (RPI, 1985).The observed community structure of the major taxonomic groups with a pattern in decreasing order of Cyanophyceae> Bacillariophyceae > Euglenophyceae > Chlorophyceae (0.5 - 14.4%) contrasts with that of reported for equivalent un-impacted habitat with sequence of Bacillariophyceae > Cyanophyceae > Euglenophyceae > Chlorophyceae in that decreasing order of importance in the phytoplankton community. The prominence of Cyanophyceae assumed in the community structure of the study area is based on the contribution of some blue green algal species *Microcoleus sociatus, Microcystis aeruginosa* and *Synechococcusaquatilis* particularly at the lower stretch of the stream where the crude oil impact appeared more prominent. These species appeared to have in the presence of crude oil opportunistically performed more than expected for non oil impacted environment (RPI, 1985, and Chindah, 2003). Comparable conditions observed for this impacted freshwater habitat had been reported for similar impacted areas (Ibiebele *et al*., 1987, Chindah and Braide, 2001). This state of affairs is responsible for relatively high densities of phytoplankton observed in this study and are about two to fourfolds higher than values of relatively low impacted area.

The effect observed on phytoplankton reoccurred in the periphyton study in relation to predominant species, community structure shift and relatively high population densities were also observed. This implies that the crude oil equally impacted on the periphyton community. The increase in periphyton and phytoplankton population appeared a positive impact but the effect of ascendancy of Cyanophyceae (blue green algae) on organisms that depend on periphyton as food may be far reaching as the condition could be described as attaining bloom condition. Blue green algal have been described as having several consequences on water quality, wildlife (wild birds and mammals) that depend directly or indirectly on the water body (Round, 1962). This scenario may be responsible for the poor occurrence of some benthic and fish species such as the hydrometera, and that are usually common occurring in such freshwater habitat.

3.3 SEDIMENT STUDIES

3.3.1 Physiochemical Properties of the Related Sediments

Appendix 3.3.1 shows physiochemical properties of the related sediments. The sediment textures are clayey with clay fractions ranging from 62.4% to 65.8% silt and sand fractions between 30.0 – 32.6% and 3.6 – 5.0% respectively. pH values vary from strongly acid 5.51 to slightly acid 6.51 in reaction. Electrical conductivity values (29 – 527µS/cm) show no salt deposit in the area since the area is a fresh water swamp. Organic carbon content is high (2.40 – 3.35%) with corresponding high nitrogen (0.36 – 0.51%). This means that the environment is conducive for the microorganisms to degrade hydrocarbon (oil) introduced into the system, hence low carbon/nitrogen ratio (0.67).

The sediment is rich in nutrient reserve; available phosphorus and nitrate concentrations are moderate, ranging from 12.2 to 13.4µg/g and 16.0 – 19.8µg/g respectively. Nitrite concentrations (6.3 – 8.3µg/g) indicate that there are no adverse reactions occurring in the sediments. The levels of the basic cations are satisfactory with high clay contents to bind and oxidize any pollutants introduced in the environment.

Oil and grease concentrations ranged from low (17.45µg/g) around Station 04 to moderate (2116.06mg/kg) at Station 01. The levels observed indicate that there is gradual reduction of hydrocarbons in the environment probably as a result of the initial cleaning up exercises. The water system is also dynamic and could have assisted in flushing the oil introduced into the environment.

3.3.2 Sediment Microbiology

Heterotrophic bacterial counts for Oruma samples ranged from 6.10 x 10^4 cfu/g to 3.52 x 10^5 cfu/g. The Oruma samples relatively contained more petroleum-degrading bacteria than the Goi samples with proportions ranging from <0.01 % to 1.45 % (Figure 3.3.1).

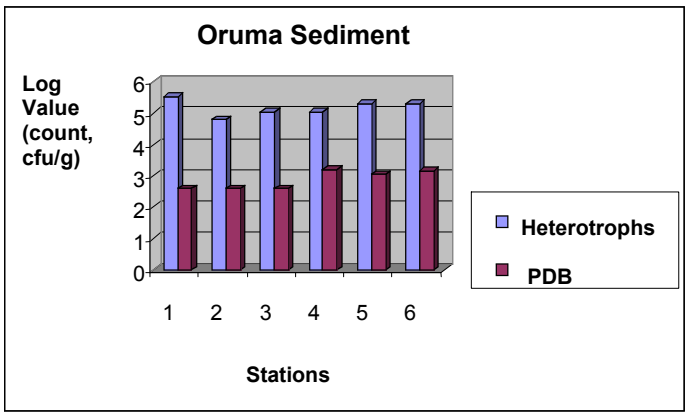

Figure 3.3.1: Log counts of heterotrophic and petroleum-degrading bacteria in Oruma sediment samples.

3.3.3 Benthos

Benthic organisms are those found in the sediments of surface water which are usually the ultimate sinks of everything that goes into water. The distribution of the benthic organisms normally reflects the nutrient status among other features as well as the degree of pollution of the sediments.

During the study period, 13 benthic taxa were identified, representing 3 major taxonomic groups (Insecta, Gastropoda and Pisces) Appendix 3.3.1. Pisces contributed more number of species (54%) followed by insecta (38%) and the least being gastroda (8%) in that respective declining order of species number (Fig. 3.3.2).

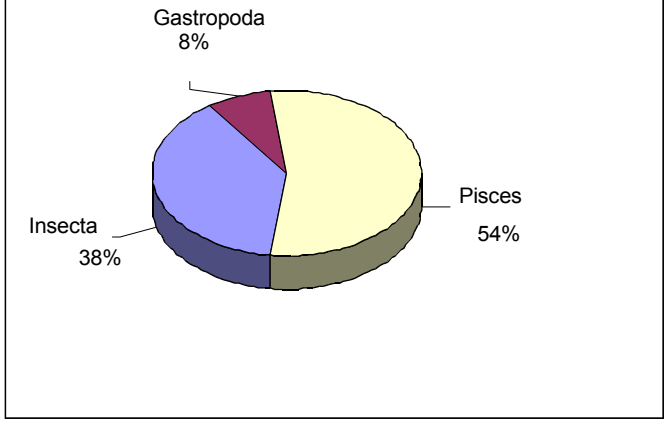

Fig. 3.3.2: The relative contribution of species by different benthic fauna taxonomic groups.

The species richness distribution for the entire stations ranged from 0 - 7 species, with over 50% of the study stations being azoic (stations 4,5,6,7 and 9) while the rest stations (Oruma 1, 2, 3 and 8) recorded between 1 and 7 species. The maximum number of species was observed in Oruma -1 (Fig. 3.3.3).

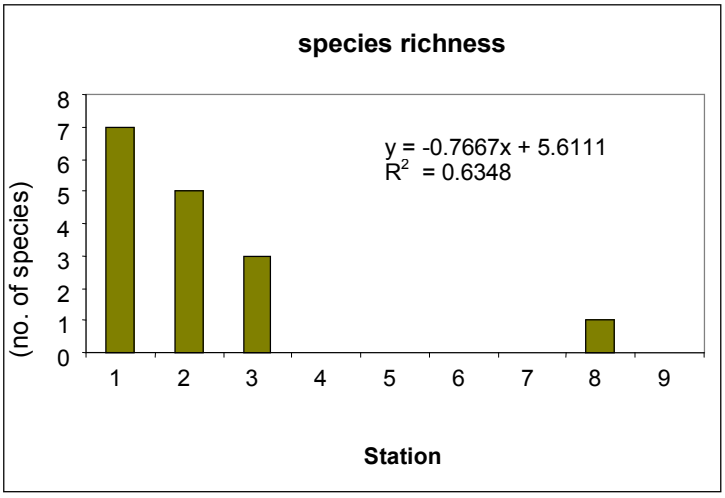

Fig 3.3.3: The distribution of benthic fauna species richness at the different study stations

The distribution of species richness was significant, an index indicating the poor distribution amongst the stations ($R^2 = 0.64$).
The community structure amongst the stations that recorded presence of benthic fauna had contribution of major taxonomic forms in the sequence of Pisces (37.5 - 100%) >Insecta (0 - 50) > gastropoda (0 - 12.5%) in that decreasing importance in the benthic community (Fig. 3.3.4).

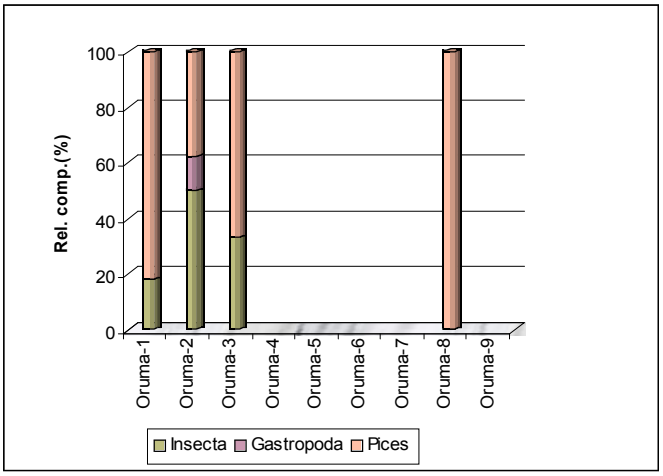

Fig. 3.3.4: The relative proportion of major taxonomic groups of the benthic fauna population

The benthic faunal densities were low ranging from 0 -11 individuals/1000cm^3, the maximum value of 11 indiv/1000cm^3 recorded at Oruma -1 is attributed to the relative number of juvenile fish species observed in the station and the distribution of densities were relatively significant ($R^2 = 0.58$) Fig. 3.3.5. The general low densities recorded especially the azoic (absence) nature of some stations is in conformity with data on benthic faunal species richness for those stations.

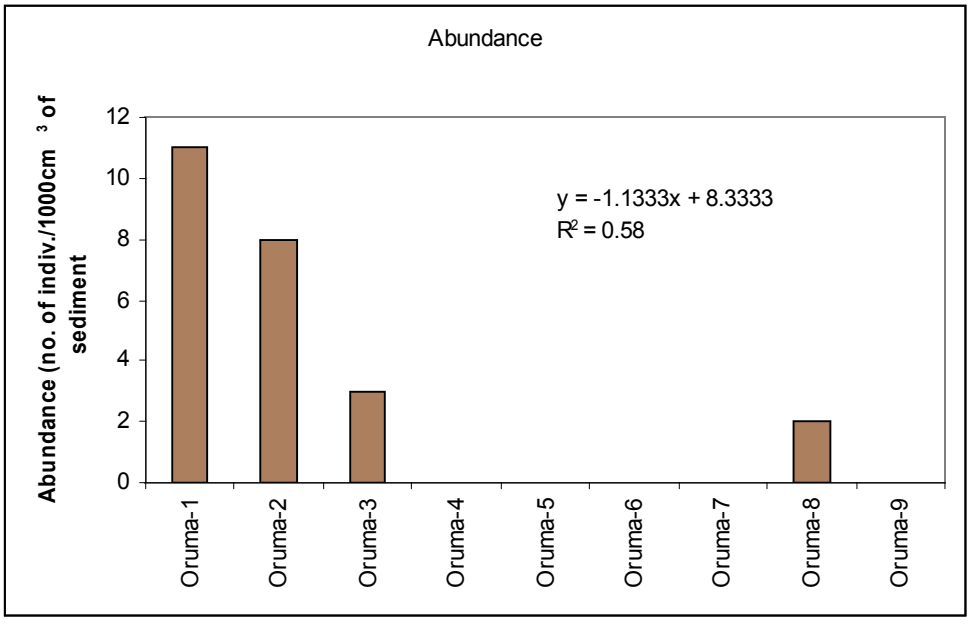

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Fig. 3.3.5: The distribution of benthic fauna densities amongst the study stations

3.4 PETROLEUM HYDROCARBON STUDIES

3.4.1 Total Petroleum Hydrocarbon in Surface Water

The results of Total Petroleum Hydrocarbon (TPH) concentrations in the water samples from Oruma spill site are presented in Table 3.4.1. The results show that TPH values range from 0.17 – 1.35 mg/l with a mean value of 0.60 mg/l.

Table 3.4.1: Total Petroleum Hydrocarbon Concentrations in Water Samples

S/No.	Study Station	TPH (mg/l)
1	Oruma 1	0.17
2	Oruma 2	0.53
3	Oruma 3	0.17
4	Oruma 4	0.45
5	Oruma 5	0.48
6	Oruma 6	0.38
7	Oruma 7	1.16
8	Oruma 8	1.35

3.4.2 Polyaromatic Hydrocarbon Concentrations in Surface Water

Polyaromatic hydrocarbon concentrations in the water samples from Oruma study area are presented in Table 3.4.2 .The table shows that polyaromatic hydrocarbons were not detected in any of the surface water study stations.

Table 3.4.2:
Polyaromatic Hydrocarbon Concentrations in Surface Water in the Study Area (mg/l)

S/No.	Parameter	Oruma 1	Oruma 2	Oruma 3	Oruma 4	Oruma 5	Oruma6	Oruma 7	Oruma 8
1	Naphthalene	ND	ND	ND	ND	ND	ND	ND	ND
2	2-Methylnaphthalene	ND	ND	ND	ND	ND	ND	ND	ND
3	Acenaphthylene	ND	ND	ND	ND	ND	ND	ND	ND
4	Acenaphthene	ND	ND	ND	ND	ND	ND	ND	ND
5	Fluorene	ND	ND	ND	ND	ND	ND	ND	ND
6	Phenanthrene	ND	ND	ND	ND	ND	ND	ND	ND
7	Anthracene	ND	ND	ND	ND	ND	ND	ND	ND
8	Fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND
9	Pyrene	ND	ND	ND	ND	ND	ND	ND	ND
10	Benzo(a)anthracene	ND	ND	ND	ND	ND	ND	ND	ND
11	Chrysene	ND	ND	ND	ND	ND	ND	ND	ND
12	Benzo(b)fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND
13	Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND
14	Benzo(a)pyrene	ND	ND	ND	ND	ND	ND	ND	ND
15	Dibenzo(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND	ND
16	Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	ND	ND
17	Indeno(1,2,3-d)pyrene	ND	ND	ND	ND	ND	ND	ND	ND

3.4.3 Total Petroleum Hydrocarbon in Sediment

The results of Total Petroleum Hydrocarbon (TPH) concentrations in the sediment samples from Oruma are presented in Table 3.4.3. The results show that TPH values range from 0 – 58.2 mg/kg with a mean value of 40.82 mg/kg.

Table 3.4.3: Total Petroleum Hydrocarbon Concentrations in Sediment Samples

S/No.	Study Station	TPH (mg/kg)
1	Oruma 1	ND
2	Oruma 2	40.2
3	Oruma 3	58.2
4	Oruma 4	49.8
5	Oruma 5	48.0
6	Oruma 6	48.7

3.4.4 Polyaromatic Hydrocarbon Concentrations in Sediment

Polyaromatic hydrocarbon concentrations in the sediment samples from Oruma are presented in Table 3.4.4. The table shows that polyaromatic hydrocarbons were generally not detected in any of the study stations except Oruma 1 where low concentrations of some components of polyaromatic hydrocarbons were recorded.

Table 3.4.4: Polyaromatic Hydrocarbon Concentrations in Sediments (mg/kg)

S/No.	Parameter	Oruma 1	Oruma 2	Oruma 3	Oruma 4	Oruma 5	Oruma 6
1	Naphthalene	ND	ND	ND	ND	ND	ND
2	2-Methylnaphthalene	ND	ND	ND	ND	ND	ND
3	Acenaphthylene	ND	ND	ND	ND	ND	ND
4	Acenaphthene	0.08	ND	ND	ND	ND	ND
5	Fluorene	0.09	ND	ND	ND	ND	ND
6	Phenanthrene	0.18	ND	ND	ND	ND	ND
7	Anthracene	0.23	ND	ND	ND	ND	ND
8	Fluoranthene	ND	ND	ND	ND	ND	ND
9	Pyrene	0.38	ND	ND	ND	ND	ND
10	Benzo(a)anthracene	0.23	ND	ND	ND	ND	ND
11	Chrysene	ND	ND	ND	ND	ND	ND
12	Benzo(b)fluoranthene	0.14	ND	ND	ND	ND	ND
13	Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND
14	Benzo(a)pyrene	ND	ND	ND	ND	ND	ND
15	Dibenzo(a,h)anthracene	ND	ND	ND	ND	ND	ND
16	Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND
17	Indeno(1,2,3-d)pyrene	ND	ND	ND	ND	ND	ND

3.4.5 Total Petroleum Hydrocarbon in Soil

The results of Total Petroleum Hydrocarbon (TPH) concentrations in soil samples from Oruma are presented in Table 3.4.5. The results show that TPH values range from 12.0 – 6,991.0 mg/kg.

Table 3.4.5: Total Petroleum Hydrocarbon Concentrations in Soil Samples

S/No.	Study Station	TPH (mg/kg)
1	Oruma 1	24.3
2	Oruma 2	4,348.0
3	Oruma 3	25.3
4	Oruma 4	27.6
5	Oruma 5	6,991.0
6	Oruma 6	12.0

3.4.6 Polyaromatic Hydrocarbon Concentrations in Soil

Polyaromatic hydrocarbon concentrations in the soil samples from Oruma study area are presented in Table 3.4.6. The table shows that polyaromatic hydrocarbons were generally low in all the study stations except stations 3, 4 and 6 where none were detected.

Table 3.4.6: Polyaromatic Hydrocarbon Concentrations in Soil (mg/kg)

S/No.	Parameter	Oruma 1	Oruma 2	Oruma 3	Oruma 4	Oruma 5	Oruma 6
1	Naphthalene	ND	0.07	ND	ND	0.11	ND
2	2-Methylnaphthalene	ND	0.12	ND	ND	0.15	ND
3	Acenaphthylene	0.07	0.15	ND	ND	0.21	ND
4	Acenaphthene	0.08	0.13	ND	ND	0.26	ND
5	Fluorene	0.13	0.32	ND	ND	1.08	ND
6	Phenanthrene	0.22	0.26	ND	ND	1.37	ND
7	Anthracene	0.13	0.55	ND	ND	1.38	ND
8	Fluoranthene	ND	0.13	ND	ND	4.84	ND
9	Pyrene	ND	0.81	ND	ND	6.98	ND
10	Benzo(a)anthracene	0.33	0.33	ND	ND	6.92	ND
11	Chrysene	0.12	0.40	ND	ND	14.1	ND
12	Benzo(b)fluoranthene	0.24	1.02	ND	ND	9.58	ND
13	Benzo(k)fluoranthene	ND	0.64	ND	ND	7.58	ND
14	Benzo(a)pyrene	0.44	0.76	ND	ND	9.76	ND
15	Dibenzo(a,h)anthracene	ND	0.75	ND	ND	1.69	ND
16	Benzo(g,h,i)perylene	ND	0.35	ND	ND	3.13	ND
17	Indeno(1,2,3-d)pyrene	ND	2.58	ND	ND	3.31	ND

CHAPTER FOUR: CONCLUSIONS

The study has shown that the Oruma study area is impacted by hydrocarbon. The hydrocarbon concentration in the study area is generally above biogenic levels, suggesting introduction of hydrocarbon from either the spill source or previous incidents of existing SPDC activities in the area.

This assessment study has been undertaken twenty four months after the spill. There are indications there has been a significant decrease in the hydrocarbon concentration since the spill occurred. This decrease may have been fastened by the relatively dynamic nature of the water system in the area.

Hydrocarbon concentrations
The concentration of Total Petroleum Hydrocarbon (TPH) recorded in the surface water of the study area is 0.17 – 1.35 milligram/liter. This concentration has a negative impact on the resources of the area and the recruitment potential of the system.

The presence of hydrocarbon in soils and sediments of the study area is partly responsible for the stress observed in the ecology of the environment. This is based on the results of field observation, epipelic algae (algae that grow on the surface of intertidal mudflats or substrates) and benthos (sediment organisms) where the presence of oil appears to have affected the abundance and distribution of the organisms.

Previous studies have shown that oil trapped in soils and sediment persists much longer and is likely to cause more environmental problems than oil in water. It is therefore likely that the ecological problems associated with the hydrocarbon concentration in the sediment of the study area persist for a much longer period since cleansing mechanism is slower.

The results of studies show that generally, the study area has a fairly poor composition and poor amount of benthic communities (various organisms in the sediment system) when compared to areas of similar ecological system (IPS, 1989). Field observations suggest that the area is recovering gradually (Photo Plate).

Impacts on fish
Oil spills result in fish kills and reduced fish abundance in any impacted environment. Furthermore, the staining of fishing gears with oil renders the gears unsuitable for reuse by the fishermen. This results in the reduced fishing activities and hence a drastic reduction in the earnings of fishermen.

The critical value for oil that can induce toxic effects has been a cause for concern. The recruitment potential in the water body can be adversely affected through deformations in exposed eggs and fish larvae. Concentrations as low as 50 ugl^{-1} of oil can already cause these deformations (FOH, 1984). This is several times lower than the range 0.17 – 1.35 milligram/liter reported in the area.

Adult fish are able to avoid oil-tainted water masses, because they can perceive the presence of oil in very low concentrations. In the event of an oil spill, fish may be exposed to concentrations of oil in water that may be too low to cause death but high enough for the oil to accumulate in the fish.

Impact on plants

Oil spill in aquatic environment generates varying ecological responses from plants ranging from outright mortality to wilting of the plants, defoliation of plant leaves, loss of reproductive cycle and species loss. The magnitude of impact varies, depending on the quantity spilled, spread, and habitat type, physiographic nature of the area, containment and cleanup measures adopted. At the time of the study, there was evidence of the regeneration of plants indicating that the older plant species had been destroyed by the spill.

In Oruma, the clean up operations involved burning of recovered oil within the vicinity of the oil spill. This caused more damage to environment as several timber and non-timber forest products such as plantains, cassava, snails etc. were destroyed. This therefore impacts negatively on the economy of the community especially for the persons that whose livelihood depends on the natural resources in the area. The ecological implication is difficult to quantify. In dry and flooded zones of the Niger Delta there have also been cases of disappearance of rare and endangered wild life species resulting in biodiversity loss (IPS 1994, NDES 2001).

In a fresh water environment (streams, floodplains and backswamps) as in Oruma study environment, the effect of oil spill on plants causes great damage to the plant communities (emergent, rooted and climbers).This impact of oil is often devastating due to high retention time occasioned by limited flow (low energy of water current) caused by thick macrophytes cover and enormous herbs, shrubs, and trees which make flow extremely difficult. The entire process results in low productivity and or loss of plant species (Chindah and Braide, 2001). The plant materials needed by the locals for various ecological and economic activities are usually depleted or totally obliterated by the oil spill.

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Appendix 3.1.1:
Physiochemical Properties of Soil around Oruma in Bayelsa State (June, 2007)

Sample	Co-ordinates		Cm		µS/cm	‰	mg/kg	‰		C:N	µg/g					Meg/100gsoil					%			Clay
Identity	N	E	Depth	pH	EC	Sal	THC	Org. C	TN	ratio	Av.P	NO^-_3	NO_2^-	NH^+_4	SO_4^{2-}	K^+	Na^+	$Ca2^+$	Mg^{2+}	CEC	Sand	Silt	Clay	Class
01	04°55' 34.0"	006°25' 22.2"	0-15	5.67	65	0.0	693.7	3.55	0.50	7	13.0	20.5	7.0	18.4	27.5	17.2	9.8	20.0	22.1	22.0	3.5	31.2	65.3	Clay
(Spill source)			15-30	5.61	96	0.2	562.8	3.34	0.50	7	12.2	19.3	6.8	18.0	26.8	17.1	9.0	18.9	20.5	21.0	3.4	29.5	67.1	Clay
02	04°55' 33.2"	006°25' 22.1"	0-15	5.21	42	0.0	3106.5	3.37	0.50	7	12.7	18.8	7.2	18.0	28.0	16.9	7.8	19.3	20.5	19.3	3.4	29.0	67.6	Clay
			15-30	5.20	38	0.0	4864.7	3.90	0.54	7	13.6	20.0	6.3	18.8	29.8	18.9	10.7	20.1	23.8	22.2	3.4	29.5	67.1	Clay
03	04°55' 34.9"	006°25' 23.6"	0-15	4.94	83	0.0	2207.7	3.85	0.54	7	11.4	14.2	6.2	16.4	26.8	16.4	8.8	20.2	22.0	24.1	13.5	47.0	39.5	Silty clay loam
			15-30	5.16	34	0.0	1448.5	3.61	0.52	7	10.6	13.4	7.1	15.0	24.4	15.8	8.0	14.8	20.2	22.4	11.0	40.9	48.1	Silty clay
04	04°55' 34.8"	006°25' 26.0"	0-15	5.16	49	0.0	<4.4	3.42	0.52	7	12.4	12.1	7.0	17.8	22.3	14.4	7.8	16.8	18.8	20.6	9.4	40.1	50.5	Silty clay
			15-30	5.08	25	0.0	<4.4	3.26	0.51	6	10.2	11.4	6.4	16.2	20.2	16.2	7.4	12.4	16.4	18.8	9.4	48.1	42.5	Silty clay
05	04°55' 35.1"	006°25' 29.9"	0-15	5.28	45	0.0	10471.2	3.00	0.48	6	10.0	113	5.9	15.2	19.6	15.3	6.6	18.2	18.9	18.6	12.0	46.5	41.5	Silty clay loam
(Near fish pond)			15-30	5.32	35	0.0	157.1	2.45	0.41	6	10.8	13.2	6.4	16.8	20.4	9.3	6.4	12.8	13.3	16.7	8.0	43.5	48.5	Silty clay
06	04°55' 33.8"	006°25' 20.3"	0-15	5.13	41	0.0	100.3	2.38	0.39	6	12.0	14.9	8.0	17.0	23.7	8.7	6.0	12.0	12.9	16.0	4.2	31.0	64.5	Clay
(Treated Area)			15-30	5.14	57	0.0	61.1	3.11	0.40	8	13.4	16.4	6.8	18.6	22.4	8.8	6.2	14.4	13.9	20.1	3.4	29.5	67.1	Clay
07			0-15	5.03	65	0.0	13.1	2.93	0.41	7	12.1	14.2	6.4	17.2	24.2	9.0	6.1	12.4	16.4	18.2	3.8	29.6	66.6	Clay

Appendix 3.2.1:
Physiochemical Properties Surface water contaminated sites in Oruma, Bayelsa State (June, 2007)

Sample station	Coordinates			µ S/cm	NTU	‰	mg/l							mg/l$CaCO_3$		mg/l		ppm
	N	E	pH	EC	Turb.	Sali-nity	TDS	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	Cl^-	∑Alk.	∑Hard	Ca^{2+}	Mg^{2+}	THC
01	04°55' 33.3"	006°25' 22.0"	6.4	63	10	0.0	44.1	4.61	42.63	0.16	0.05	6.5	0.50	37.0	17.24	2.53	2.66	<0.02
02	04°55' 33.2"	006°25' 22.1"	7.1	73	13	0.0	51.1	4.06	213.15	0.31	<0.05	8.9	0.63	34.0	14.37	3.30	1.50	<0.02
03	04°55' 34.4"	006°25' 23.7"	6.1	41	4	0.0	28.7	0.81	73.8	0.20	<0.05	7.4	0.76	29.0	8.05	1.72	0.91	<0.02
04			6.7	225	6	0.0	157.5	3.25	51.77	0.19	<0.05	8.8	13.0	38.0	19.54	6.28	0.93	<0.02
05			6.3	7.6	8	0.0	53.2	3.26	48.72	0.20	<0.05	9.1	101.01	44.0	14.37	3.83	1.17	<0.02
06			7.1	55	5	0.0	38.5	6.92	384.38	0.12	0.07	2.5	0.63	26.0	8.05	3.30	0.91	<0.02
Kolo Creek			6.2	43	3	0.0	30.1	8.53	30.45	0.18	<0.05	5.3	0.25	30.0	8.62	1.38	1.26	<0.02

Appendix 3.2.2:
The phytoplankton species and their respective numerical count at the study stations.

	Oru-ma 1	Oru-ma 2	Oru-ma 3	Oru-ma 4	Oru-ma 5	Oru-ma 6	Oru-ma 7	Oru-ma 8	Oru-ma 9
Euglenophyceae									
Cyclidiopsis acus	1	2	7		34	6	4	1	11
Euglena acus	3	3	1		6	4	2	6	6
Euglena pascheri	1	3	5				3	4	4
Lepocinclis marssonii	3		1	2		16	8	18	12
Lepocinclis ovata		12		24		1	2	3	
Lepocinclis ovum				7	22	12	14	6	4
Lepocinclis steinii		3	2	7	9	17	12	21	31
Phacus ocellatus	4	18	141	25	6	11	18	13	82
Phacus acuminatus	6	1	3		4		2		
Phacus globosus		1	3	23	1	7	1		
Phacus longicauda	18	36		16	5		4	1	1
Phacus mirabilis	5	8	11	42	1	2	4	5	5
Phacus onyx	6	3		2	3	7	18		
Phacus pleronectes		2	2			48	18	1	1
Phacus trapezoides	13	7		43		1	3		
Phacus undulatus	9	5	1		1	7	1	1	1
Strombomonas ensifera			2			21			
Strombomonas gibberosa		13	2		15		4	4	4
Strombomonas pungens		4	7					2	2
Trachelomonas botanica	4	1				4	12		
Trachelomonas dastrugei	4	3						1	1
Trachelomonas dictyophora	3	4	5	6	2		19	1	1
Trachelomonas hystrix	1		7	9	6	45	21	32	23
Trachelomonas mirabilis	5	14	12				7	3	4
Trachelomonas neotropica	5		8						
Trachelomonas torquata	3	1	1		4	11	12	2	2
Euglenophyceae	**94**	**144**	**221**	**206**	**119**	**220**	**189**	**125**	**195**
Bacillariophceae									
Achnanthes coarctata		3	7		1	3	5	1	1

Achnanthes flexella			5						
Achnanthes gibberula	3		8	2	5			2	2
Achnanthes inflata		1	2			1	1		1
Achnanthes lanceolata	1		1	3	4			2	
Achnanthes nodusa									
Bacillaria paradoxa	2	5	3			5	5	1	
Cymbella affinis	6		1		3				1
Cymbella amphioxys	3			5	4				
Cymbella cymbiformis								5	7
Cymbella microcephala	8	6	20	20	27	16	3	8	24
Diatoma elongatum	32	54	26	12	18	18	22	10	12
Diatoma hiemale	12	15	54	78	96	162	72	30	15
Diatoma vulgare	32	48	8	32	24	8	8	68	8
Diploneis interrupta	1	5	2			1			
Diploneis ovalis	39	19	40	53	26	12	22	37	46
Eunotia exigua	3	2	2	4	1	3		3	1
Eunotia fallax				4	2			6	
Eunotia gracilis	3		2						2
Eunotia praerupta	2		1	23	22				
Fragilaria construens	8	28	12	72	4	5	2		3
Fragilaria virescens		1			2				
Frustulia rhomboides	4			12	11				
Frustulia vulgaris	11	8	4	5	20	8	8	3	8
Mastogloia braunii	1		1	3	7			2	
Mastogloia smithii			2		1				2
Meridium circulare	3		1	1	1				
Navicula bacillum	1		2						
Navicula confervacea	5			2	3				
Navicula contenta			18						3
Navicula cuspidata			4		2			2	1
Navicula flagilaroides	5	12	8	6	1	13	8	3	1
Navicula mutica	2		2		3				1
Navicula oblonga	29	52	12	21	18	2	2		
Navicula soodensis	1		1						1
Navicula ventralis	2			2	2				

Nitzschia acicularis	2		9	3		1		2	
Nitzschia closterium	32	54	69	11	43			7	2
Nitzschia hungarica	17		45		4			2	9
Nitzschia linearis	1		4	3					2
Nitzschia sublinearis			4					1	
Nitzschia trybionella			2	4	3				4
Pinnularia debesil	1		5		5			1	3
Pinnularia gibba			2	4					
Pinnularia maior	19	11	7	12	16			2	3
Pinnularia viridis	4			1	1				3
Rhoicosphenia curvata	6							2	2
Stauroneis anceps	3	2	1	5	12	2	2		
Stauroneis dialatata	12		2	2	8				
Stauroneis obtusa	1								5
Synedra acus	13	9	12	43	3			5	5
Synedra amphicephala	1	2		5		1	1		3
Synedra nana		1				1	1	2	2
Synedra tabulata	8	3	18	6	13				
Tabellaria binalis	4	6		2	4	5	5		
Tabellaria fenestrata	2			6	5			9	5
Tabellaria flocculosa	2	1	1			1	1	2	3
Bacillariophceae	**347**	**348**	**430**	**467**	**425**	**268**	**168**	**218**	**191**
Cyanophyceae									
Anabaena aqualis	2	7		1	9	9	18	12	34
Aphanotheca		14	1			14	14		5
Dactylococcopsis rhaphidiodes				1	2	3			6
Eucapsis minor	5	3		4					
Gloeocapsa minima	41	10	12	62	136	237	542	257	223
Gomphosphaeria aponica	59	39	64	146	163	44	339	645	486
Lyngbya epiphytica	1	8	2	3	1	8	8		
Lyngbya holsatica	32	54	26	12	18	18	22	10	12
Lyngbya limnetica	12	15	54	78	96	162	72	30	15
Lyngbya molischii	32	48	8	32	24	8	8	68	8
Lyngbya pseudospirulina	3	104	1	1		104	104	1	1

Lyngbya rimosa	1	18	2	1		18	18		
Marssoniella elegans					1				1
Merismopedia maior	1		1					1	3
Microcoleus sociatus	62	45	118	67	105	259	204	394	199
Microcystis aeruginosa	58	28	103	98	261	256	645	757	482
Microcystis marginata			3		2				
Oscillatoria amphibia	15	25	5	71	52	251	198	134	178
Oscillatoria brevis	8		7		4	12			
Oscillatoria deflexoides		1		1		1			1
Oscillatoria lacustris		1		1		1			1
Oscillatoria mirabilis		3	2		4				2
Oscillatoria nigra		2		2		2			2
Oscillatoria rupicola		3		3		3			3
Oscillatoria simplicissima		21		5	8	2	5		
Oscillatoria trichoides	3		2				3		
Phormedium ambiguum		2		5			2		
Phormedium cebennense			4		3	2			
Phormedium cincinnatum			2		3				
Phormedium papillaterminatum		2		2		2			2
Phormedium uncinatum	5	8	18	23	32	37	39	65	78
Spiriluna labyrinthiformis			4	8	4	8	3	4	8
Spiriluna minima	5	1	2	4	6				4
Synechococcus aquatilis		54	26	12	35	18	122	271	151
Synechococcus cedrorum		15	12	78	96	162	72	30	15
Synechococcus maior		48	35	32	24	76	87	68	32
Tetrapedia crux-michaeli	1		2		3	1			
Cyanophyceae	**346**	**579**	**516**	**753**	**1092**	**1718**	**2525**	**2747**	**1952**
Chlorophyceae									
Actinastrum sp		2		4	5				
Cladophora oligoclona			5	1	4			2	9
Closterium acerosum	24	35	45	23	38	2			
C. closteriodes	7	4	8	6	1	3	2		1
C. ehrenbergii	3	4	8	17	3	11			
C. gracile	4	4	6	14	4	4		2	

C. lunula	6	6	20	4	6	4			2
C. parvulum	2	1	6	6	8	1	2		4
Microspora flocossa	1	8	16	10		8		4	6
Mougeotia sphaerocarpa	6	10	8	8	23	38			
Oedogonium crassum	10	2							
Pediastrum simplex	8	28	34	62	2		3		
P. sp.		3	6	5					
Scenedesmus dubia	2	5	8	2	1	2	7	3	8
S. insignis	9	8	5	3	7				3
S. karnalae	8	13	16	18		8			
Scenedesmus quadrincauda	2	5	2	4	1		5	3	4
Ulothrix tenuissima	2				2		3		
U. zonata		3		2					
Volvox aureus			3	8	3				
Chlorophyceae	**94**	**141**	**196**	**197**	**108**	**81**	**22**	**14**	**37**

Appendix 3.2.3: Phytoplankton species within the families that exhibited wide distribution in the study area

Euglenophyceae	Bacillariophyceae	Euglenophyceae	Cholorophyceae
Cyclidiopsis acus	*Achnanthes coarctata*	*Gloeocapsa minima*	*C. gracile*
Euglena acus	*Bacillaria paradoxa*	*Gomphosphaeria aponica*	*C. lunula*
Euglena pascheri	*Cymbella microcephala*	*Lyngbya epiphytica*	*C. parvulum*
lepocinclis marssonii	*Diatoma elongatum*	*Lyngbya holsatica*	*Microspora flocossa*
lepocinclis ovata	*Diatoma hiemale*	*Lyngbya limnetica*	*Pediastrum simplex*
Lepocinclis ovum	*Diatoma vulgare*	*Lyngbya molischii*	*Scenedesmus dubia*
Lepocinclis steinii	*Diploneis ovalis*	*Lyngbya pseudospirulina*	*Scenedesmus quadrincauda*
Phacus ocellatus	*Eunotia exigua*	*Phormedium uncinatum*	
Phacus acuminatus	*Fragilaria construens*	*Spiriluna labyrinthiformis*	
Phacus globosus	*Frustulia vulgaris*	*Spiriluna minima*	
Phacus longicauda	*Navicula flagilaroides*	*Synechococcus aquatilis*	
Phacus mirabilis	*Navicula oblonga*	*Synechococcus cedrorum*	
Phacus undulatus	*Nitzschia closterium*	*Synechococcus maior*	
Strombomonas gibberosa	*Pinnularia maior*		
Trachelomonas dictyophora	*Stauroneis anceps*		
Trachelomonas hystrix	*Synedra acus*		
Trachelomonas torquata	*Tabellaria flocculosa*		

Appendix 3.2.4:
Zooplankton species and the count for the respective species at the study stations

	Oru-ma 1	Oru-ma 2	Oru-ma 3	Oru-ma 4	Oru-ma 5	Oru-ma 6	Oru-ma 7	Oru-ma 8	Oru-ma 9
Ciliata									
Arcella sp.	2		3	5		3			
Coleps elongatus	5	13	6	2	13		2		5
Dysteria fluviatilis			3	6					3
Eupotes patella	3	8		2					2
Opercularia coarctata		3	2	8	7		2	1	
Opercularia glomerata	2		3		3	6		3	3
Phascolodon vorticella	2	2		2	8	4			
Vorticella campaula			2		2				
Vorticella citrina	2	7	2	4		3			
Vorticella picta	2	2	2						
Ciliata	**18**	**35**	**23**	**29**	**33**	**16**	**4**	**4**	**13**
Rotatoria									
Anuraeopsis sioli	3	1	1						
Asplanchna brightwelli	8	7	3	5	2		3	4	2
Brachionus bidentata	4		1	18	3	3		3	18
Brachionus budapestinneneis	1	2	5	3	3	2	6	8	5
Brachionus calyciflorus	2	4	7						
Brachionus caudatus	28	34	45	32	27	21			5
Brachionus leydigi		3	6	2			4		5
Brachionus patulus	6	7	3	8	2	2		1	2
Brachionus plicatilis		13	3	7		5			2
Colurella colurus	4			14			1	17	
Euchlanis contorta		4		12	4	8	4	5	10
Euchlanis deflexa				1	2		1		
Euchlanis dialatata	2	5	8		1	3		1	2
Euchlanis lyra		16	19	22	7	8	1	19	11
Euchlanis parameneta				3	5	8			
Euchlanis proxima	18	13	10	4					2
Euchlanis triquetra	15	38	14	16	14	7	9	9	2
Filina longiseta		7	3	6					3

Filina oploliensis									
Filina passa	2	7	3	4	6	2		5	
Kellicottia longispina	6	9		5		3	7		7
Lepadella ovalis	5	13	6	2	13		6		5
Lepadella patella			3	6			5		
Lepadella pyriformis	3	8	6				5		6
Lepadella rhomboides		3	2		7		4	1	
Lepadella triptera	2		3	8	12	6		3	3
Lucane aquila	3	1	1		19	16	6	9	6
Lucane flexilis	8	7		5	2		3	7	3
Lucane hastata	4		1	18	3	3		6	2
Lucane kostei	1			3	3	2	6	8	5
Lucane lunaris	2	4	7				4	2	2
Lucane nana	10	12	18	12	7	21			4
Lucane paxiana	3	2		6	4	8			
Lucane rhytida	3	5	8	8	3	7			
Lucane signifera		13	3	7		5	4	2	3
Lucane stichaea	4			14			1	3	
Notholca baioalensis		4		12	17	8	4	5	10
Notholca cochlearis				1	2		1		
Notholca cruciformis	2	5	8		1	11		1	
Notholca foliacea		16	19	22	7	8	1	5	
Notholca labis				3	5	8			
Notholca quadrata	18	13	10	4					2
Notholca squamula	2		5	3		2			
Platyias leloupi	5	13	6	2	13		6		5
Polyathra vulgaris			3						
Testudinella elliption	6	7	3	8		2			
Rotatoria	**180**	**296**	**243**	**306**	**194**	**179**	**92**	**124**	**132**
Cladocera									
Alona quadrangularis			3	6					3
Cerodaphnia rotunda	3	8	6	2					
Chydorus sphaericus	6	9		5		3	3		
Diaphanosoma brachyurum	5	7	3	5	2				

Eurycercus sp.	4		1		3	3			
Moina recttirostris	1			3	3	2			
Polyphemus pediculus	2	4	7						
Cladocera	**21**	**28**	**20**	**21**	**8**	**8**	**3**	**0**	**3**
Copepoda									
Nauplii normal type	32	24	18	21					
Calanus finmarchicus		13	3	7		5	2		2
Copila mirabilis	4		5	3			1		
Cyclops americanus		2							
Cycopina longicornis				1	2		1		
Diaptomus oregonensis Lill.	2	5	8		1	11			
Eucalanus bungii Giesbrecht				2	1		1		
Mesocyclops salirius				3	5	8			
Murocalanus	18	13	10	4					2
Oithona nana	15	23	14	16	24	3			2
Copepoda	**71**	**80**	**58**	**57**	**33**	**27**	**5**	**0**	**6**

Appendix 3.2.5:
Periphyton species and their numerical values at the study stations

	Oru-ma 1	Oru-ma 2	Oru-ma 3	Oru-ma 4	Oru-ma 5	Oru-ma 6	Oru-ma 7	Oru-ma 8	Oru-ma 9
Euglenophyceae									
Cyclidiopsis acus			3	12					
Euglena acus		9	6		6	9	12	21	45
Euglena pascheri						4	8	17	18
Phacus ocellatus		4			6	11	18	13	82
Phacus acuminatus							2		
Phacus globosus			3		2	12	8	14	22
Phacus longicauda	2		4	6			4	5	9
Phacus onyx		2	8	4		5	6		2
Phacus pleronectes						15	21	6	
Phacus trapezoides		8	5	4		6	3		
Phacus undulatus	6		2			7			
Trachelomonas dictyophora				8				2	
Trachelomonas hystrix							5		
Trachelomonas torquata		3		3		11	5	3	7
Euglenophyceae	**8**	**26**	**31**	**37**	**14**	**80**	**92**	**81**	**185**
Bacillariophceae									
Achnanthes gibberula	2	6	8	11					
Achnanthes inflata		1	2						
Achnanthes nodusa	2	2	3						
Bacillaria paradoxa	2	5	3	4		5	5	1	
Cymbella affinis	3	2			2	3			1
Cymbella amphioxys	3			5	4				
Cymbella microcephala	8	6	20	20	27	16	5	2	24
Diatoma elongatum	5	54	26	8	7				
Diatoma hiemale	12	15	54	78	12				
Diatoma vulgare	4	6	8	14	9				
Diploneis interrupta	1		6		2	1			
Diploneis ovalis	39	19	40	53	26	3			14
Eunotia exigua		2		3	2		4	1	3

Eunotia fallax				4	2			6	
Eunotia gracilis	3		2						2
Eunotia praerupta	2		1	23	22				
Fragilaria construens	5	11	23	8	14	3	2	4	8
Frustulia rhomboides	8			2	3				
Frustulia vulgaris	21	12	8	9	4			2	
Meridium circulare	3		1	1	1				
Navicula bacillum	1		2						
Navicula confervacea	5			2	3				
Navicula contenta	23	38	19	11	5		2		6
Navicula cuspidata	8	8	5		3		7		5
Navicula flagilaroides			2	3	12				
Navicula mutica	5	7	2	8	9	3			1
Navicula oblonga	29	52	12	21	18	2	2		
Navicula ventralis	2			2	2				
Nitzschia acicularis	2		9	3		1		2	
Nitzschia acuta									
Nitzschia angustata									
Nitzschia closterium	321		69	11	43				
Nitzschia linearis	1		4	3			2		1
Nitzschia sublinearis			4						
Nitzschia trybionella			2	4	3		3	2	
Pinnularia debesil		2			5			5	
Pinnularia gibba	12		22	5	16	2		4	
Pinnularia maior	16			5					3
Pinnularia viridis	1		5	5					
Rhoicosphenia curvata		1		3					
Stauroneis anceps	12	1	2	2		1			
Stauroneis dialatata	8					1			
Stauroneis obtusa			9	5					
Synedra acus	33	21	27	18	45	25	14	5	8
Synedra ulna		2		5		1			
Synedra nana		1				1			
Synedra tabulata	4	3	18	6				4	
Tabellaria fenestrata	5			6		8			2

Tabellaria flocculosa		1	1			2			
Bacillariophceae	**611**	**278**	**419**	**371**	**301**	**78**	**46**	**38**	**78**
Cyanophyceae									
Anabaena aqualis	2	7		1	7	3	8	2	2
Dactylococcopsis rhaphidiodes				1	2	3			6
Gloeocapsa minima	6	16	22	38	55	166	178	288	182
Gomphosphaeria aponica	5	7	12	16	22	17	18	34	25
Lyngbya epiphytica		2		4	3	3	122	68	109
Lyngbya holsatica	32	54	26	12	18	18	22	10	12
Lyngbya limnetica	12	15	54	78	96	162	72	30	15
Lyngbya molischii	32	48	8	32	24	8	8	68	8
Marssoniella elegans					1				1
Microcoleus sociatus	62	45	118	67	105	259	204	394	199
Microcystis aeruginosa	58	128	203	198	261	256	645	757	482
Microcystis marginata			3		2				
Oscillatoria amphibia	15	25	5	71	52	251	198	134	178
Oscillatoria brevis	8		7		4	12			
Oscillatoria deflexoides		1		1		1			1
Oscillatoria lacustris		1		1		1			1
Oscillatoria mirabilis		3	2		4				2
Oscillatoria nigra		2		2		2			2
Oscillatoria rupicola		3		3		3			3
Oscillatoria trichoides	3		2				3		
Phormedium ambiguum		2		5			2		
Phormedium cebennense			4		3	2			
Phormedium cincinnatum			2		3				
Phormedium papillaterminatum		2		3	6	2			
Phormedium uncinatum	5	8	18	67	88	51	57	89	102
Spiriluna minima	4		5	5	35	23	16	13	9
Synechococcus aquatilis	5	3	56	35	45	12	122	271	151
Synechococcus cedrorum	2		21	78	61	664	438	356	489
Synechococcus maior	7	12	3	32	86	176	106	286	338
Tetrapedia crux-michaeli						1			
Cyanophyceae	**258**	**384**	**571**	**750**	**983**	**2.096**	**2.219**	**2.800**	**2.317**

Chlorophyceae									
Closterium acerosum	3	9	6	6	2	4	2	3	
C. closteriodes	11		6		3	7			
C. ehrenbergii	4		1	13					3
C. gracile	4		10	5	8				4
C. lunula	1	2	2					6	
C. parvulum	12	5	4	7		4	1		
Mougeotia sphaerocarpa			2	2	6				
Oedogonium crassum		3		8	4	3	3		
Pediastrum simplex	2	7		2		4	2		5
Scenedesmus dubia							5		
S. insignis	8	14	28	34	62				
S. karnalae		5	5	8	2		4	2	
Scenedesmus quadrincauda		3	8	5	3			3	
Ulothrix tenuissima			13	16	18	4	2		
U. zonata			5	2	4				
Chlorophyceae	**45**	**48**	**90**	**108**	**112**	**26**	**19**	**14**	**12**

Appendix 3.3.1
Physiochemical Properties of the Related Sediments (June, 2007)

Sample	Co-ordinates			µS/cm	Mg/kg	%		C:N	µg/g					Meg/100g Soil					%			Textural
Identity	E	N	pH	EC	THC	Org. C	TN	ratio	Av.P	NO^-_3	NO_2^-	NH^+_4	SO_4^{2-}	K^+	Na^+	Ca^{2+}	Mg^{2+}	CEC	Sand	Silt	Clay	Class
01	04°55' 33.3"	006°25' 22.0"	5.51	67	2116.06	3.35	0.51	7	13.4	19.8	6.3	17.9	28.6	14.8	8.0	18.7	20.0	18.3	3.6	30.6	65.8	Clay
02	04°55' 33.2"	006°25' 22.1"	6.24	527	91.62	2.98	0.45	7	12.8	18.2	6.8	18.0	25.1	13.6	8.1	15.6	18.4	18.4	4.2	31.0	64.8	Clay
03	04°55' 34.4"	006°25' 23.7"	5.73	92	235.60	3.02	0.40	8	13.2	16.8	7.2	18.1	24.7	13.2	9.0	14.1	17.2	18.0	4.5	30.0	65.5	Clay
04			5.71	29	17.45	3.12	0.46	7	13.1	16.0	7.0	17.2	25.4	12.8	7.8	14.8	16.8	19.2	3.4	29.5	67.1	Clay
05			5.86	127	161.43	2.86	0.36	8	12.6	17.4	6.2	18.4	26.2	14.0	8.0	15.2	14.4	17.8	3.6	30.6	65.8	Clay
06			6.51	365	209.42	3.35	0.38	9	12.9	16.6	8.3	17.5	25.4	12.9	8.2	13.8	16.8	17.7	5.0	32.6	62.4	Clay
Kolo Creek			6.48	205	211.40	2.40	0.42	6	12.2	16.0	7.9	17.0	24.2	13.0	8.2	15.0	13.8	17.9	4.6	30.0	65.4	Clay

Appendix 3.3.2:
The benthic fauna species and their numeric values at each of the study stations

	Stations								
	Oru-ma 1	**Oru-ma 2**	**Oru-ma 3**	**Oru-ma 4**	**Oru-ma 5**	**Oru-ma 6**	**Oru-ma 7**	**Oru-ma 8**	**Oru-ma 9**
Oligochaeta									
Styleria lacustius									
Insecta									
Dytiscus marginalis	1	1							
Hydroporus sp. (after brocher)			1						
Aeshina cyanea (odonata)	1								
Coenagrion puella		1							
Gyrimus sp.		2							
Insecta	**2**	**4**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Gastropoda									
Pila ovata		1							
Gastropoda	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pisces									
Aphyosimion syeostedti	1							2	
Eleotis senegalensis			1						
Rana sp. (frog)	2	3							
Clarias camerunensis			1						
Thysochiomis ansorgi	1								
Hemichromis elongatus	1								
Desmoclharis tripanosa	4								
Pisces	**9**	**3**	**2**	**0**	**0**	**0**	**0**	**2**	**0**

A Open dump for collection and burning of oil
B Creek blocked by logs used during cleaning
C Impact of burning of recovered oil on vegetation
D Pond of water with oil sheen
E Field team at work in Oruma study area
F Field team with some members of Oruma