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Seasonal Variation in Abundance, Distribution and Environmental Impacts of Geomicrobiological Communities in the Lower Calabar River Channel, Calabar, Nigeria

Fidelis Abija [1,4*] Ta Harry[2] and Ho Nwankwoala[3]

[1]Centre for Geomechanics, Energy and Environmental Sustainability, Port Harcourt, Nigeria

[2]Department of Geology, Akwa Ibom State University, Nigeria

[3]Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria

[4]Institute of Geosciences and Space Technology, Rivers State University, Port Harcourt, Nigeria

ABSTRACT

Microbes act as geochemical agents for the degradation of environmental contaminants hence their abundance and distribution influences ecological response to pollution stress in soils, sediments, and rivers systems and in environmental protection. In this paper seasonal variation in geomicrologicl abundance in the river water, sediments and adjoining soils have been assessed. The results indicate a higher microorganism count during the wet season. The presence of E. coli in 100ml of water implies that water is unsuitable for any domestic use without disinfection. The Faecal and Total Coliform counts also indicate that undesirable sources are contaminating the river and posing environmental health risk. However environmental self-remediation and possible absence of sources of the microorganisms was promoted during the wet season than the dry season.

***Corresponding author**

Fidelis Abija, Centre for Geomechanics, Energy and Environmental Sustainability, Port Harcourt, Nigeria. E-mail: fidelabija@yahoo.co.uk

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Introduction

Microorganisms such as bacteria, fungi, algae, and protozoa serve as geochemical agents in the uppermost lithosphere and hydrosphere [1]. Microbes promote rock weathering by mobilizing mineral constituents with inorganic or organic acids or ligands that they excrete, redox attack on minerals such as Fe and Mn or causation of passive or active mineral formation by precipitation or subsequent nucleation of crystals. The interaction between microorganisms and earth materials is important in the near surface environment and where biotic and abiotic factors control the conditions of life sustaining resources and virtually all elements can be transformed by microbes [2]. Geomicrobiology deals with the interaction between microorganisms and earth materials. The effective design of contaminated sites as well as environmental self-cleansing rely on the relative abundance and distribution of geomicrobiological communities with the ecosystem. Geomicrobiological processes are relevant in the natural environment such as aquifers geological and geochemical processes, extreme environments and metal reduction [3]. Microbial roles in geo-environmental cycles include dissolution of inorganic phosphate minerals in soils, release of organically bound Phosphorus, assimilation and transformation of inorganic Phosphorus, degradation of organic Sulfur compounds, Sulfur transformations, oxidation of Hydrogen Sulfide to Sulfur and reduction of Sulfur to Hydrogen Sulfide. Certain bacteria such as Heterotrophic bacteria process organic Carbon in the environment. In the aquatic ecosystem, planktonic microorganisms constitute the lowest level in the food chain supporting fisheries, bivalves, and whales [4]. Microorganisms provide carbon from grazing of phyto and zooplanktons and planktons also take up anthropogenic carbon dioxide [5-8]. Photosynthetic processes of phytoplanktons also Oxygen into the river ecosystem as a by-product and estimated that about 50% world Oxygen is a produced by phytoplankton photosynthesis [9]. Even atmospheric carbon dioxide/Oxygen balance has been controlled by phytoplankton photosynthesis since the Precambriam [10]. Microorganisms enzymatically attack environmental contaminants and convert them into harmless products hence their use in bioremediation processes. Riverbed sediments are more stable and less variable active biogeochemical media and microorganisms play key role in nutrient cycle and heavy metal immobilization [11]. Understanding the role of contaminants with a focus on how microbial communities and ecological functions respond to pollution stress has been recognized as essential in protection the environment (soils, sediments, and rivers systems) [12,13]. Human health is also linked highly to microbial abundance in

the geological environment as increase accumulation of E. Coli in riverbed sediments has been reported by [14]. Sediments are notable inks and sources of Fecal Coliform with sources including wastewater releases, human population, in situ growth, infrequent deposition of faeces, agricultural livestock waste and run off from arable farms [15,16]. Reported that wastewater input of E [17]. Coli and intestinal enterococci were 35 and 15 times higher respectively than non-point source in puts in the Scheldt estuary. Weather and diffuse agricultural and wastewater contributions to increase in E. Coli have been reported by and underscoring the need for evaluation of temporo-spatial abundance and distribution of microbes in environmental geomicrobiological assessment [15,18]. Moreso, the mobility, persistence, and metabolic activity within or between indicator species is not constant in the environment [19]. Metabolic activity may decrease with exposure to saltwater and boosted by elevated nutrient levels [20].

This research was carried out to assess the baseline seasonal abundance and distribution of the geomicrobiological communities in view of their roles in the breakdown of toxic compounds, remediation potential and environmental impacts in soils, sediments and aquatic ecosystem in and around the river channel.

Study Area

The study area is the Calabar River channel and adjoining land which has been discussed by [21]. It is located between latitudes 040 56''N and 050 4''N and longitudes 080 15''E and 080 24''E. The river is tidal with a tidal range varying along the shoreline subjected to relatively low waves (Figure 1). The climate is tropical equatorial with sunshine being high throughout the year and maximum between January and May while minimum occurs in July and September. Temperatures range on average between 26 and 27 °C during the dry months of to March; and about 24 °Cduring wet months of June and September. Daily temperatures oscillate between 31. 7 °C and 23 °C in dry season highest average values of humidity reach 90 in August as against an average minimum of 74 % in February. Rainfall is most intense (>3500 mm) between April and October, the values being 5 - 7 times higher than in November to March (500 mm). The heavy rainfall tends to accelerate runoff volume and rate thereby resulting in flooding and environmental degradation in the city.

The geotectonic evolution and regime is the same as that of the Niger Delta and Benue trough, Nigeria [22]. The Calabar flank is a hinge line bordering the East-South-East limit of the Niger Delta basin. Tectonically, Cretaceous fracture zones controlled basin evolution during the triple junction rifting and opening of the south Atlantic and the palaeo-indicators include trenches and ridges in the deep Atlantic [23]. These fracture zone ridges subdivide the margin into individual basins and forms the boundary faults of the Cretaceous Benue - Abakaliki trough that cuts far into the West African shield. The Benue trough, an aulacogen of the triple junction rift system started opening in the Late Jurassic and persisted into the Middle Cretaceous diminishing in the Niger delta in the Late Cretaceous [24]. The Niger Delta basin evolved through triple junction rifting, opening of the continent and extension of the fracture zones into the Gulf of Guinea during the Cretaceous. The development of the Niger Delta resulted from the formation of the Benue trough as a failed arm of a rift triple junction associated with the separation of the African and South American continent and subsequent opening of the South Atlantic [26]. Most parts of Calabar are overlain by a veneer of consolidated and unconsolidated coastal plain sands of the Benin Formation which overlies the Nkporo shale [27].

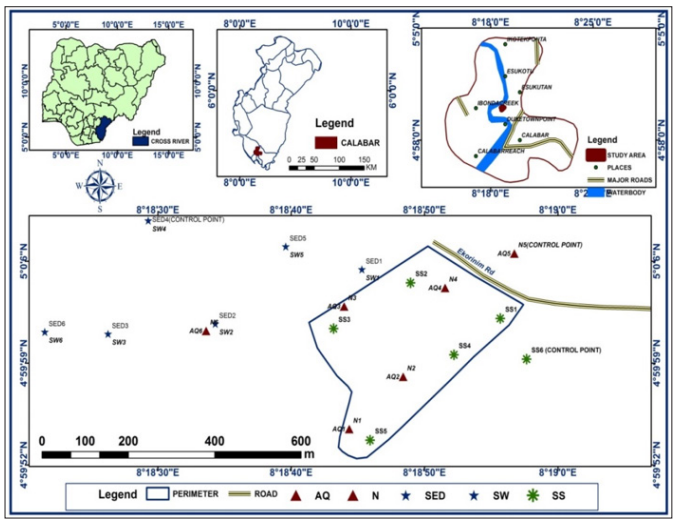

Figure 1: Map of the study area showing sampling locations

These Pleistocene continental sands, sandstones and gravels are friable and of fresh water origin forming excellent aquifer properties with occasional intercalation of shales. The Benin Formation forms the regional aquifer of the Niger Delta basin and it grade into various types of quaternary alluvial deposits comprising mainly of recent deltaic sands on the surface [28-30]. Adjoining Calabar to the north, are the Calabar Flank, a cretaceous sedimentary unit and the Precambrian basement complex of the Oban massif. The coastal pain sands of the Benin Formation are overlain by Quaternary deposits of about 40-50 m thick. Hydrogeologically, the main water-bearing unit in the area is the coastal plain sand aquifer of the Benin Formation. It is composed of unconsolidated and loose sediments; predominantly gravel, sand, silt and clay of Tertiary to recent age. The sands comprising of medium - coarse grained, moderately sorted, subangular to subrounded grains constitute more than 80% of the aquifer materials. The Benin Formation in Calabar area has been divided into two major water bearing units: the upper gravelly and the lower sandy groundwater aquifers. The upper aquifer has mean thickness of 52.7m and average static water level of about 35.0m. The static water level varies from as low as 22.10 to 68.80 m during the wet season. Groundwater table elevation varies from 10m to 50m in the central part. The regional groundwater flow is in the north/south with divide at central parts of Calabar area [31]. Present day tectonic activities are dominated by the NE – SW Ifewara – Zungeru complex fault system that cuts across the metamorphic basement complex and the younger sedimentary rocks of Nigeria [32].

Study Methods

Field methods involved in situ sampling of soil, sediment and water; and laboratory analysis. Sampling was done in between 18th–20th July 2013 (wet season), 14th –16th March, 2014 (dry season) and December 18th –20th 2018. The methodology and procedures for sample collections, storage/handling and analysis were such that dependability and reproducibility were assured. Care and diligence were exercised to ensure that the samples collected were truly representative of the environmental component and no chemical, biological or physical changes occurred before analyses were completed. Sediment samples were collected from the same sampling stations as that of surface water samples by the use of an Eckman grab that was lowered to the bottom of the stream, and triggered to bite large quantities of sediment through the release of a messenger which forces the grab's key to open its jaws and close when filled. A composite of three successful

grab samples was removed from the grab using an acid washed plastic scoop, and placed in appropriately labeled, acid washed plastic or glass containers. Benthic macro fauna was sampled by sieving 0.01cm3 of sediments through a 1.0mm mesh sieve in the field, using fresh water and organisms picked into plastic containers and stained with Rose Bengal dye in 5% formalin and stored at room temperature in plastic bottles. Rose Bengal (0.5 g/l) dye stains the organism bright pink and aids the subsequent sorting of organisms from sediments and detritus, which do not pick up the dye.

Surface water samples were collected by the use of a 2litre hydrobious at each station. Three samples were collected at each station and composited one for use in laboratory identification of the microbes. Samples for phytoplankton studies were collected at 0.5m water depth and preserved with Lugol's iodine solution and stored in dark polythene bags. Zooplankton samples were collected with a plankton net of 100micron mesh size. The net was towed for two minutes at a depth of 2m from a dug-out canoe. In the laboratory zooplanktons samples were concentrated to about 50ml by gravity over 24hours and another 5mls by centrifugation. Triplicate samples were taken from each concentrate and transferred to Sedgwick rafter slides for identification and enumeration using the keys of and for the zooplanktons and for phytoplankton [33-37].

The soil sampling was carried out with a 30cm core cutter. Three (3) borings samples were collected from a sampling station and composited into one. Surface soils were collected at 0-15cm depths while subsurface soils were collected at 15cm-30cm depths. The soil samples were kept inside polythene bags, labeled and stored inside the cooler. Indirect cell count on soil sample was carried out to determine the total viable microbial populations. The test method used is the ASTM D5465- 93: determining microbial colony counts from water analyzed by plating methods, and APHA907: standard plate count. Total microbial count in colony forming unit per milliliter were calculated using equation (1).

$$Plate\ count\ (cfu/ml) = \frac{no.of\ colonies\ on\ plate/av\ no.\ of\ colonies \times dil.\ factor}{actual\ volume\ of\ samples} \quad \ldots\ldots\ldots\ (1)$$

Results and Discussion

Surface Water Microbiology

The microbial counts (in range), as expressed by the densities of heterotrophic/hydrocarbon utilizing bacteria, and heterotrophic/ hydrocarbon utilizing fungi, for the wet season periods are presented in Table 1a, 1b and 1c. The total coliform counts in the surface water samples during the wet season of 2013 ranged from 100 - 110 per 100ml (Table 1a); 92 – 102per 100ml of water in the dry season of 2014 (Table 1b) and 4.5 – 4.6 in the dry season of 2018 (Table 1c). Faecal coliform ranged from 4.0 – 7.0 per 100ml and 2 – 4,0 per 100ml of water in the 2013 wet and 2014 dry seasons respectively (Tables 1a and b). Escherichia coli range from Nil - 1.0 x 10^1 cfu/ml during the 2013 wet season (Table 1a) and 0 – 4.0 during the dry season waters samples in 2014 (Table 1b). There was no hydrocarbon utilizing bacteria detected during the 2013 and 2014. However, during the 2018 dry season sampling the hydrocarbon bacteria count varies from 0.20 x10^1 to 0.22 x10^1cfu/ml. The Hydrocarbon utilizing fungi range from 0.0 - 1.0 x 10^1 cfu/ml during the 2013 wet season, 0 - 1.0 x 10^2cfu/ml and non was detected in 2018 (tables 1a, 1b and 1c). Total heterotrophic bacteria count range from 5.0 x10^4- 9.0 x10^4 cfu/ml in 2013 wet season, 3.0 x10^2 - 2 x10^3 cfu/ml in the dry season of 2014 and 1.20 x10^2 – 1.21 x10^2 cfu/ml during the 2018 dry season while Nitrobater was not detected in any of the samples (Tables 1a, 1b and 1c). A reduction in the total heterotrophic bacteria count was indicated between the dry and wet seasons with the wet season recording higher density. The hydrocarbon utilizing bacteria was totally absent in the wet and dry seasons of 2013 and 2014 respectively while in 2018 there was abundance which varies from 3.30x10^1 to 3.50x10^1 cfu/ml of water. Faecal coliforms range from 7 – 4cfu per 100ml of water in the wet season of 2013 and 2 – 4cfu per 100ml of water in the dry season of 2014. The results indicate a higher microorganism count during the wet season. The presence of E. coli in 1ooml of water implies that water is unsuitable for any domestic use without disinfection. The Faecal and Total Coliform counts also indicate that undesirable sources are entering into the river posing environmental health risk. However environmental self-remediation and possible absence of sources of the microorganisms was promoted during the wet season than the dry season.

Table 1a: 2013 Wet season microbial densities of surface water

Sample	Nitrobacter	THBC (cfu/ml)	HUBC (cfu/ml)	FCC (per 100 ml)	HUFC (cfu/ml)	ECC per 100 ml	THFC (cfu/ml)	TCC per 100ml
SW1	Nil	9.0 x10^4	Nil	7	1.0 x 10^1	1.0 x 10^1	2.0 x10^1	110
SW2	Nil	7.1 x10^4	Nil	4	1.0 x 10^1	1.0 x10^1	1.0 x10^1	100
SW3	Nil	5.0 x10^4	Nil	5	1.0 x 10^1	1.0 x 10^1	2.0 x10^1	110
SW4	Nil	8.0 x10^4	Nil	7	Nil	1.0 x 10^1	1.0 x10^1	105
SW5	Nil	8.0 x10^4	Nil	7	1.0 x 10^1	Nil	2.0 x10^1	110
SW6	Nil	9.0 x10^4	Nil	7	Nil	1.0 x 10^1	2.0 x10^1	110

Table 1b: 2014 Dry season microbial densities of surface water

Sample	Nitrobacter	THBC (cfu/ml)	HUBC (cfu/ml)	FCC (per 100 ml)	HUFC (cfu/ml)	ECC per 100 ml	THFC (cfu/ml)	TCC per 100ml
SW1	Nil	3.0 x102	Nil	3	Nil	1	6	101
SW2	Nil	4 x102	Nil	2	5	Nil	3	102
SW3	Nil	4 x102	Nil	4	1.0 x 102	3	9	90
SW4	Nil	1 x103	Nil	3	Nil	2	10	97
SW5	Nil	2 x103	Nil	3	Nil	1	12	63
SW6	Nil	5 x102	Nil	2	Nil	4	3	92

Table 1c: 2018 Dry season microbial densities of surface water

PARAMETERS	CONTROL SW	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
TCC (cfu/100ml	4.5	4.6	4.5	4.5	4.6	4.5	4.5	4.6	4.5
THB(mg/l)	1.20 x102	1.21x102	1.21x102	1.20x102	1.21x102	1.21x102	1.20x102	1.21x102	1.21x102
HUB(mg/l)	0.20 x101	0.22x101	0.22x101	0.20x101	0.22x101	0.22x101	0.20x101	0.22x101	0.22x101
THF(mg/l)	3.30x101	3.50x101	3.50x101	3.30x101	3.50x101	3.50x101	3.30x101	3.50x101	3.50x101
HUF(mg/l)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

TCC = Total Coliform Count

Sediment Microbiology

The summary results of the Total Heterotrophic Bacterial Counts (THBC), Hydrocarbon Utilizing Bacterial Counts (HUBC), and their fungal types are presented in Table 2a, 2b and 2c. Results showed that total hydrocarbon utilizing bacteria count 1.0 x 10^4 to 1.5 x 10^4cfu/g during the 2013 wet season, 0.0 to 2 x10^2cfu/g of sediment in the dry season of 2014 and 1.0x10^6 to 2.06 x10^6cfu/g during the 2018 dry season sampling period. The hydrocarbon utilizing bacteria count varies from 0.0 - 1.0 x 10^2 cfu/g during the 2013 wet season, 6.0 – 10.0cfu/g in the 2014 dry season and totally undetected in 2018. The total heterotrophic fungal count 1.0 - 8cfu/g in the wet season of 2013, 3.0 – 6.0 cfu/g during the 2014 dry season and absent in all the samples during the 2018 dry season sampling (Tables 2a, 2b and 2c). These results implied relatively low levels of hydrocarbon utilizing bacterial counts/population.

Table 2a: 2013 Wet season bacterial population densities of sediment samples

Sample	Season	THBC (cfu/g)	HUBC (cfu/g)	THFC (cfu/g)	HUFC
SED1	Wet	1.0 x10^4	1.1 x10^2	1.0 x10^2	4
SED2	Wet	1.0 x10^4	1.5 x10^2	1.0 x10^2	8.0
SED3	Wet	1.5 x10^4	1.0 x10^2	1.0 x10^2	5.0
SED4	Wet	1.0 x10^4	1.0 x10^2	1.0 x10^2	5.0
SED5	Wet	1.0 x10^4	Nil	1.0 x10^2	5.0
SED6	Wet	1.5 x10^4	1.0 x10^2	1.0 x10^2	1.0

Table 2b: 2014 Dry season bacterial population densities of sediment samples

Sample	Season	THBC (cfu/g)	HUBC (cfu/g)	THFC (cfu/g)	HUFC
SED1	Dry	Nil	10	10	3
SED2	Dry	1.0 x10^2	10	10	4
SED3	Dry	2 x10^2	9	Nil	3
SED4	Dry	1.0 x10^2	12	7	6
SED5	Dry	1.0 x10^2	6	11	2
SED6	Dry	1. x10^2	10	9	3

Table 2c: 2018 Dry season bacterial population densities of sediment samples

PARAMETERS	SED I	SED 2	SED3	SED4	SED5	SED6	SED7	SED8	SED9
THB(mg/l)	2.06x10^6	1.0x10^6	2.06x10^6	2.06x10^6	2.06x10^6	2.06x10^6	2.06x10^6	2.06x10^6	2.06x10^6
HUB(mg/l)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
THF(mg/l)	9.00X10^6	8.00X10^6	8.00X10^6	7.00X10^6	9.00X10^6	9.00X10^6	9.00X10^6	7.00X10^6	8.00X10^6
HUF(mg/l)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Phytoplankton

The abundance and distribution of phytoplankton in lower Calabar River during the 2013 wet, 2014 and 2018 dry seasons are presented in Tables 3a and 3b and Figures 1a and 1b and 1c respectively showing the contribution each of the major families of phytoplankton. Five major families of phytoplankton were recorded; namely Baccillariophyta, Chlorophyta Cyanophyta, Xanthophyta and Euglenophyta. The Chlorophyta were the most dominant family and constituted 27.73% in the wet season and 29.63% in the dry season (Fig 1a and 1b). The Chlorophyta were represented by 5 species the most abundant species being *Micrasterias decemdenta* (59) while *Closterium sp*. (8) is least abundant during the wet season. The second dominant group of phytoplankton was the Baccillariophyta, which contributed 27.17% of the total number of phytoplankton recorded in the wet season (Fig 1a). The Baccillariophyta was 30% in relative abundance in the dry season, a little higher than the wet season with 7 species recorded. The most dominant Baccillariophyta species were *Synedra sp*. (31), while *Amphora ovalis* (2) and *Melosira varians* (2) are the least

abunndant. Other members of this family include *Tabelarai fenestrata* (5), *Cyclotella operculata* (15), *Cosinodiscuas sp*. (23), and *Navicula sp*. (19). The Xanthophyta recorded 26.61% and 29.63% during the wet and dry seasons respectively. Two species were represented in this family and these include *Tribonema valgare* (42) and *Tribonema virides* (53). In all, the dominance pattern of the various families of phytoplankton was Chlorophyta > Baccilariophyta > Xanthophyta > Euglenophyta > Cyanophyceae in the wet season of 2013 (Table 3a) and Chlorophyta > Euglenophyta > Cyanophyta in the dry season (Table 3b). The results of the 2018 dry season sampling indicate the diatoms (brown algae) to have the highest abundance and distribution (61.05%) followed by the Chlorophyta (green algae) with 25.08%, the Cyanophyceae with 6.27%, Euglenophyceae (4.29%) and Xanthophyceae with 3.30% (Table 3c and Figure 1). The diatoms can be considered as an indicator species with respect to phytoplankton occurrence within the study area. Sample location 4 has the highest number of diatoms, algae and protozoan, followed by site 2 then site 1 and site 3. This trend in abundance and distribution of phytoplankton species is expected in view of the fact that site 1 and 3 are within the dredged area and this has decreased the phytoplankton species unlike the other unimpacted sampling site 2 and 4.

Table 3a: Phytoplankton Distribution and Abundance in 2013 wet season

	Sample Locations			
PHYLUM/CLASS / SPECIES	1	2	Total/class	Relative Abundance
Baccillariophyta				
Synedra sp.	23	8		
Amphora ovalis	2	0		
Cyclotella operculata	11	4		
Melosira varians	0	2		
Navicula sp.	8	11		
Cosinodiscus sp.	16	7		
Tabelaria fenestrata	3	2		
Sub-Total	63	34	97	27.17
Xanthophyta				
Tribonema valgare	24	18		
Tribonema virides	31	22		
Sub-Total	55	40	95	26.61
Chlorophyta				
Cladophora sp.	8	4		
Netrium digitus	6	3		
Micrasterias decemdenta	38	21		
Closterium sp.	8	0		
Spirogyra sp.	4	7		
Sub-Total	64	35	99	27.73
Cyanophyta				
Oscillatoria spiroides	3	1		
Oscillatoria princes	2	0		
Sub-Total	5	1	6.0	1.68
Euglenophyta				
Phacus sp.	33	27		
Sub-Total	33	27	60	16.81
Total No. of Species			357	100

Table 3b: Phytoplankton Distribution and Abundance in the 2014 Dry season

PHYLUM/CLASS / SPECIES	Sample Locations			
	1	2	Total/class	Relative Abundance
Baccillariophyta				
Synedra sp.	18	11		
Amphora ovalis	3	1		
Cyclotella operculata	4	1		
Melosira varians	0	1		
Navicula sp.	3	7		
Cosinodiscus sp.	1	4		
Tabelaria fenestrata	1	1		
Sub-Total	30	26	56	29.63
Xanthophyta				
Tribonema valgare	12	7		
Tribonema virides	23	14		
Sub-Total	35	21	56	29.63
Chlorophyta				
Cladophora sp.	3	1		
Netrium digitus	4	1		
Micrasterias decemdenta	14	23		
Closterium sp.	2	1		
Spirogyra sp.	2	3		
Sub-Total	25	29	54	28.56
Cyanophyta				
Oscillatoria spiroides	1	2		
Oscillatoria princes	1	1		
Sub-Total	2	3	5	2.65
Euglenophyta				
Phacus sp.	12	6		
Sub-Total	12	6	18	9.52
Total No. of Species			189	100

Table 3c: 2018 Phytoplankton Distribution and Abundance in the 2018 Dry season

Taxonomic Group	SW1	SW2	SW3	SW4	Total	% Total
Baccilariophyceae						
Cymbella cistula	14	10	8	11		
Cymbella specie	8	5	3	7		
Melosira varians	11	8	7	12		
Amphora ovalis	1	0	2	1		
Navicula radiosa	6	4	3	7		
Cyclotella operculata	10	8	6	11		
Nitzschi denticula	4	6	7	5		
Total	54	41	36	54	185	61.05
CHLOROPHYCEAE						
Cladophora sp.	1	0	2	4		
Volvox globator	3	1	3	5		
Gonium pectorole	1	0	2	4		
Eudorina Califernica	4	2	1	3		
Crucigenia sp.	8	5	7	7		
Microspore sp.	0	1	3	3`		

Spirogyra sp.	2	0	1	3		
Total	19	9	19	29	76	25.08
Xanthophyceae						
Tribonema vulgare	4	1	0	3		
Tribonema vivide	1	0	0	1		
TOTAL	5	1	0	4	10	3.30
Euglenophyceae						
Phacus caudatus	3	1	3	4		
Euglena acus	0	0	1	1		
Total	3	1	4	5	13	4.29
Cyanophyceae						
Spirulina princeps	2	1	1	2		
Oscillatoria sp.	2	0	1	1		
Raphidiopsis	3	1	2	3		
Total	7	2	4	6	19	6.27
					303	100

Zooplankton

The zooplanktonic fauna identified can be categorized into Copepods, Cladocera, Rotifers, Protozoa and Crustacea (Tables 4a, 4b and 4c and Figures 2a, 2b and 2c). The percentage composition of each of these major zooplankton groups are presented in Figures 2a, 2b and 2c. The Copepods with 69.92% and 77% in the 2013 wet and 2014 dry seasons respectively of the total zooplankton constituted the most dominant group while the Crustaceans with 0.81% in the wet season and 1% in the dry season of the population was the least dominant; Cladocera constituted 24.19% and 8% in the 2013 wet and 2014 dry seasons respectively. Rotifers recorded 13.01% and 10%, Protozoa 4.01% and 4.0% in the 2013 wet and 2014 dry seasons respectively. In all, the dominance pattern of the various families of zooplankton was Copepoda > Cladocera > Rotifera > Protozoa > Crustacea. The abundance and distribution of zooplankton during the 2018 dry season sampling is shown in Table 4.c and Figure 2c. Copepoda has the highest percentage occurrence (57.28%), followed by cladoceran (24.12%), Rotiferan with (11.05%), protozoan with (6.03%) and insecta with 1.51%. The balance in the composition of zooplankton, in the river underscores the importance of secondary producers in the energy flow pattern in the system, an indication of a healthy non-polluted system.

Table 4a: Zooplankton Distribution and Abundance in the 2013 Wet Season

PHYLUM/CLASS / SPECIES	**Sample Locations**			
	1	2	Total/class	Relative Abundance
Rotifers				
Trichotria pocillum	8	3		
Trichotria tetractis	2	1		
Plosoma truncates	0	2		
Sub-Total	10	6	16	13.01
Cladocera				
Semocephalus semilata	4	1		
Moina macrocopa	3	6		
Albna costata	1	0		
Sub-Total	8	7	15	24.19
Copepoda				
Anomalocera patersoni	6	8		
Centropages typicus	23	14		
Arcatia longiremis	8	0		
Mesocyclops sp.	4	2		
Calamus sp.	3	0		
Paracyclops sp.	0	9		
Mesochara suifunensis	7	2		
Sub-Total	51	35	86.0	69.92

PROTOZOA				
Zoothinmoium sp.	3	0		
Epitilis sp.	0	2		
Sub-Total	3	2	5.0	4.01
CRUSTACEA				
Caridina sp.	1	0		
Sub-Total	1	0	1	0.81
Total No. of Species			123	100

Table 4b: Zooplankton Distribution and Abundance in the 2014 Dry Season

PHYLUM/CLASS / SPECIES	Sample Locations			
	1	2	Total/class	Relative Abundance
Rotifers				
Trichotria pocillum	5	1		
Trichotria tetractis	1	1		
Plosoma truncates	1	1		
Sub-Total	7	3	10	10
Cladocera				
Semocephalus semilata	2	1		
Moina macrocopa	1	3		
Albna costata	1	0		
Sub-Total	4	4	8	8
Copepoda				
Anomalocera patersoni	4	7		
Centropages typicus	22	15		
Arcatia longiremis	7	3		
Mesocyclops sp.	0	1		
Calamus sp.	0	1		
Paracyclops sp.	2	5		
Mesochara suifunensis	3	7		
Sub-Total	38	39		77
PROTOZOA				
Zoothinmoium sp.	2	1		
Epitilis sp.	1	0		
Sub-Total	3	1	4.0	4
CRUSTACEA				
Caridina sp.	0	1		
Sub-Total	0	1	1	1
Total No. of Species				100

Table 4c: Zooplankton Distribution and Abundance in the 2018 dry season

Taxonomic Group	SW1	SW2	SW3	SW4	Total occurrence per group	Relative abundance per group
COPEPODA						
Temora sp.	4	2	3	6		
Nitocra lacustris	1	0	3	3		
Calamus sp.	8	5	4	7		
Paracyclops fimbriata	3	4	7	6		
Limnothona sinesis	1	0	0	3		
Macrocyclops albidus	1	3	1	4		
Centropages typicus	8	6	4	7		
Total	**36**	**20**	**22**	**36**	**114**	**57.28**
ROTIFERA						
Trichotria pocillium	3	0	1	2		
Brachionus angularis	2	1	4	4		
Colurella obtuse	0	0	2	3		
Total	**5**	**1**	**7**	**9**	**22**	**11.05**
CLADOCERA						
Bosmina fatalis	3	4	3	8		
Moina dubia	5	3	2	4		
Daphnia carinata	3	3	6	4		
Total	**11**	**10**	**11**	**16**	**48**	**24.12**
PROTOZOA						
Verticella sp.	**2**	**0**	**1**	**1**		
Centropyxis constrida	**3**	**1**	**1**	**2**		
Euglypha cilita						
Erontonia leucas	**0**	**1**	**0**	**0**		
Total	**5**	**2**	**2**	**3**	**12**	**6.03**
INSECTA						
Chironomus larva	**2**	**0**	**0**	**1**		
Total	**2**	**0**	**0**	**1**	**3**	**1.51**
					199	**100**

The Copepods can be considered as the indicator species of the zooplankton species within the study sites. Sampling site 4 and site 2 has the richest zooplankton abundance and distribution followed by sampling site 3, then sampling site 1 has the least zooplankton abundance and distribution, table 2. The trend observed among sampling sites in zooplankton abundance and distribution is similar to phytoplankton occurrence. This is expected as there is a positive correlation between phytoplankton and zooplankton. High occurrence of phytoplankton specie in most cases is reflected with high occurrence of zooplankton species. As noted for phytoplankton, the impact of dredging has reduced the occurrence of zooplankton species at site 1 and site 2 as compared to sites 3 and 4.

Benthic Fauna

The list of benthic fauna and their distribution within riverbed is presented in the Tables 5a, 5b and 5c; and Figures 3a, 3b and 3c. for the 2013 wet, 2014 dry and 2088 dry seasons respectively. A total of 5.0 organisms were encountered and these belong to four (3) major taxonomic groupings. The groupings and percentage contributions to the total macro-benthic collection are Oligochaeta (11.76% - wet season 2013, 8% dry season 201) and Bivalvia (35.28% - wet season 2013 and 42% - dry season 2014) and Insecta larvae (52.93% - wet season 2013 and 50% - dry season 2014) (Figures 3a and 3b). Insect larvae were the dominant benthos and consisted of chironomus and Odonata larvae. The only ecological factor that may be responsible for this is the decreased salinity and conductivity of the area in the wet season making the sediment more favorable for occupation by benthos.

Table 5a: Distribution and Abundance of Benthic fauna during the 2013 Wet Season sampling

PHYLUM/CLASS / SPECIES	Sample Locations				
	1	2	3	Total	% Total
Oligochaete					
Tubificid sp.	0	1	1	**2**	**11.76**
INSECTA					
Chironomus (Larvae)	2	1	1	**4**	**23.52**
Odonta (Larvae)	1	3	1	**5**	**29.41**
Bivalvia					
Aspatheria sinuate	2	1	0	**3**	**17.64**
Spathopsis sp.	1	0	2	**3**	**17.64**
Total (No. of orgnism/sq.m)				**17**	**100.0**

Table 5b: Distribution and Abundance Benthic fauna during the 2013 Dry Season sampling

PHYLUM/CLASS / SPECIES	Sample Locations				
	1	2	3	Total	% Total
Oligochaeta					
Tubificid sp.	1	0	0	**1**	**8.33**
INSECTA					
Chironomus (Larvae)	1	1	0	**2**	**16.67**
Odonta (Larvae)	0	3	1	**4**	**33.33**
Bivalvia					
Aspatheria sinuate	1	0	1	**2**	**16.67**
Spathopsis sp.	1	1	1	**3**	**25.0**
Total (No. of orgnism/sq.m)				**12**	**100**

Table 5c: Distribution and abundance of benthic fauna during the 2018 dry season sampling

Taxonomic group	SW1	SW2	SW3	SW4	Total	% Total
OLIGOCHAETA						
Tubificid sp.	3	0	4	3		
Lumbriciilus australis	1	0	1	0		
Total	**4**	**0**	**5**	**3**	**12**	**22.22**
POLYCHAETA						
Neathes sp.	4	2	5	4		
Nepthys sp.	3	0	3	3		
Total	**7**	**2**	**8**	**7**	**24**	**44.44**
NEMATODE						
Mirmis sp.	1	0	1	0		
Total	**1**	**0**	**1**	**0**	**2**	**3.70**
INSECTA						
Chironomus larva	6	3	4	3		
Total	**6**	**3**	**4**	**3**	**16**	**29.63**
					54	**100**

The 2018 dry season sampling's abundance and distribution of benthic fauna is shown in Table 5c and Figure3c. The order of relative abundance and distribution recorded was Polychaeta (44.44%) > Oligochaeta (22.22%) > Insecta (29.63%) > Nematoda 3.70%. Generally the study sites are poor in benthic fauna. Benthic fauna acts as a receptor for most of the materials/pollutants entering the river and thus impacted due to their docile nature. The dredging activities in the river have caused the elimination of the benthic fauna as its habitat has also been removed.

Citation: Fidelis Abija, Ta Harry, Ho Nwankwoala (2021) Seasonal Variation in Abundance, Distribution and Environmental Impacts of Geomicrobiological Communities in the Lower Calabar River Channel, Calabar, Nigeria. Journal of Earth and Environmental Science Research. SRC/JEESR-178.
DOI: doi.org/10.47363/JEESR/2021(3)153

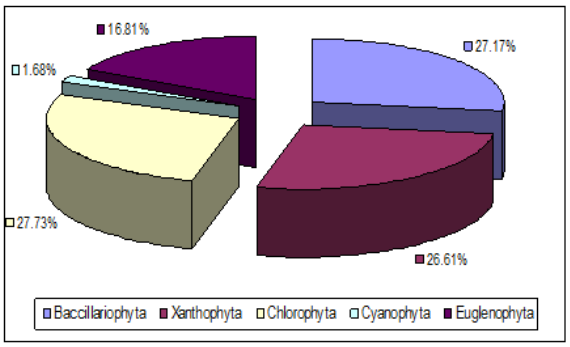

Figure 1a: Wet season 2013 phytoplankton

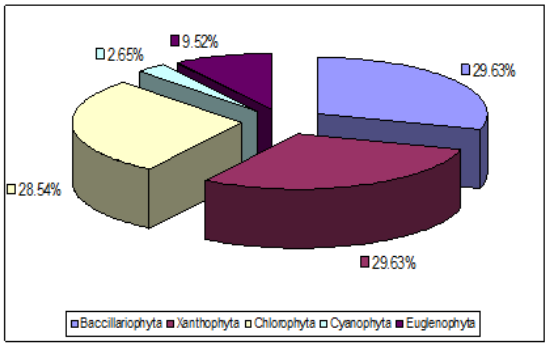

Figure 1b: 2014 dry season Phytoplankton

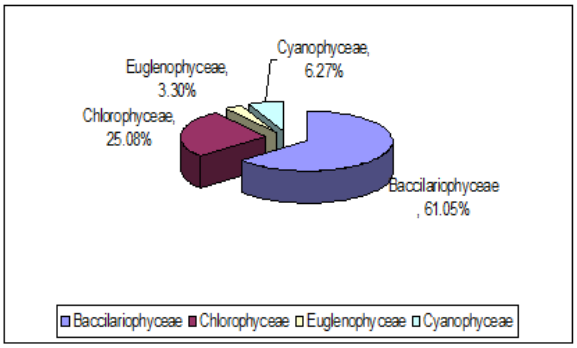

Figure 1c: 2018 dry season Phytoplankton

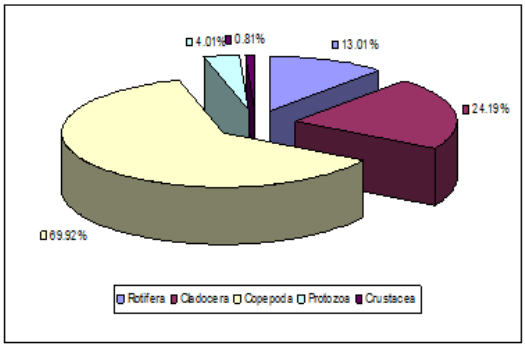

Figure 2a: 2013 Wet season Zooplankton

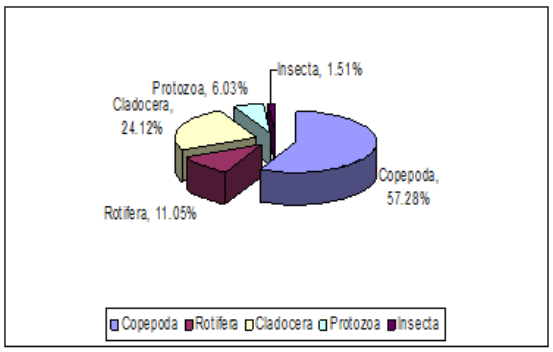

Figure 2b: 2014 dry season zooplankton abundance

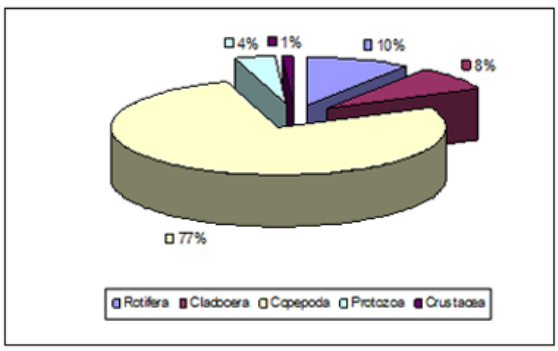

Figure 2c: 2018 Zooplankton abundance

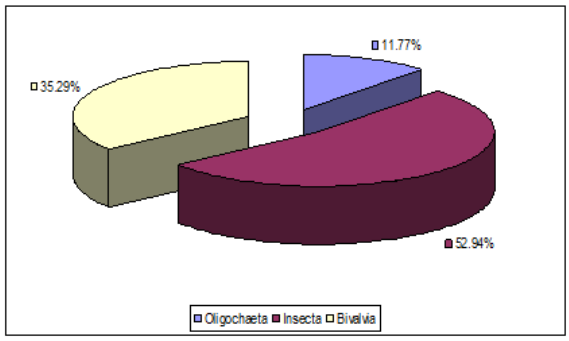

Figure 3a: 2013 Wet season abundance of benthic fauna

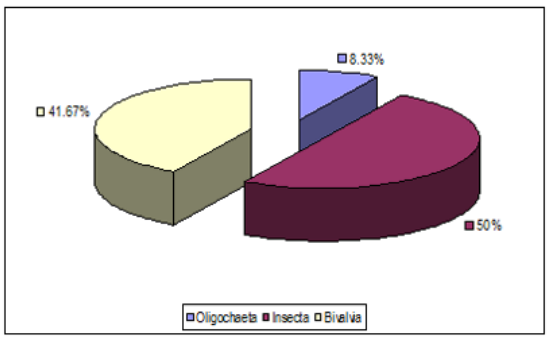

Figure 3b: 2014 Dry Season Benthic fauna

Citation: Fidelis Abija, Ta Harry, Ho Nwankwoala (2021) Seasonal Variation in Abundance, Distribution and Environmental Impacts of Geomicrobiological Communities in the Lower Calabar River Channel, Calabar, Nigeria. Journal of Earth and Environmental Science Research. SRC/JEESR-178.
DOI: doi.org/10.47363/JEESR/2021(3)153

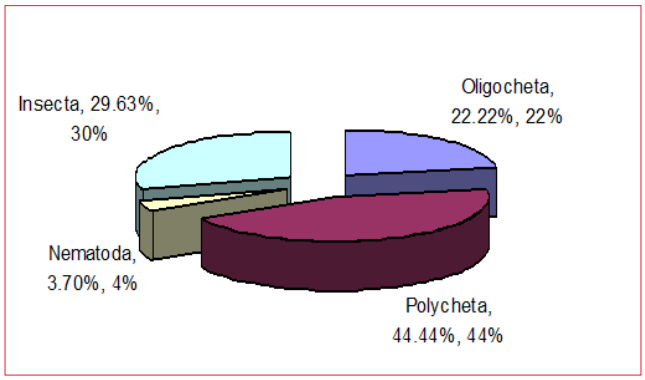

Figure 3c: 2018 dry season benthic fauna abundance

Soil Microbiology

The results of the soil microbiology investigations are presented in Tables 6a, 6b and 6c. The Total heterotrophic bacteria count during the 2013 wet season varies from 0.0 – 1.0 x x 10^6 cfu/g in the top 15cm of the soils and 1.0 x 10^6 , to 1.7 x 10^7cfu/g in the bottom 15 – 30cm in the soil samples. The hydrocarbon utilizing bacteria range from 0.0 to 1.0 x 10^5cfu/g and 0.0 to 1.0 x 10^5cfu/g of soil in the top 15cm and bottom 15 – 30cm respectively. The total heterotrophic fungal count varies from 100 to 200cfu/g in the top 15cm and 100 - 170cfu/g in the bottom 15 – 30cm of the soil layer. The hydrocarbon utilizing fungal count range from 0.0 – 100 and 0.0 – 110cfu/g in the top 15cm and bottom 15 – 30cm respectively. Nitrobacter, Total coliforms and E. coli were total absent in the soil samples during the wet season of 2013 (Table 6a).

The result of dry season sampling in 2014 depicts that the total heterotrophic bacteria count in the soils varies from 0.0 – 1.0 x 10^6cfu/g in the top 15cm and 1.0 x 10^6 - 1.0 x 10^7cfu/g in the bottom 15 – 30cm of the soils layer while the hydrocarbon utilizing bacteria count ranged from 0.0 - 1.0 x 10^5cfu/g and 1.0 x 10^5 – 1.3 x 10^5cfu/g in the top and bottom layers respectively. The total heterotrophic fungal count varies from 100.0 – 200.0cfu/g in to top and 100.0 – 170.0cfu/g in the bottom soil layers. The hydrocarbon utilizing bacteria count ranged from 0.0 – 100.0cfu/g and 100.0 – 110.0cfu/g in the top and bottom soils layer respectively. Nitrobacter, Total coliforms and E. coli were not detected in any of the soils samples during the 2014 dry season sampling period.

In 2018, Nitrobacter was discovered to vary from 2 – 6cfu/g occurring in the top 15cm of the oils layers. The total heterotrophic bacteria count also ranged from 1000.0 – 1.42 x 10^6cfu/g in the top 15cm and 0.0 – 11.0cfu/g in the bottom 15 – 30cm; hydrocarbon utilizing bacteria varied from 100.0 – 1.0 x 10^5cfu/g and 0.0 - 1.3 x 10^4cfu/g in the top and bottom samples respectively while the total heterotrophic fungal count ranged from 100.0 – 1.02 x 10^4cfu/g and 0.0 – 1.7 x 10^2cfu/g in the top (0-15cm) and bottom (15 – 30cm) samples respectively. The hydrocarbon utilizing bacteria count varied from 0.0 – 1.0 x 10^3cfu/g in the top 15cm soil layer and 0.0 – 12cfu/g in the bottom 15 – 30cm of the underlying soil cover adjoining thee river. No coliforms and e. coli were present in any of the soils samples during the 2018 dry season.

Table 6a: Bacterial Population Densities of Soil Samples in the Wet season of 2013

Sample Id	Depth	THBC (cfu/g)	HUBC (cfu/g)	THFC (cfu/g)	HUFC (cfu/g)	Nitrobacter (cfu/g)	TCC (cfu/g)	FCC (cfu/g)	E.Coli (cfu/g)
SS1	T B	2.0 x 10^6 2.0 x 106	Nil 1.0 x 10^5	5.0 x 10^2 2.5 x 10^2	2.0 x 10^2 1.2 x 10^2	ND ND	ND ND	ND ND	ND ND
SS2	T B	1.96 x 10^7 1.0 x 10^6	1.8 x 10^5 1.0 X 10^5	3.0 x 102 2.1 x 102	Nil 2.1 x 10^2	1.7 x 10^3 ND	ND ND	ND ND	ND ND
SS3	T B	1.0 x 10^7 1.0 x 10^6	1.0 x 10^5 1.5 x10^5	4.0 x 102 2.5 x 102	2.0 x 10^2 Nil	1.0 x 10^3 1.0 x 10^3	ND ND	ND ND	ND ND
SS4	T B	2.0 x 10^6 1.5 x 10^7	1.1 x 10^5 1.0 x 10^5	3.5 x 102 1.0 x 102	Nil 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND
SS5	T B	3.0 x 10^6 2.0 x 10^6	1.5 x 10^5 1.0 x 10^5	1.5 x 102 1.0 x 102	Nil 2.0 x 10^2	ND ND	ND ND	ND ND	ND ND
SS6	T B	1.60 x 10^6 1.0 x 10^7	1.1 x 10^5 1.0 x 10^5	1.0 x 102 1.0 x 102	1.0 x 10^2 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND

ND = Not detected

Table 6b: Bacterial Population Densities of Soil Samples in the Dry season of 2014

Sample Id	Depth	THBC (cfu/g)	HUBC (cfu/g)	THFC (cfu/g)	HUFC (cfu/g)	Nitrobacter (cfu/g)	TCC (cfu/g)	FCC (cfu/g)	E.Coli (cfu/g)
SS1	T B	1.0 x 10^6 1.3 x 10^6	Nil 1.0 x 10^5	2.0 x 10^2 1.0 x 10^2	1.0 x 10^2 1.1 x 10^2	ND ND	ND ND	ND ND	ND ND
SS2	T B	1.0 x 10^7 1.1 x 10^6	1.0 x 10^5 1.1 X 10^5	1.0 x 10^2 1.4 x 10^2	1.0 x 10^2 1.1 x 10^2	ND ND	ND ND	ND ND	ND ND
SS3	T B	1.0 x 10^7 1.0 x 10^6	1.0 x 10^5 1.2 x10^5	1.0 x 10^2 1.7 x 10^2	1.0 x 10^2 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND
SS4	T B	Nil 1.1 x 10^7	Nil 1.0 x 10^5	1.5 x 10^2 1.0 x 10^2	Nil 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND
SS5	T B	1.0 x 10^6 1.0 x 10^6	1.0 x 10^5 1.3 x 10^5	1.0 x 10^2 1.1 x 10^2	Nil 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND
SS6	T B	1.1 x 10^6 1.0 x 10^7	1.0 x 10^5 1.0 x 10^5	1.1 x 10^2 1.5 x 10^2	1.0 x 10^2 1.0 x 10^2	ND ND	ND ND	ND ND	ND ND

ND = Not detected

Table 6c: Bacterial Population Densities of Soil Samples in the Dry season of 2018

Sample Id	Depth	THBC (cfu/g)	HUBC (cfu/g)	THFC (cfu/g)	HUFC (cfu/g)	Nitrobacter (cfu/g)	TCC (cfu/g)	FCC (cfu/g)	E.Coli (cfu/g)
SS1	T B	1.42x10^6 Nil	1.0 x 10^3 Nil	1.02x10^4 3	1.0 x 10^3 12	Nil Nil	Nil Nil	Nil Nil	2l Nil
SS2	T B	1.0 x 10^3 11	1.0 x 10^2 12	1.0 x 10^2 1.4 x 10^2	1.0 x 10^2 Nil	6 Nil	Nil Nil	1 Nil	Nil Nil
SS3	T B	1.0 x 10^2 10	1.0 x 10^2 9	1.0 x 10^2 1.7 x 10^2	100 Nil	11 Nil	Nil Nil	1 Nil	3 Nil
SS4	T B	Nil Nil	1.0 x 10^3 Nil	1.12 x 10^3 Nil	Nil Nil	2 Nil	Nil Nil	Nil Nil	1 Nil
SS5	T B	1.0 x 10^3 Nil	1.0 x 10^5 1.3 x 10^5	100 Nil	Nil 1	Nil Nil	Nil Nil	3 Nil	Nil Nil

Conclusion

Environmental self-cleansing and remediation significantly contributed to the lower microorganisms count in the wet season suggesting a lower environmental health risk during the period. In the dry season however, increased abundance and distribution cross the different ecosystems would pose higher environmental risk. However, the abundance during the dry season implies higher rates of geochemical degradation of polluting agents.

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