Acta Scientific Microbiology (ISSN: 2581-3226)

Volume 1 Issue 6 June 2018

Research Article

# The Ecotoxicological Dynamics of the Coastal Marine Ecosystem of Oil-Producing Areas in Ilaje Ondo State, Nigeria

**Adenike A Akinsemolu[1,2]*, Felix A Akinyosoye[1] and Daniel J Arotupin DJ[1]**

[1]*Department of Microbiology, Federal University of Technology, Akure, Nigeria*

[2]*The Green Institute, Ondo, Nigeria*

***Corresponding Author:** Adenike A Akinsemolu, Department of Microbiology, Federal University of Technology, Akure, Nigeria.

**Received:** April 25, 2018; **Published**: May 22, 2018

## Abstract

Intense anthropogenic growth coupled with the irresponsible expulsion of waste products into natural ecosystems contributes to acute environmental degradation, eventually leading to hazardous consequences. The coastal marine ecosystem of Ondo state, Nigeria, is one such adversely affected site due to crude oil extraction operations. The physicochemical analysis of the zone conducted during this study revealed that the water samples, as well as the sediment samples, was acidic. This water samples was contaminated with excess ammonia (> 15 ppm during the dry season) and contained excess of phosphate (>100 ppm during the dry season), which has potential to cause eutrophication. Excess toxic heavy metals contaminated the water in most of the sampling sites and several enteric microorganisms and disease-causing agents such as *Escherichia coli* were detected in the ecosystem. The sediments were also contaminated with high amount of toxic heavy metals and excess nutrients such as ammonia and phosphorus. There was an ascertainable pattern of seasonal variance in most of the contaminants and parameters measured since their concentration and values were demonstrably higher during the dry season in comparison to the wet season. This comprehensive research study explored the various features of this sensitive ecosystem including the potential ecotoxicity and environmental hazards, which ultimately pose a serious threat to the socio-economic and health well-being of the local people.

**Keywords:** Toxic Heavy Metals; Ecotoxicity; Coastal Marine Ecosystem; Eutrophication; Ondo State

## Introduction

From the dawn of the industrial revolution, exponential anthropogenic growth has led to large-scale overexploitation of natural assets such as marine and coastal ecosystems, imposing overwhelmingly colossal demands on these resources [1]. The resulting imminent environmental threats have not exclusively resulted from human population growth [2,3], but intense technological development has also led to acute environmental degradation. One of the most far-reaching detrimental effects of this unrestrained growth has been the production of excess solid and liquid waste materials that are contaminated with a wide range of toxic recalcitrant, heavy metals and harmful substances [3,4], whose irresponsible release into natural ecosystems can lead to environmentally perilous events with hazardous consequences [5]. As a result, aquatic ecosystems including marine and coastal environments are collectively undergoing accelerated rates of qualitative and quantitative degradation [6]. Much as certain societies can temporarily cope with acute pollution and availability constraints and reduce the adverse effects of widespread environmental degradation, the control and reversal of this monumental threat to natural ecosystems requires, in most parts of the world, proper socioeconomic valuation of natural resources coupled with their effective and sustainable utilization and the implementation of responsible waste discharge practices [3]. Therefore, the study of natural environments such as marine and coastal ecosystems needs to be intensified to understand them sufficiently and evaluate their resilience and capability to respond to anthropogenic exploitation and loading of toxic contaminants [1,3]. In this respect, any constructive analytical study of natural environments such as marine and coastal environments must address the overwhelming pre-eminence of exponential anthropogenic growth coupled with overutilization of natural resources [3].

Both offshore and coastal drilling for crude oil constitutes major sources of environmental concern, as to the occasional spillages, industrial accidents and irresponsible waste discharge practices lead to the loading of toxic contaminants into the natural environment. This study focused its research on the marine and coastal environment of Ondo state region in Nigeria, which is a major site for coastal and marine oil drilling operations conducted by several multinational corporations [7]. Additionally, the lack of large-scale treatment facilities in the region causes a substantial amount of the domestic wastewater produced in the area to flow through the network of rivers into the coastal region under investigation [8]. Our objective, therefore, was to evaluate water and sediment samples collected from different sites of our study area for a better understanding of the impact of environmental degradation on marine and coastal environments.

## Materials and Methods

### The study area

The study area for the research is the oil-producing coastal region of Ondo State, Nigeria, Ilaje community (Lat. $5^{o}50'N$ – $6^{o}09'N$ and Long. $4^{o}45'E$ - $5^{o}05'E$) (Figure 1). It has an area of 1,318 $km^2$ and a population of 336,740 according to the 2011 census [9]. The weather of the study area is typically sultry and humid with average rainfall records of 1,500 - 2000 mm [10]. The region experiences a wet season from March to October while the dry season spans from November to February. The mean values for the maximum temperature, minimum temperature and relative humidity are 34.33°C, 26.02°C, and 68.00%, respectively [11]. Ilaje is a Local Government Area constituted by many towns and villages whose local headquarters are located in the town of Igbokoda. Samples were obtained from the ten (10) major kingdoms which make up

the Ilaje community, Igbokoda, Mahin, Ugbo-Nla, Ayetoro, Ilowo, Obenla, OdoNla, Ikuyinminu, and Awoye, serving Igbokoda as the control. The sites were chosen for accessibility and represent the different geological group, land use, sub-catchment and soil types of the Ilaje community (Figure 1).

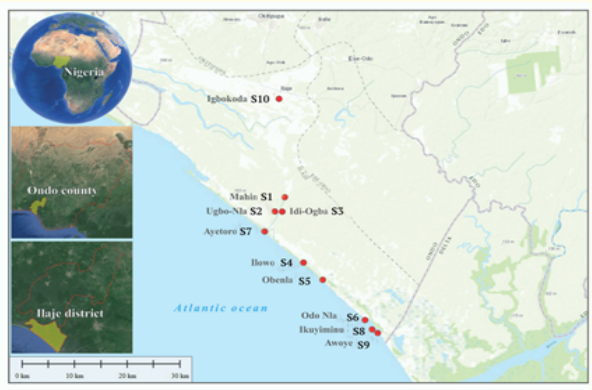


**Figure 1:** Map depicting sampling site of the marine coastal ecosystem in Ondo State region, Nigeria.

## Field and sample collection

Water and sediment samples were collected from ten (10) different sample sites following standard protocols as described previously [12-14]. Water samples were collected using sterile polyethene sample bottles of about 200 ml in triplicates from each sample source. Sediment samples were collected using a 24-L Van Veen Grab Sampler (WILDCO, Florida, USA). The samples were immediately transported to the laboratory in cold condition ($2^0$C - $4^0$C) in heat-isolated protective containers for further analysis and preserved at $4^0$C until the biological assays were carried out.

## Physicochemical analysis

Tests for odour, colour, temperature, and pH were conducted *in situ.* For water samples, chemical analyses such as total hardness (TH), total chlorides (TCl), potassium (K), sodium (Na), magnesium (Mg), ammonia ($NH_3$), sulphate ($SO_4^{2-}$), nitrate ($NO_3$-), total solids (TS), total dissolved solids (TDS), and biochemical oxygen demand (BOD) were measured following standard protocols [15,16]. The sediment quality parameters were analysed following standard protocols as described previously [17]. Parameters such as total chlorides (TCl), organic matter, ammonia ($NH_3$), nitrogen (N), Sulphur (S), and phosphorus (P), content were measured following standard protocols as described previously [14,18]. The organic matter content of sediment was measured by modified Walkley-Black method [19].

## Heavy metal analysis by atomic absorption spectrophotometer (AAS) technique

A Perkin- Elmer ASS-280 Flame Atomic Absorption Spectrophotometer from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State, Nigeria was used to quantify the following heavy metals: calcium (Ca), arsenic (As), iron (Fe), zinc (Zn), lead (Pb), copper (Cu), vanadium (V), chromium (Cr), cadmium (Cd), and nickel (Ni) in accordance with standard operating procedures [20]. Pre-treatment of samples including acid digestion was done following standard methods as described previously [21] Different calibration curves were utilized for each heavy metal, being a blank used to correct for impurities in the samples and the mean value of three repetitions taken as the actual measurement.

## Microbiological Analysis

## Determination of Bacterial and Fungal Populations

Pour plate method was used for the microbiological analysis of samples. Serial dilution and estimation of microbial counts were done according to the methods of Ben-David and Davidson [22]. 0.1 ml aliquots of serially diluted samples were inoculated into plates containing Nutrient Agar (NA) for the cultivation of bacteria. Eosin Methylene Blue (EMB) was used as a selective medium for Gram-negative bacteria. The plates were inoculated at 37OC for 24 hours. In turn, 0.1 ml aliquots of serially diluted samples were seeded into prepared plates of Potato Dextrose Agar (PDA) containing chloramphenicol (30 mg/l) for the isolation of fungi. The plates were incubated for seven days at ambient room temperature (25 - 30OC). Bacterial and fungal colonies were recorded in colony- (CFU/ml) and spore-forming units (SFU/ml), respectively.

## Identification and characterization of bacteria

Identification was made according to the Bergey's Manual of Determinative Bacteriology [23], which entailed the use of different biochemical tests such as carbohydrate fermentation, methyl red and Voges-Proskauer test, starch hydrolysis, lactose utilization, motility test, catalase test, citrate test and Gram staining. Gideon Informatics Database, which matches samples using biochemical characteristics, was used for this purpose.

## Microscopic examination and identification of fungal isolates

Fungal identification was performed by examining morphology traits of the colonies: surface appearance, shape, texture, and colour. Alternative observations consisted of the identification of sexual and asexual reproductive structures such as arthrospores, conidial head, sporangia and septate/non-septate mycelia [24,25]. The Wet Mount Needle Method was used for microscopic observation.

## Molecular analysis: polymerase chain reaction (PCR)

Total DNA was extracted from fungal and bacterial cells utilising ZR bacterial DNA kit following methods as prescribed by the manufacturer's protocol (Zymo Research, CA, U.S.A). Polymerase Chain Reaction (PCR) was done to amplify the 16S rRNA genes using primer sets 1525r (5' -AAG GAG GTG WTC CAR CCG CA- 3') and 27f (5' –AGA GTT TGA TCM TGG CTC AG- 3') for bacteria and PTS 4 (5' –TCC TCC GCT TAT TGA TAT GC- 3') and ITS 1 (5' –TCC GTA GGT GAA CCT GCG G-3') for fungi [26,27]. The Polymerase Chain Reaction (PCR) reaction was done using the following programme: one cycle of 5 minutes at $94^0$C for denaturation; Thirty-five cycles of amplification with 30 seconds of denaturation at $94^0$C, 1 minutes of annealing at $55^0$C and1.5 minute for extension at $72^0$C, and a final extension step of 7 minutes at $72^0$C. Then 5 µl of the amplicons were mixed with an equal volume of denaturing solution (0.05% xylene cyanol, 95% formamide, 0.05% bromophenol blue and 20 mM EDTA). The mix was heated at $95^0$C for about 10 minutes and then put on ice. The samples were loaded onto a 1.5 percent agarose gel and the characteristic electrophoresis bands were utilized for subsequent analyses [26].

The PCR product was purified by adding 70% ethanol and centrifuging the mix at 9000 rpm. An ABI 3130xL Genetic Analyzer (Applied Biosystems, California, USA) was utilised for nucleotide sequencing. The sequence was compared to the NCBI GenBank database using BLAST (Basic Alignment Search Tool) program [26].

NCBI taxonomy ID was used for each of the species to reconstruct the phylogenetic tree, while its visualization was performed in FigTree (http://tree.bio.ed.ac.uk/software/figtree/) and the phylogenetic tree was constructed using phyloT (http://phylot.biobyte.de/) [28].

### Statistical Analysis

The SPSS 22.0 statistical package (IBM, California, USA) was employed for data analysis. Data collected on various parameters were subjected to analysis of variance (ANOVA) using the t-test. Duncan's multiple range tests were used for comparing several treatment groups with a control at 0.05 level of statistical significance. All the results of statistical analysis related to ANOVA and t-test have been provided in the supplementary information section.

## Results

### Physicochemical analysis of water samples

Several standard water quality parameters were analysed to understand the nature and extent of the pollutant loading and presence within the marine coastal aquatic ecosystem. The pH values indicated that the water samples was acidic during both the dry and wet seasons (Table 1). In all the sampling sites, the temperature of the water samples was approximately 30$^{o}$C during the dry season and decreased marginally during the wet season (Table 1). Similarly, the total solids content of the water samples was significantly high during the dry season and reduced to a great extent during the wet season (Table 1). The total hardness and chlorinity of the water samples also exhibited similar patterns (Table 1). Significantly, sampling sites 5, 6 and 7 were associated with high levels of total hardness in water (Table 1) while site 2 was characterized by elevated levels of total high chlorinity (Table 1). Water samples, especially those from sampling sites 5, 6, 7, 8 and 9, were also associated with significantly high levels of oxygen demand as demonstrated by the BOD content (Table 1), particularly during the dry season.

| Locations | Physicochemical parameters | | | | | |
|---|---|---|---|---|---|---|
| | pH | T ($^{o}$C) | TS (ppm) | TH (ppm) | TCl (ppm) | BOD (ppm) |
| | Dry Season | | | | | |
| 1 | 6.52 ± 0.06$^{b}$ | 29.39 ± 0.04$^{b}$ | 0.87 ± 0.12$^{b}$ | 12.88 ± 0.23$^{c}$ | 60.02± 12.93$^{bc}$ | 58.70 ± 8.47$^{a}$ |
| 2 | 6.43 ± 0.16$^{ab}$ | 29.39 ± 0.09$^{b}$ | 0.62 ± 0.14$^{ab}$ | 14.04 ± 0.29$^{d}$ | 86.03 ± 0.83$^{f}$ | 59.17 ± 9.66$^{a}$ |
| 3 | 6.39 ± 0.16$^{ab}$ | 29.42 ± 0.16$^{b}$ | 0.67 ± 0.13$^{b}$ | 14.23 ± 0.29$^{d}$ | 41.59 ± 1.01$^{a}$ | 68.22 ± 1.42$^{b}$ |
| 4 | 6.35 ± 0.09$^{ab}$ | 29.40 ± 0.17$^{b}$ | 0.80 ± 0.18$^{b}$ | 13.89 ± 0.29$^{d}$ | 50.73 ± 3.27$^{b}$ | 68.74 ± 0.20$^{b}$ |
| 5 | 6.02 ± 0.62$^{a}$ | 28.51 ± 0.29$^{a}$ | 0.56 ± 0.15$^{ab}$ | 14.92 ± 0.29$^{e}$ | 58.02 ± 4.21$^{c}$ | 71.58 ± 4.10$^{b}$ |
| 6 | 6.39 ± 0.38$^{ab}$ | 29.02 ±0.65$^{ab}$ | 0.71 ± 0.18$^{b}$ | 15.23 ± 0.29$^{e}$ | 59.18 ± 6.16$^{cd}$ | 75.16 ± 0.67$^{b}$ |
| 7 | 6.24 ± 0.29$^{ab}$ | 28.75 ± 0.61$^{ab}$ | 0.81 ± 0.25$^{b}$ | 15.91 ± 0.29$^{f}$ | 66.07 ± 2.56$^{de}$ | 73.37 ± 2.10$^{b}$ |
| 8 | 5.95 ± 0.30$^{a}$ | 28.99± 0.43$^{ab}$ | 0.36 ± 0.22$^{a}$ | 11.02 ± 0.29$^{b}$ | 69.19 ± 0.63$^{e}$ | 75.12 ± 4.76$^{b}$ |
| 9 | 5.94 ± 0.32$^{a}$ | 29.17± 0.49$^{ab}$ | 0.79 ± 0.23$^{b}$ | 11.26 ± 0.29$^{b}$ | 71.45 ± 2.15$^{e}$ | 74.28 ± 5.09$^{b}$ |
| 10 | 6.99 ± 0.01$^{c}$ | 28.92 ±1.04$^{ab}$ | 0.68 ± 0.19$^{b}$ | 10.24 ± 0.29$^{a}$ | 70.95 ± 0.78$^{e}$ | 59.52 ± 9.51$^{a}$ |
| | Wet Season | | | | | |
| 1 | 6.52 ± 0.01$^{a}$ | 28.16 ± 0.49$^{a}$ | 0.02 ± 0.01$^{c}$ | 9.39 ± 1.15$^{b}$ | 37.76 ± 8.74$^{b}$ | 42.20 ± 7.47$^{d}$ |
| 2 | 6.62 ± 0.31$^{a}$ | 27.80 ± 1.43$^{a}$ | 0.02 ± 0.01$^{c}$ | 9.82 ± 1.62$^{b}$ | 38.92± 10.33$^{b}$ | 46.30 ± 12.93$^{d}$ |
| 3 | 6.83 ± 0.05$^{ab}$ | 27.13 ± 1.50$^{a}$ | 0.02 ± 0.01$^{c}$ | 9.92 ± 2.11$^{b}$ | 34.66± 10.19$^{b}$ | 37.32± 12.15$^{bcd}$ |
| 4 | 6.71 ± 0.19$^{a}$ | 27.39 ± 1.03$^{a}$ | 0.03 ± 0.01$^{c}$ | 8.84 ± 2.13$^{b}$ | 32.00 ± 9.13$^{b}$ | 28.98 ± 7.19$^{b}$ |
| 5 | 6.34 ± 0.83$^{a}$ | 26.90 ± 1.03$^{a}$ | 0.02 ± 0.01$^{c}$ | 8.90 ± 2.03$^{b}$ | 32.51 ± 8.78$^{b}$ | 29.53 ± 6.30$^{b}$ |
| 6 | 6.81 ± 0.03$^{ab}$ | 28.56 ± 0.49$^{a}$ | 0.02 ± 0.01$^{c}$ | 9.33 ± 1.98$^{b}$ | 34.80 ± 7.74$^{b}$ | 33.47 ± 5.22$^{bc}$ |
| 7 | 6.47 ± 0.33$^{a}$ | 27.66 ± 0.71$^{a}$ | 0.02 ± 0.01$^{bc}$ | 8.59 ± 1.91$^{b}$ | 32.92 ± 9.46$^{b}$ | 33.54 ± 4.46$^{bc}$ |
| 8 | 6.42 ± 0.60$^{a}$ | 28.13 ± 0.90$^{a}$ | 0.01 ± 0.01$^{abc}$ | 8.13 ± 2.55$^{b}$ | 30.48± 16.70$^{b}$ | 32.34 ± 6.89$^{bc}$ |
| 9 | 6.68 ± 0.21$^{a}$ | 28.58 ± 0.05$^{a}$ | 0.01 ± 0.01$^{ab}$ | 6.85 ± 1.79$^{b}$ | 26.49 ± 9.71$^{b}$ | 37.94± 1.00$^{bcd}$ |
| 10 | 7.32 ± 0.21$^{a}$ | 27.60 ± 1.77$^{a}$ | 0.01 ± 0.00$^{a}$ | 5.09 ± 1.46$^{a}$ | 2.42 ± 0.73$^{a}$ | 16.34 ± 1.71$^{a}$ |

**Table 1:** Physicochemical analysis of water samples at different locations during dry and wet seasons.
Means with the same superscript letter down the same column are not significantly different ($P < 0.05$).

### Non-metallic and metallic nutrient content of water samples

Ecosystem stability and resilience to external perturbations can be affected by some factors including the availability of a wide range of nutrients that may be of non-metallic and metallic nature. For this study, the concentration of several nutrients including nitrate, phosphates, sulphates, calcium, sodium, potassium, ammonium, and magnesium were analysed. The results indicated that the nitrate concentration of the water samples was higher during the dry season in comparison to that measured in samples collected during the wet season (Table 2). Excess phosphate, which can be detrimental to the marine ecosystem, was also found as a contaminant (Table 2). The sulphate content of the water samples was acutely high sampling sites 1 to 9, all of which were affected by inappropriate discharge practices that lead to contamination by this non-metal (Table 2). Among the metallic nutrients calcium, sodium, potassium and magnesium showed high levels in the water fraction, being the dry season characterised by more elevated levels of these elements when compared to the wet season (Table 3). The water samples was also characterised by excess loading of ammonia, particularly during the dry season (Table 3).

### Toxic heavy metal content of the water samples

Among the toxic heavy metals that are of grave concern, cadmium, chromium, vanadium, lead and arsenic were analysed in the water samples to assess the extent of pollution in the region. The results indicated that the sampling sites 7, 8, 9 contained relatively higher levels of cadmium contamination during the dry season, being the wet season characterised by negligibly low content of this metal (Table 4). The chromium content of the water samples also exhibited a similar pattern of seasonal variance (Table 4). In turn, the total vanadium concentration in all the sampling sites was significantly low and below safety levels except in sampling site 9 (Table 4). The concentration of lead in the water samples was negligible during the wet season, whereas its content was elevated during the dry seasons (Table 4). As for the case of arsenic, its distribution in the water samples also exhibited a similar pattern of seasonal variation (Table 4).

| Locations | Non-metallic parameters (ppm) | | |
|---|---|---|---|
| | $SO_4$ | $NO_3$ | $PO_4$ |
| | Dry Season | | |
| 1 | 90.56 ± 0.38$^{c}$ | 60.62 ± 0.35$^{b}$ | 160.54 ± 0.30$^{d}$ |
| 2 | 90.89 ± 0.34$^{e}$ | 60.80 ± 0.35$^{c}$ | 180.56 ± 0.29$^{f}$ |
| 3 | 90.95 ± 0.34$^{e}$ | 60.94 ± 0.35$^{d}$ | 150.98 ± 0.31$^{c}$ |
| 4 | 90.92 ± 9.97$^{e}$ | 70.13 ± 0.35$^{e}$ | 190.67 ± 0.32$^{g}$ |
| 5 | 90.92 ± 0.14$^{e}$ | 70.91 ± 0.35$^{f}$ | 170.29 ± 0.31$^{e}$ |
| 6 | 80.96 ± 0.34$^{b}$ | 80.42 ± 0.35$^{g}$ | 210.09 ± 0.31$^{i}$ |
| 7 | 90.76 ± 0.50$^{d}$ | 80.73 ± 0.35$^{h}$ | 220.71 ± 0.31$^{j}$ |
| 8 | 90.88 ± 0.34$^{e}$ | 80.81 ± 0.35$^{i}$ | 110.10 ± 0.31$^{b}$ |
| 9 | 90.96 ± 0.34$^{e}$ | 80.99 ± 0.35$^{j}$ | 200.99 ± 0.31$^{h}$ |
| 10 | 30.46 ± 0.14$^{a}$ | 10.08 ± 0.36$^{a}$ | 90.26 ± 0.29$^{a}$ |
| | Wet Season | | |
| 1 | 80.20 ± 0.99$^{bc}$ | 50.07 ± 6.56$^{cd}$ | 120.70 ± 0.13$^{cd}$ |
| 2 | 90.05 ± 0.14$^{c}$ | 50.58 ± 10.28$^{d}$ | 130.77 ± 0.31$^{d}$ |
| 3 | 8.50 ± 0.13$^{bc}$ | 50.46 ± 7.74$^{d}$ | 120.86 ± 0.36$^{cd}$ |
| 4 | 80.49. ± 0.15$^{bc}$ | 50.67 ± 10.05$^{d}$ | 70.40 ± 0.16$^{ab}$ |
| 5 | 80.56 ± 0.87$^{bc}$ | 50.25 ± 9.04$^{c\,d}$ | 80.58 ± 0.20$^{ab}$ |
| 6 | 70.78 ± 0.18$^{bc}$ | 40.84 ± 10.79$^{cd}$ | 50.35 ± 0.290$^{a}$ |
| 7 | 60.70 ± 0.16$^{b}$ | 40.46 ± 15.52$^{cd}$ | 90.66 ± 0.27$^{bc}$ |
| 8 | 60.48 ± 0.23$^{b}$ | 30.65 ± 18.42$^{bc}$ | 70.33 ± 0.15$^{ab}$ |
| 9 | 60.61 ± 0.71$^{b}$ | 20.16 ± 4.08$^{ab}$ | 70.01 ± 0.67$^{ab}$ |
| 10 | 20.30 ± 0.61$^{a}$ | 0.82 ± 2.42$^{a}$ | 50.15 ± 0.13$^{a}$ |

**Table 2:** Non-metallic nutrient content of water samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

| Locations | Metallic parameters (ppm) | | | | | |
|---|---|---|---|---|---|---|
| | Ca | K | $NH_3$ | Mg | Fe | Na |
| | Dry Season | | | | | |
| 1 | 2.96 ± 0.09$^{b}$ | 2.33 ± 0.28$^{a}$ | 17.42 ± 0.37$^{e}$ | 2.03 ± 0.37$^{bc}$ | 1.81 ± 0.23$^{b}$ | 15.78 ± 0.35$^{b}$ |
| 2 | 2.64 ± 0.42$^{b}$ | 2.47 ± 0.28$^{a}$ | 18.36 ± 0.37$^{f}$ | 2.04 ± 0.33$^{bc}$ | 1.43 ± 0.37$^{b}$ | 15.88 ± 0.35$^{bc}$ |
| 3 | 2.68 ± 0.42$^{b}$ | 2.57 ± 0.28$^{a}$ | 18.39 ± 0.37$^{f}$ | 2.32 ± 0.48$^{c}$ | 1.60 ± 0.30$^{b}$ | 15.98 ± 0.36$^{bc}$ |
| 4 | 2.74 ± 0.42$^{b}$ | 2.62 ± 0.28$^{a}$ | 17.78 ± 0.37$^{e}$ | 2.45 ± 0.33$^{c}$ | 1.37 ± 0.38$^{b}$ | 16.52 ± 0.35$^{cd}$ |
| 5 | 2.83 ± 0.42$^{b}$ | 2.52 ± 0.28$^{a}$ | 16.73 ± 0.38$^{d}$ | 2.23 ± 0.36$^{c}$ | 1.37 ± 0.39$^{b}$ | 16.91 ± 0.74$^{d}$ |
| 6 | 2.89 ± 0.42$^{b}$ | 2.40 ± 0.28$^{a}$ | 15.86 ± 0.37$^{bc}$ | 1.42 ± 0.33$^{a}$ | 1.64 ± 0.32$^{b}$ | 16.02 ± 0.35$^{bc}$ |
| 7 | 2.99 ± 0.42$^{b}$ | 2.53 ± 0.29$^{a}$ | 16.00 ± 0.37$^{c}$ | 1.44 ± 0.33$^{a}$ | 1.46 ± 0.37$^{b}$ | 16.12 ± 0.35$^{bc}$ |
| 8 | 2.44 ± 0.42$^{ab}$ | 2.66 ± 0.30$^{a}$ | 16.11 ± 0.37$^{c}$ | 1.55 ± 0.33$^{ab}$ | 1.46 ± 0.25$^{b}$ | 16.34 ±0.35$^{bcd}$ |
| 9 | 3.10 ± 0.42$^{b}$ | 2.89 ± 0.66$^{a}$ | 15.38 ± 0.37$^{b}$ | 2.55 ± 0.33$^{c}$ | 1.62 ± 0.29$^{b}$ | 16.93 ± 0.35$^{d}$ |
| 10 | 1.90 ± 0.42$^{b}$ | 2.84 ± 0.28$^{a}$ | 9.73 ± 0.37$^{a}$ | 2.53 ± 0.35$^{c}$ | 0.46 ± 0.37$^{a}$ | 14.48 ± 0.35$^{a}$ |
| | Wet Season | | | | | |
| 1 | 2.38 ± 0.64$^{bc}$ | 1.51 ± 0.23$^{\mathbf{bc}}$ | 15.44 ± 2.24$^{b}$ | 1.49 ± 0.31$^{d}$ | 0.94 ± 0.07$^{bc}$ | 14.87 ± 0.60$^{c}$ |
| 2 | 2.46 ± 0.66$^{c}$ | 1.53 ± 0.35$^{c}$ | 15.37 ± 2.69$^{b}$ | 1.50 ± 0.31$^{d}$ | 0.97 ± 0.10$^{c}$ | 16.14 ± 0.95$^{c}$ |
| 3 | 2.34 ± 0.50$^{bc}$ | 1.39 ± 0.21$^{bc}$ | 14.86 ± 2.54$^{b}$ | 1.28 ± 0.26$^{cd}$ | 0.89 ± 0.07$^{bc}$ | 15.94 ± 0.60$^{c}$ |
| 4 | 2.35 ± 0.53$^{bc}$ | 1.33 ± 0.17$^{bc}$ | 13.91 ± 2.69$^{b}$ | 1.22 ± 0.13$^{bcd}$ | 0.84 ± 0.12$^{bc}$ | 14.95 ± 1.95$^{c}$ |
| 5 | 2.33 ± 0.50$^{bc}$ | 1.31 ± 0.20$^{bc}$ | 13.80 ± 2.97$^{b}$ | 1.26 ± 0.20$^{cd}$ | 0.85 ± 0.08$^{bc}$ | 15.31 ± 0.97$^{c}$ |
| 6 | 2.05 ± 0.05$^{abc}$ | 1.35 ± 0.26$^{bc}$ | 12.93 ± 3.06$^{b}$ | 1.25 ± 0.42$^{cd}$ | 0.73 ± 0.15$^{abc}$ | 15.25 ± 0.89$^{c}$ |
| 7 | 1.55 ± 0.73$^{a}$ | 1.12 ± 0.15$^{ab}$ | 12.95 ± 3.24$^{b}$ | 1.03 ± 0.1$^{bcd}$ | 0.69 ± 0.13$^{ab}$ | 15.12 ± 0.78$^{c}$ |
| 8 | 1.58 ± 0.29$^{ab}$ | 1.21 ± 0.27$^{abc}$ | 12.03 ± 2.99$^{b}$ | 1.01 ± 0.1$^{bc}$ | 0.69 ± 0.18$^{ab}$ | 14.73 ± 1.04$^{c}$ |
| 9 | 2.01 ± 0.16$^{abc}$ | 1.40 ± 0.23$^{bc}$ | 14.30 ± 2.23$^{b}$ | 0.20 ± 0.11$^{a}$ | 0.90 ± 0.00$^{bc}$ | 12.11 ± 2.39$^{b}$ |
| 10 | 1.43 ± 0.17$^{a}$ | 0.92 ± 0.26$^{a}$ | 7.64 ± 0.26$^{b}$ | 0.77 ± 0.51$^{b}$ | 0.51 ± 0.36$^{a}$ | 0.77 ± 0.10$^{a}$ |

**Table 3:** Metallic nutrient content of water samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

## Physicochemical analysis of sediment samples

Several standard sediment quality parameters were analysed to understand the nature and extent of pollutant loading within the coastal marine ecosystem. The pH values indicated that the sediment samples was acidic during both the dry and the wet season (Table 5). In all the sampling sites, the temperature of the water samples was approximately 28$^{0}$C during the dry season and decreased marginally during the wet seasons (Table 5). In contrast, the temperature of the sediment samples remained relatively similar during the wet season. The total chlorinity of the sediment samples also exhibited seasonal variance but was higher during the wet season in comparison to the dry season (Table 5). Similar to other parameters measured, the organic matter content of the sediment was higher during the dry season and decreased during the wet season (Table 5), being sites 1, 2 and 3 associated with highest concentration of organic matter (Table 5).

## Non-metallic and metallic nutrient content of sediment samples

The results demonstrated that ammonia was available in excess (ammonia content > ~20 ppm) in most of the sampling sites during the dry season (Table 6). Moreover, the total Kjeldahl nitrogen content was also high during this period in the sediment samples (Table 6). However, during the wet season, the ammonia content, as well as the total Kjeldahl nitrogen content in the sediment samples, decreased marginally in most of the sampling sites (Table 6). The sediment samples was also rich in sulphur and phosphorus content during the dry and wet season, being the wet season marked by marginally lower contents of these nonmetals (Table 6). Among the metallic nutrients, calcium, sodium, potassium and magnesium were characterised by elevated levels during the dry season and marginal decreases during the wet season (Table 7).

## Toxic heavy metal content of the sediment samples

Consistent with the measurements for the water samples, the results indicated that the sampling site 7 was contaminated with relatively higher levels of cadmium during the dry season (Table 8). Conversely, the wet season was characterised by slightly low cadmium content in line with the negligibly low cadmium levels measured in the water samples (Table 8). The chromium content of the sediment samples also demonstrated a similar pattern of seasonal alterations, with a higher concentration (~4 ppm) in most of the sampling sites (Table 8). The concentration of lead in

the sediment samples was relatively low during the wet season, being the dry seasons characterised by significantly elevated levels of this metal in the sediment (Table 8). The total vanadium concentration in the whole area was significantly low and below safety levels, with the sampling sites 9 and 10 having almost negligible vanadium concentration (Table 8). The distribution of arsenic in the sediment samples also exhibited a similar pattern of seasonal variation (Table 8). However, it is important to note that the toxic heavy metal contamination for all the metals was much higher in the sediment samples compared to the water samples.

| Locations | Heavy metal parameters (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ni | Cd | V | Cu | Pb | Cr | Zn | As |
| | Dry | | | | | | | |
| 1 | 0.73 ± 0.20$^{abc}$ | 0.73 ± 0.20$^{d}$ | 0.03 ± 0.01$^{a}$ | 0.81 ± 0.17$^{bc}$ | 0.29 ± 0.09$^{a}$ | 0.77 ± 0.31$^{ab}$ | 0.80 ± 0.08$^{bc}$ | 2.40 ± 0.24$^{c}$ |
| 2 | 0.69 ± 0.31$^{ab}$ | 0.69 ± 0.31$^{c}$ | 0.37 ± 0.10$^{bc}$ | 0.65 ± 0.20$^{bc}$ | 0.27 ± 0.04$^{a}$ | 0.79 ± 0.31$^{ab}$ | 0.44 ± 0.14$^{ab}$ | 2.46 ± 0.24$^{c}$ |
| 3 | 0.77 ± 0.31$^{abc}$ | 0.77 ± 0.31$^{e}$ | 0.34 ± 0.15$^{b}$ | 0.07 ± 0.10$^{a}$ | 0.27 ± 0.05$^{a}$ | 0.83 ± 0.31$^{ab}$ | 0.67 ± 0.18$^{bc}$ | 2.54 ± 0.24$^{c}$ |
| 4 | 0.82 ± 0.33$^{abc}$ | 0.82 ± 0.33$^{b}$ | 0.37 ± 0.13$^{bc}$ | 1.50 ± 0.38$^{bc}$ | 0.33 ± 0.05$^{ab}$ | 0.92 ± 0.31$^{ab}$ | 0.55 ± 0.32$^{abc}$ | 2.50 ± 0.24$^{c}$ |
| 5 | 0.89 ± 0.31$^{abc}$ | 0.89 ± 0.31$^{bc}$ | 0.33 ± 0.15$^{b}$ | 1.11 ± 0.21$^{cd}$ | 0.29 ± 0.04$^{a}$ | 0.99 ± 0.31$^{ab}$ | 0.56 ± 0.36$^{abc}$ | 1.95 ± 0.16$^{b}$ |
| 6 | 0.93 ± 0.31$^{abc}$ | 0.93 ± 0.31$^{d}$ | 0.43 ± 0.11$^{bc}$ | 0.91 ± 0.21$^{bc}$ | 0.33 ± 0.05$^{ab}$ | 1.03 ± 0.31$^{ab}$ | 1.43 ± 0.32$^{d}$ | 2.50 ± 0.24$^{c}$ |
| 7 | 1.09 ± 0.31$^{bc}$ | 1.09 ± 0.31$^{d}$ | 0.46 ± 0.12$^{bc}$ | 0.59 ± 0.40$^{b}$ | 0.32 ± 0.06$^{ab}$ | 1.09 ± 0.31$^{b}$ | 1.24 ± 0.26$^{d}$ | 2.45 ± 0.35$^{c}$ |
| 8 | 1.15 ± 0.31$^{bc}$ | 1.15 ± 0.31$^{d}$ | 0.40 ± 0.12$^{bc}$ | 0.64 ± 0.40$^{bc}$ | 0.33 ± 0.07$^{ab}$ | 1.14 ± 0.31$^{b}$ | 0.24 ± 0.26$^{a}$ | 2.62 ± 0.24$^{c}$ |
| 9 | 1.23 ± 0.34$^{c}$ | 1.23 ± 0.34$^{b}$ | 0.54 ± 0.03$^{c}$ | 0.61 ± 0.40$^{bc}$ | 0.36 ± 0.05$^{ab}$ | 1.13 ± 0.31$^{b}$ | 0.85 ± 0.04$^{c}$ | 2.65 ± 0.24$^{c}$ |
| 10 | 0.50 ± 0.24$^{a}$ | 0.50 ± 0.24$^{a}$ | 0.00 ± 0.00$^{a}$ | 0.56 ± 0.40$^{b}$ | 0.41 ± 0.11$^{b}$ | 0.56 ± 0.19$^{a}$ | 0.90 ± 0.07$^{c}$ | 0.52 ± 0.31$^{a}$ |
| | Wet | | | | | | | |
| 1 | 0.01 ± 0.01$^{bcd}$ | 0.01 ± 0.01$^{bcd}$ | 0.02 ± 0.01$^{c}$ | 0.02 ± 0.01$^{b}$ | 0.01 ± 0.01$^{a}$ | 0.23 ± 0.14$^{bc}$ | 0.03 ± 0.01$^{bc}$ | 1.35 ± 0.48$^{b}$ |
| 2 | 0.02 ± 0.01$^{cd}$ | 0.02 ± 0.00$^{cd}$ | 0.01 ± 0.00$^{b}$ | 0.02 ± 0.01$^{b}$ | 0.01 ± 0.01$^{a}$ | 0.24 ± 0.14$^{bc}$ | 0.05 ± 0.01$^{c}$ | 1.46 ± 0.56$^{b}$ |
| 3 | 0.03 ± 0.01$^{e}$ | 0.03 ± 0.01$^{e}$ | 0.01 ± 0.01$^{b}$ | 0.02 ± 0.01$^{b}$ | 0.02 ± 0.01$^{a}$ | 0.31 ± 0.20$^{c}$ | 0.03 ± 0.01$^{bc}$ | 1.44 ± 0.56$^{b}$ |
| 4 | 0.02 ± 0.01$^{de}$ | 0.02 ± 0.00$^{de}$ | 0.00 ± 0.00$^{a}$ | 0.02 ± 0.01$^{b}$ | 0.02 ± 0.01$^{a}$ | 0.27 ± 0.18$^{c}$ | 0.04 ± 0.02$^{bc}$ | 1.38 ± 0.56$^{b}$ |
| 5 | 0.01 ± 0.01$^{bc}$ | 0.01 ± 0.01$^{bc}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.01$^{ab}$ | 0.02 ± 0.01$^{a}$ | 0.29 ± 0.19$^{c}$ | 0.03 ± 0.01$^{ab}$ | 1.16 ± 0.45$^{b}$ |
| 6 | 0.01 ± 0.01$^{ab}$ | 0.01 ± 0.00$^{ab}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.01$^{ab}$ | 0.02 ± 0.01$^{a}$ | 0.26 ± 0.17$^{c}$ | 0.02 ± 0.01$^{ab}$ | 1.07 ± 0.47$^{b}$ |
| 7 | 0.01 ± 0.00$^{ab}$ | 0.01 ± 0.00$^{ab}$ | 0.00 ± 0.00$^{a}$ | 0.02 ± 0.02$^{b}$ | 0.01 ± 0.01$^{a}$ | 0.17 ± 0.11$^{abc}$ | 0.03 ± 0.02$^{ab}$ | 1.59 ± 0.33$^{b}$ |
| 8 | 0.01 ± 0.01$^{bcd}$ | 0.01 ± 0.01$^{bcd}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.01$^{ab}$ | 0.01 ± 0.01$^{a}$ | 0.11 ± 0.09$^{abc}$ | 0.02 ± 0.01$^{ab}$ | 1.53 ± 0.31$^{b}$ |
| 9 | 0.01 ± 0.00$^{ab}$ | 0.01 ± 0.00$^{ab}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.01$^{ab}$ | 0.01 ± 0.01$^{a}$ | 0.01 ± 0.01$^{ab}$ | 0.01 ± 0.01$^{a}$ | 0.96 ± 0.44$^{b}$ |
| 10 | 0.00 ± 0.01$^{a}$ | 0.00 ± 0.01$^{a}$ | 0.00 ± 0.00$^{a}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.00$^{a}$ | 0.00 ± 0.00$^{a}$ | 0.01 ± 0.01$^{a}$ | 0.07 ± 0.03$^{a}$ |

**Table 4:** Toxic heavy metal content of the water samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

| Locations | Physiochemical parameters | | | |
|---|---|---|---|---|
| | pH | T (°C) | TCl (ppm) | Organic Matter |
| | Dry Season | | | |
| 1 | 5.58 ± 0.45$^{a}$ | 28.32 ± 0.90$^{ab}$ | 358.45 ± 0.39$^{f}$ | 368.83 ± 73.98$^{c}$ |
| 2 | 5.62 ± 0.35$^{a}$ | 28.59 ± 1.38$^{ab}$ | 361.89± 0.38$^{h}$ | 6.39 ± 0.37$^{c}$ |
| 3 | 6.63 ± 0.11$^{b}$ | 28.16 ± 0.84$^{ab}$ | 359.51 ± 0.37$^{g}$ | 6.57 ± 0.37$^{c}$ |
| 4 | 5.72 ± 0.27$^{a}$ | 27.89 ± 0.61$^{ab}$ | 358.32 ± 0.38$^{f}$ | 6.60 ± 0.37$^{b}$ |
| 5 | 6.56 ± 0.34$^{b}$ | 27.94 ± 0.49$^{ab}$ | 357.90 ± 0.38$^{f}$ | 5.51 ± 0.37$^{c}$ |
| 6 | 6.23 ± 0.14$^{b}$ | 29.29 ± 1.11$^{b}$ | 326.59 ± 0.38$^{e}$ | 6.39 ± 0.37$^{c}$ |
| 7 | 6.20 ± 0.34$^{b}$ | 27.60 ± 0.47$^{a}$ | 301.88 ± 0.38$^{b}$ | 6.38 ± 0.37$^{c}$ |
| 8 | 5.75 ± 0.25$^{a}$ | 28.66 ± 0.57$^{ab}$ | 312.11 ± 0.38$^{d}$ | 6.09 ± 0.37$^{a}$ |
| 9 | 6.22 ± 0.35$^{b}$ | 29.22 ± 1.01$^{b}$ | 304.09 ± 0.38$^{c}$ | 4.59 ± 0.37$^{b}$ |
| 10 | 6.60 ± 0.08$^{b}$ | 29.02 ± 0.53$^{b}$ | 7.22 ± 0.38$^{a}$ | 5.38 ± 0.37$^{a}$ |
| Wet Season | | | | |
| 1 | 5.60 ± 0.44$^{a}$ | 28.04 ± 0.49$^{ab}$ | 370.87 ± 75.09$^{c}$ | 4.79 ± 0.78$^{b}$ |
| 2 | 5.65 ± 0.33$^{a}$ | 28.06 ± 0.54$^{ab}$ | 362.78 ± 68.01$^{c}$ | 4.87 ± 0.76$^{b}$ |
| 3 | 6.65 ± 0.14$^{b}$ | 27.89 ± 0.39$^{ab}$ | 348.76 ± 64.42$^{c}$ | 5.27 ± 1.14$^{b}$ |
| 4 | 5.80 ± 0.18$^{a}$ | 27.87 ± 0.59$^{ab}$ | 365.39 ± 17.37$^{c}$ | 5.18 ± 1.12$^{b}$ |
| 5 | 6.58 ± 0.35$^{b}$ | 27.67 ± 0.19$^{a}$ | 243.12 ± 30.26$^{c}$ | 5.09 ± 1.14$^{b}$ |
| 6 | 6.26 ± 0.12$^{b}$ | 28.77 ± 0.09$^{c}$ | 220.29 ± 18.30$^{b}$ | 4.57 ± 0.99$^{b}$ |
| 7 | 6.22 ± 0.32$^{b}$ | 27.57 ± 0.49$^{a}$ | 334.43 ± 26.19$^{b}$ | 5.58 ± 1.39$^{b}$ |
| 8 | 5.78 ± 0.23$^{a}$ | 28.40 ± 0.13$^{bc}$ | 355.42 ± 60.95$^{c}$ | 4.16 ± 1.28$^{b}$ |
| 9 | 6.24 ± 0.34$^{b}$ | 28.69 ± 0.11$^{c}$ | 6.25 ± 2.56$^{c}$ | 4.49 ± 1.16$^{b}$ |
| 10 | 6.62 ± 0.08$^{b}$ | 28.74 ± 0.08$^{c}$ | 370.87 ± 75.09$^{a}$ | 2.36 ± 0.54$^{a}$ |

**Table 5:** Physicochemical analysis of sediment samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

| Locations | Non-metallic parameters | | |
|---|---|---|---|
| | S | N | P |
| | Dry Season | | |
| 1 | 100.33 ± 1.31$^{def}$ | 50.66 ± 0.37$^{f}$ | 80.85 ± 0.37$^{e}$ |
| 2 | 100.53 ± 1.31$^{f}$ | 50.80 ± 0.37$^{a}$ | 80.79 ± 0.37$^{d}$ |
| 3 | 100.32 ± 1.31$^{def}$ | 50.66 ± 0.37$^{f}$ | 80.78 ± 0.37$^{d}$ |
| 4 | 100.41 ± 1.31$^{ef}$ | 50.65 ± 0.37$^{f}$ | 80.78 ± 0.37$^{d}$ |
| 5 | 100.31 ± 1.32$^{bcde}$ | 50.65 ± 0.37$^{f}$ | 80.65 ± 0.38$^{c}$ |
| 6 | 10.18 ± 1.31$^{bcd}$ | 50.55 ± 0.37$^{e}$ | 80.65 ± 0.37$^{c}$ |
| 7 | 100.10 ± 1.31$^{bc}$ | 40.66 ± 0.37$^{d}$ | 80.61 ± 0.37$^{c}$ |
| 8 | 100.12 ± 1.31$^{b}$ | 40.22 ± 0.37$^{c}$ | 70.54 ± 0.37$^{b}$ |
| 9 | 90.94 ± 1.31$^{a}$ | 40.09 ± 0.37$^{b}$ | 80.77 ± 0.37$^{d}$ |
| 10 | 100.32 ± 1.31$^{cde}$ | 10.17 ± 0.37$^{a}$ | 2.10 ± 0.37$^{a}$ |
| | Wet Season | | |
| 1 | 90.62 ± 0.13$^{a}$ | 50.25 ± 0.73$^{bc}$ | 80.31 ± 0.19$^{c}$ |
| 2 | 90.64 ± 0.13$^{a}$ | 50.45 ± 0.87$^{c}$ | 80.26 ± 0.12$^{c}$ |
| 3 | 90.52 ± 0.13$^{a}$ | 50.27 ± 0.77$^{bc}$ | 80.25 ± 0.12$^{c}$ |
| 4 | 90.40 ± 0.12$^{a}$ | 50.14 ± 0.68$^{bc}$ | 80.22 ± 0.12$^{c}$ |
| 5 | 90.59 ± 0.14$^{a}$ | 50.38 ± 0.10$^{c}$ | 80.15 ± 0.12$^{c}$ |
| 6 | 80.62 ± 0.13$^{a}$ | 40.78 ± 0.10$^{bc}$ | 80.34 ± 0.16$^{c}$ |
| 7 | 80.52 ± 0.16$^{a}$ | 40.35 ± 0.10$^{bc}$ | 70.30 ± 0.15$^{bc}$ |
| 8 | 70.98 ± 0.21$^{a}$ | 30.68 ± 0.11$^{b}$ | 50.88 ± 0.19$^{b}$ |
| 9 | 80.91 ± 0.15$^{a}$ | 40.17 ± 0.17$^{bc}$ | 80.57 ± 0.18$^{c}$ |
| 10 | 80.11 ± 0.21$^{a}$ | 10.33 ± 0.04$^{a}$ | 0.80 ± 0.35$^{a}$ |

**Table 6:** Non-metallic nutrient content of sediment samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

| Locations | Metallic nutrient parameters (ppm) | | | | | |
|---|---|---|---|---|---|---|
| | Ca | K | $NH_3$ | Mg | Fe | Na |
| | Dry Season | | | | | |
| 1 | 6.62 ± 0.03$^{f}$ | 0.12 ± 0.03$^{a}$ | 21.03 ± 1.41$^{b}$ | 8.79 ± 0.04$^{i}$ | 103.37 ± 2.24$^{b}$ | 1.05 ± 0.04$^{a}$ |
| 2 | 6.63 ± 0.03$^{f}$ | 0.13 ± 0.03$^{a}$ | 21.34 ± 1.41$^{b}$ | 6.27 ± 0.03$^{b}$ | 141.58 ± 2.24$^{f}$ | 1.05 ± 0.0$^{a}$ |
| 3 | 6.50 ± 0.03$^{e}$ | 0.13 ± 0.04$^{a}$ | 21.31 ± 1.41$^{b}$ | 7.93 ± 0.03$^{h}$ | 132.40 ± 2.24$^{e}$ | 1.13 ± 0.03$^{b}$ |
| 4 | 6.50 ± 0.05$^{e}$ | 0.10 ± 0.03$^{a}$ | 21.27 ± 1.41$^{b}$ | 7.56 ± 0.03$^{g}$ | 133.43 ± 2.24$^{e}$ | 1.13 ± 0.03$^{b}$ |
| 5 | 6.46 ± 0.03$^{e}$ | 0.10 ± 0.03$^{a}$ | 21.23 ± 1.41$^{b}$ | 7.50 ± 0.04$^{f}$ | 133.38 ± 2.24$^{e}$ | 1.15 ± 0.03$^{bc}$ |
| 6 | 6.36 ± 0.03$^{d}$ | 0.15 ± 0.03$^{a}$ | 21.16 ± 1.41$^{b}$ | 7.37 ± 0.03$^{e}$ | 130.29 ± 2.24$^{de}$ | 1.22 ± 0.04$^{d}$ |
| 7 | 6.24 ± 0.03$^{c}$ | 0.10 ± 0.03$^{a}$ | 21.13 ± 1.41$^{b}$ | 7.27 ± 0.03$^{d}$ | 127.95 ± 2.24$^{d}$ | 1.22 ± 0.03$^{d}$ |
| 8 | 6.17 ± 0.03$^{b}$ | 0.10 ± 0.03$^{a}$ | 21.07 ± 1.56$^{b}$ | 7.24 ± 0.03$^{d}$ | 127.26 ± 2.24$^{d}$ | 1.23 ± 0.03$^{d}$ |
| 9 | 6.15 ± 0.03$^{b}$ | 0.10 ± 0.03$^{a}$ | 20.33 ± 1.41$^{b}$ | 6.93 ± 0.03$^{c}$ | 122.78 ± 2.19$^{c}$ | 1.20 ± 0.03$^{cd}$ |
| 10 | 3.80 ± 0.03$^{a}$ | 0.15 ± 0.03$^{a}$ | 9.93 ± 1.41$^{a}$ | 2.23 ± 0.03$^{a}$ | 5.94 ± 2.24$^{a}$ | 2.24 ± 0.03$^{e}$ |
| Wet Season | | | | | | |
| 1 | 5.09 ± 0.73$^{b}$ | 0.07 ± 0.02$^{a}$ | 18.88 ± 2.52$^{b}$ | 7.71 ± 0.11$^{d}$ | 120.50 ± 23.92$^{b}$ | 0.10 ± 0.02$^{a}$ |
| 2 | 5.65 ± 1.18$^{b}$ | 0.09 ± 0.03$^{a}$ | 19.06 ± 2.43$^{b}$ | 6.88 ± 1.81$^{cd}$ | 141.16 ± 30.49$^{b}$ | 0.11 ± 0.04$^{a}$ |
| 3 | 5.44 ± 1.03$^{b}$ | 0.08 ± 0.03$^{a}$ | 19.55 ± 3.16$^{b}$ | 7.30 ± 0.64$^{d}$ | 135.08 ± 28.50$^{b}$ | 0.09 ± 0.02$^{a}$ |
| 4 | 5.49 ± 1.10$^{b}$ | 0.06 ± 0.02$^{a}$ | 19.70 ± 3.41$^{b}$ | 7.00 ± 0.57$^{cd}$ | 134.67 ± 27.95$^{b}$ | 0.11 ± 0.05$^{a}$ |
| 5 | 5.21 ± 0.90$^{b}$ | 0.09 ± 0.04$^{a}$ | 19.77 ± 3.60$^{b}$ | 6.82 ± 0.52$^{cd}$ | 132.00 ± 26.82$^{b}$ | 0.16 ± 0.14$^{a}$ |
| 6 | 5.03 ± 1.07$^{b}$ | 0.08 ± 0.02$^{a}$ | 18.40 ± 2.38$^{b}$ | 6.39 ± 0.83$^{bcd}$ | 120.52 ± 26.26$^{b}$ | 0.21 ± 0.27$^{a}$ |
| 7 | 4.81 ± 1.18$^{b}$ | 0.07 ± 0.03$^{a}$ | 21.24 ± 6.29$^{b}$ | 5.33 ± 0.98$^{b}$ | 114.01 ± 27.74$^{b}$ | 0.08 ± 0.01$^{a}$ |
| 8 | 4.55 ± 1.61$^{b}$ | 0.07 ± 0.02$^{a}$ | 17.73 ± 4.79$^{b}$ | 5.35 ± 1.42$^{b}$ | 100.45 ± 39.44$^{b}$ | 0.11 ± 0.01$^{a}$ |
| 9 | 5.42 ± 0.26$^{b}$ | 0.07 ± 0.02$^{a}$ | 18.20 ± 6.04$^{b}$ | 5.79 ± 0.31$^{bc}$ | 101.12 ± 40.29$^{b}$ | 0.19 ± 0.13$^{a}$ |
| 10 | 2.75 ± 0.25$^{a}$ | 0.08 ± 0.04$^{a}$ | 7.065 ± 1.91$^{a}$ | 1.06 ± 0.04$^{a}$ | 1.95 ± 0.85$^{a}$ | 0.11 ± 0.04$^{a}$ |

**Table 7:** Metallic nutrient content of sediment samples at different locations during dry and wet season.

Means with the same superscript letter down the same column are not significantly different (P < 0.05).

### Microbial population dynamics of the water samples

For the study of the bacterial population dynamics, both culture-dependent and -independent approaches were employed. The heterotrophic count study was conducted to estimate the bacterial population size present in the water samples. The results indicated that during the dry season, the bacterial population size was larger compared to that in the wet season (Figure 2). Moreover, sampling site 6 was associated with the largest bacterial population size (Figure 3). The fungal population size also exhibited a similar pattern of seasonal variation. (Figure 3). However, it was largest at sampling site 6 (Figure 3). The results showed the presence of different cultivable and uncultivable bacterial populations in all the water samples collected during the study. The presence of several anaerobic microorganisms belonging to Firmicutes was identified during the study (Table 9). Many organisms from the genera *Clostridium* and *Bacillus* were present in abundance in the water samples during the dry and wet season (Table 9). In addition, the presence of microorganisms belonging to Proteobacteria was also identified (Table 9). Importantly, several enteric bacteria belonging to the genera Enterobacter and strains of *Escherichia coli* were also identified, which indicated the presence of faecal contamination in the water samples (Table 9). Most of the fungi that were identified during the study belong to Ascomycota (Table 10), with only a handful comprising Basidiomycota and Zygomycota (Table 10).

| Locations | Heavy metal parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Ni | Cd | V | Cu | Pb | Cr | Zn | As |
| | Dry | | | | | | | |
| 1 | 5.60±0.04$^{h}$ | 2.48 ± 0.03$^{c}$ | 0.08 ± 0.02$^{b}$ | 3.91 ± 0.02$^{f}$ | 9.16 ± 0.03$^{g}$ | 5.02 ± 0.03$^{g}$ | 24.46 ± 0.03$^{f}$ | 6.74 ± 0.04$^{f}$ |
| 2 | 6.14±0.04$^{i}$ | 2.62±0.03$^{g}$ | 0.10 ± 0.02$^{b}$ | 8.97 ± 0.03$^{h}$ | 7.67 ± 0.03$^{f}$ | 5.12 ± 0.20$^{g}$ | 24.60 ± 0.03$^{g}$ | 6.56 ± 0.04$^{e}$ |
| 3 | 4.59±0.05$^{d}$ | 2.57±0.03$^{fg}$ | 0.09 ± 0.02$^{b}$ | 3.96 ± 0.03$^{g}$ | 7.56 ± 0.03$^{e}$ | 4.90 ± 0.03$^{f}$ | 24.44 ± 0.03$^{f}$ | 6.54 ± 0.05$^{df}$ |
| 4 | 4.69±0.04$^{e}$ | 2.53±0.03$^{ef}$ | 0.09 ± 0.01$^{b}$ | 3.89 ± 0.03$^{f}$ | 7.54 ± 0.03$^{de}$ | 4.70 ± 0.03$^{e}$ | 24.48 ± 0.03$^{f}$ | 7.03 ± 0.04$^{g}$ |
| 5 | 4.99 ± 0.04$^{f}$ | 2.42±0.03$^{bc}$ | 0.08 ± 0.02$^{b}$ | 3.78 ± 0.03$^{e}$ | 6.16 ± 0.03$^{c}$ | 4.77 ± 0.03$^{e}$ | 23.59 ± 0.04$^{e}$ | 6.48 ± 0.04$^{d}$ |
| 6 | 4.48±0.04$^{c}$ | 2.38 ± 0.03$^{b}$ | 0.09 ± 0.03$^{b}$ | 3.69 ± 0.03$^{d}$ | 6.15 ± 0.03$^{c}$ | 4.58 ± 0.03$^{d}$ | 23.20 ± 0.04$^{c}$ | 6.36 ± 0.04$^{c}$ |
| 7 | 4.36±0.04$^{b}$ | 2.70±0.03$^{h}$ | 0.06 ± 0.03$^{b}$ | 3.49 ± 0.03$^{c}$ | 4.71 ± 0.03$^{b}$ | 4.40 ± 0.03$^{c}$ | 39.01 ± 0.03$^{h}$ | 6.32 ± 0.04$^{c}$ |
| 8 | 4.56±0.04$^{d}$ | 2.50±0.03$^{de}$ | 0.06 ± 0.02$^{b}$ | 3.49 ± 0.03$^{c}$ | 6.07 ± 0.17$^{c}$ | 4.36 ± 0.03$^{c}$ | 23.48 ± 0.03$^{d}$ | 6.32 ± 0.04$^{c}$ |
| 9 | 5.09±0.04$^{g}$ | 2.46±0.03$^{cd}$ | 0.00 ± 0.01$^{a}$ | 3.42 ± 0.03$^{b}$ | 7.45 ± 0.03$^{d}$ | 4.24 ± 0.03$^{b}$ | 22.90 ± 0.03$^{b}$ | 5.59 ± 0.04$^{b}$ |
| 10 | 1.07±0.07$^{a}$ | 1.20±0.05$^{a}$ | 0.00 ± 0.00$^{a}$ | 2.00 ± 0.03$^{a}$ | 1.80 ± 0.03$^{a}$ | 1.74 ± 0.03$^{a}$ | 1.46 ± 0.03$^{a}$ | 1.24 ± 0.04$^{a}$ |
| | Wet | | | | | | | |
| 1 | 3.20±0.25$^{bc}$ | 2.37±0.55$^{c}$ | 0.03 ± 0.01$^{d}$ | 2.92 ± 0.64$^{b}$ | 7.69 ± 1.79$^{d}$ | 3.96 ± 0.80$^{b}$ | 25.88 ± 1.83$^{c}$ | 5.21 ± 0.74$^{bc}$ |
| 2 | 3.69±0.94$^{c}$ | 2.56±0.36$^{c}$ | 0.03 ± 0.01$^{d}$ | 2.98 ± 0.67$^{b}$ | 7.70 ± 1.19$^{d}$ | 3.92 ± 0.81$^{b}$ | 26.74 ± 2.42$^{c}$ | 5.12 ± 0.63$^{bc}$ |
| 3 | 2.94±0.33$^{bc}$ | 2.47±0.46$^{c}$ | 0.03±0.01$^{cd}$ | 2.58 ± 0.37$^{b}$ | 6.92 ± 0.65$^{cd}$ | 3.80 ± 0.76$^{b}$ | 26.25 ± 2.02$^{c}$ | 5.04 ± 0.59$^{bc}$ |
| 4 | 2.96±0.41$^{bc}$ | 2.34±0.44$^{c}$ | 0.03±0.01$^{bcd}$ | 2.76 ± 0.58$^{b}$ | 5.90 ± 1.20$^{bc}$ | 3.64 ± 0.71$^{b}$ | 25.90 ± 1.85$^{c}$ | 5.31 ± 0.83$^{c}$ |
| 5 | 2.94±0.61$^{bc}$ | 1.70±0.48$^{b}$ | 0.02±0.01$^{bcd}$ | 2.67 ± 0.56$^{b}$ | 5.97 ± 0.92$^{bc}$ | 3.56 ± 0.67$^{b}$ | 22.56 ± 1.60$^{bc}$ | 4.91 ± 0.66$^{bc}$ |
| 6 | 2.58±0.59$^{b}$ | 1.51±0.37$^{b}$ | 0.02 ± 0.01$^{bc}$ | 2.42 ± 0.45$^{b}$ | 5.46 ± 0.77$^{bc}$ | 3.45 ± 0.92$^{b}$ | 23.53 ± 4.30$^{bc}$ | 4.52 ± 0.81$^{bc}$ |
| 7 | 2.46±0.61$^{b}$ | 1.49 ± 0.35$^{b}$ | 0.01±0.01$^{b}$ | 2.27 ± 0.40$^{b}$ | 4.49 ± 1.40$^{b}$ | 3.30 ± 0.86$^{b}$ | 20.69 ± 5.59$^{b}$ | 4.32 ± 1.00$^{bc}$ |
| 8 | 2.30±0.86$^{b}$ | 1.52 ± 0.18$^{b}$ | 0.02±0.01$^{bcd}$ | 2.03 ± 0.57$^{b}$ | 4.90 ± 1.14$^{b}$ | 2.60 ± 0.77$^{b}$ | 22.44 ± 1.23$^{bc}$ | 3.85 ± 1.52$^{bc}$ |
| 9 | 2.53±1.04$^{b}$ | 1.38 ± 0.05$^{b}$ | 0.01 ± 0.01$^{b}$ | 2.41 ± 0.99$^{b}$ | 5.89 ± 0.41$^{bc}$ | 3.08 ± 1.23$^{b}$ | 23.32 ± 2.69$^{bc}$ | 3.71 ± 1.46$^{b}$ |
| 10 | 0.41±0.14$^{a}$ | 0.04 ± 0.01$^{a}$ | 0.00 ± 0.00$^{a}$ | 0.38 ± 0.37$^{a}$ | 0.39 ± 0.18$^{a}$ | 0.50 ± 0.08$^{a}$ | 0.20 ± 0.07$^{a}$ | 0.07 ± 0.02$^{a}$ |

**Table 8:** Toxic heavy metal content of the sediment samples at different locations during dry and wet seasons.

Means with the same superscript letter down the same column are not significantly different ($P < 0.05$).

| Organisms | Phylum | Water | | Sediment | |
|---|---|---|---|---|---|
| | | Dry | Wet | Dry | Wet |
| *Acinetobacter baumannii* ACICU | Proteobacteria | + | + | + | + |
| *Aeromonas hydrophila subsp. hydrophilia* ATCC 7966 | Proteobacteria | + | + | + | + |
| *Alcaligenes sp.* BN3 | Proteobacteria | + | - | + | + |
| *Azospirillum lipoferum* 4B | Proteobacteria | + | - | - | - |
| *Bacillus altitudinis* | Firmicutes | + | + | + | + |
| *Bacillus cereus* ATCC 10987 | Firmicutes | - | - | + | + |
| *Bacillus megaterum* QM B1551 | Firmicutes | + | + | - | - |
| *Bacillus mycoides* | Firmicutes | + | + | + | + |
| *Bacillus subtilis* | Firmicutes | + | + | + | + |
| *Bacillus* NLAE-zl-256 | Firmicutes | - | - | + | + |
| *Bacillus* NLAE-zl-C302 | Firmicutes | - | - | + | + |
| *Bacterium* NLAE-zl-H271 | Firmicutes | - | - | + | + |
| *Citrobacter freundii* | Proteobacteria | - | - | - | + |
| *Clostridium perfringens* ATCC 13124 | Firmicutes | + | + | + | + |
| *Clostridium ventriculi* | Firmicutes | + | + | + | + |
| *Enterobacter aerogenes* KCTC 2190 | Proteobacteria | + | - | - | - |
| *Enterobacter ludwigii strain* SWA1 | Proteobacteria | + | - | - | - |
| *Enterobacter sp* UI-WRF0285 | Proteobacteria | + | - | - | - |
| *Escherichia coli K-12* | Proteobacteria | + | + | + | + |
| *Klebsiella oxytoca* | Proteobacteria | + | + | + | + |
| *Lysinibacillus fusiformis* ZCI | Firmicutes | - | + | - | - |
| *Lysinibacillus varians* | Firmicutes | - | + | - | - |
| *Micrococcus flavus* | Actinobacteria | + | + | - | - |
| *Proteus mirabilis* ATCC 29906 | Proteobacteria | + | + | + | + |
| *Proteus vulgaris* | Proteobacteria | + | + | - | - |
| *Pseudomonas aeruginosa* PA01 | Proteobacteria | + | + | + | + |
| *Rhodobacter sphaeroides* 2.4.1 | Proteobacteria | + | + | + | + |

| | | | | | |
|---|---|---|---|---|---|
| *Staphylococcus aureus subsp. aureus* NCTC 8325 | Firmicutes | + | + | - | - |
| *Vibrio fluvialis* | Proteobacteria | + | + | - | - |
| *Vibrio metschnikovii* | Proteobacteria | + | + | - | - |
| *Vibrio mimicus* VM573 | Proteobacteria | + | + | - | + |

**Table 9:** Names of isolated bacteria from water and sediment samples at different locations during wet and dry seasons.

+ denotes presence of bacteria; - denotes absence of bacteria.

| Organisms | Phylum | Water | | Sediment | |
|---|---|---|---|---|---|
| | | Dry | Wet | Dry | Wet |
| *Aspergillus fumigatus* | Ascomycota | + | + | + | + |
| *Aspergillus niger ATCC 1015* | Ascomycota | + | + | + | + |
| *Aspergillus flavus NRRL3357* | Ascomycota | + | + | + | + |
| *Aspergillus pseudoglaucus* | Ascomycota | + | - | + | - |
| *Aspergillus sp ASR-161* | Ascomycota | - | - | + | + |
| *Aspergillus terreus NIH2624* | Ascomycota | - | - | + | + |
| *Bjerkandera adusta* | Basidiomycota | - | - | - | - |
| *Bjerkandera sp.B33/3* | Basidiomycota | - | - | - | - |
| *Chrysosporium tropicum* | Ascomycota | - | - | + | + |
| *Coriolopsis sp arf5* | Basidiomycota | - | - | - | - |
| *Curvularia lunata m118* | Ascomycota | - | - | + | + |
| *Mucor circinelloides f circinelloides 1006PhL* | Zygomycota | + | + | + | + |
| *Nemania serpens var. serpens* | Ascomycota | - | - | - | + |
| *Penicillium chrysogenum* | Ascomycota | - | - | + | + |
| *Penicillium oxalicum* | Ascomycota | - | - | + | + |
| *Pichia kudriavzevii* | Ascomycota | + | - | + | + |
| *Pichia sporocuriosa* | Ascomycota | - | - | + | + |
| *Rhizopus oryzeae* | Zygomycota | - | - | + | + |
| *Scedosporium apiospermum* | Ascomycota | - | - | - | - |
| *Talaromyces verruculosis* | Ascomycota | - | - | + | + |
| *Trametes polyzona* | Basidiomycota | - | - | - | - |
| *Trichodema reesei RUT C-30* | Ascomycota | + | + | + | + |
| *Trichoderma asperellum* | Ascomycota | - | - | - | - |

**Table 10:** Names of isolated fungi from water and sediment samples at different locations during wet and dry seasons.

+ denotes presence of fungi; - denotes absence of fungi.

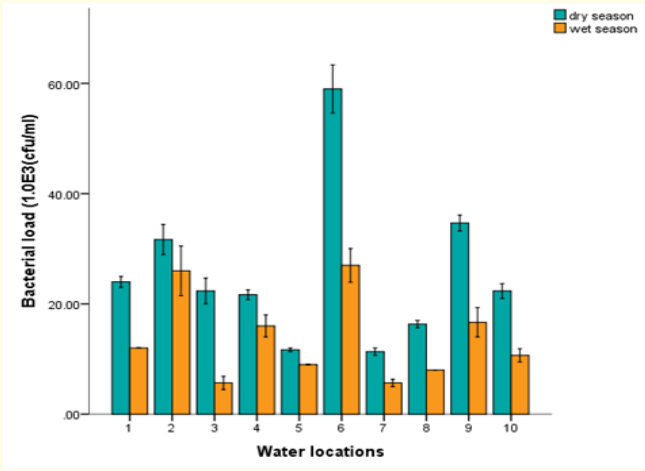


**Figure 2:** Bacterial population load of the water samples at different sampling sites during dry and wet seasons.

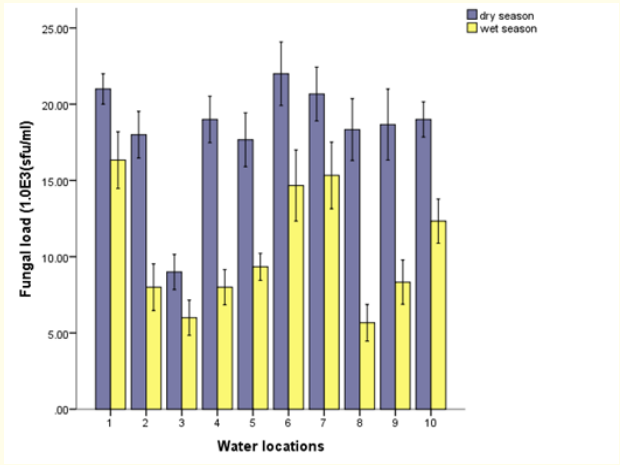


**Figure 3:** Fungal population load of the water samples at different sampling sites during dry and wet seasons.

## Microbial population dynamics of the sediment

In the present study, the microbial community structure of the sediment samples at different sampling sites was investigated to understand the microbial population dynamics of the ecosystem during the dry and wet seasons. For the study of bacterial population, both culture-dependent and culture-independent approaches were employed. The heterotrophic count study was conducted to estimate the bacterial population size present in the water samples. The results indicated that during the dry season, the bacterial population size in the water samples was larger compared to that observed during the wet season (Figure 4). Moreover, the sampling sites 2 and 3 were associated with the largest bacterial population size (Figure 4). The fungal population size also exhibited a similar pattern of seasonal variation (Figure 5), being largest at sampling sites 3 and 10 (Figure 5). The results showed the presence of a different bacterial population in all the sediment samples collected during the study, including the presence of several anaerobic microorganisms belonging to the genera *Enterobacter* (Table 9). Moreover, many organisms belonging to the genera *Clostridium, Vibrio* and *Bacillus*, were present in abundance in the sediment samples during the different seasons (Table 9). The presence of several enteric bacteria belonging to the genera *Enterobacter, Vibrio, Clostridium* and strains of *Escherichia coli* also indicated the presence of disease-causing pathogenic bacteria in the sediment samples (Table 9). Most of the fungi that were identified during the study belong to Ascomycota (for example, *Penicillium chrysogenum, Penicillium oxalicum*) (Table 10).

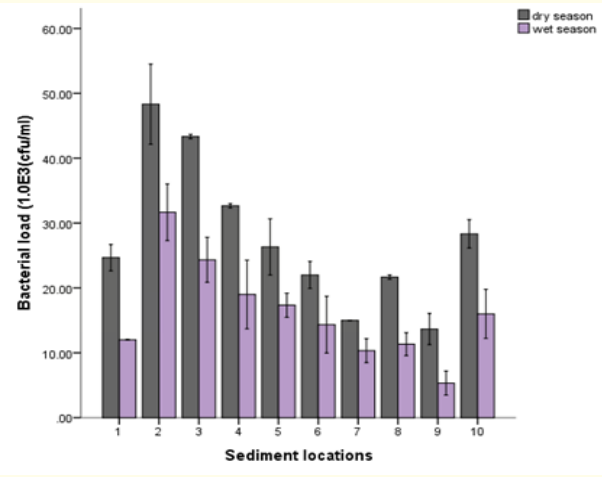


**Figure 4:** Bacterial population load of the sediment samples at different sampling sites during dry and wet seasons.

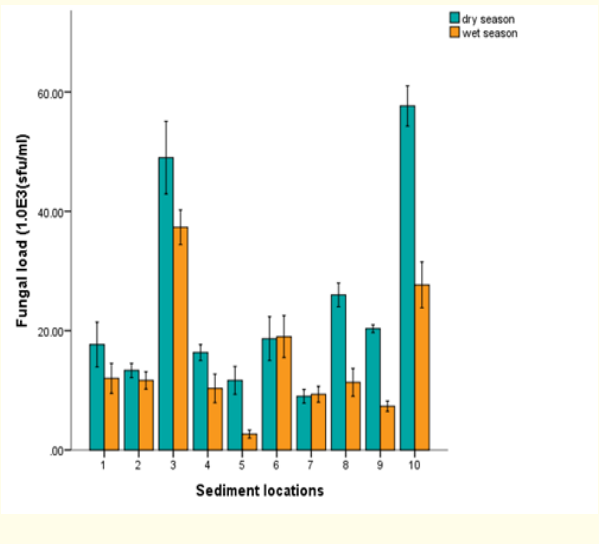


**Figure 5:** Fungal population load of the sediment samples at different sampling sites during dry and wet seasons.

## Discussion

As expected, the physicochemical analysis in conjunction with the toxic heavy metal contamination study within this investigation revealed that the natural environment at Igbokoda (Site 10-control site) was least affected by hazardous pollution including toxic heavy metal contamination. The overall results demonstrated that both the water samples and the sediment samples, and therefore the whole coastal ecosystem, were acidic during both the dry and wet seasons. The temperature of the ecosystem was around 30OC through the sampling period. During the dry season, the loading of total solids was drastically higher compared to the wet season. Untreated domestic wastewater is typically rich in organic matter, which is also associated with a relatively high oxygen demand [29,30], and loading of untreated domestic wastewater into an aquatic ecosystem can significantly lower the dissolved oxygen availability [18], thus adversely affecting higher aquatic organisms such as fishes.

As indicated by the results, most of the sampling sites were associated with relatively high biological oxygen demand (BOD). Since the local people in the region largely depend on fishery for their livelihood, the high BOD content of the water samples can have hazardous consequences on their socio-economic well-being. BOD contents were highly elevated at sites 3 to 9 when compared to the control site over both seasons, implying inhabitants of these areas faced potentially more critical problems, particularly in the dry season. Sites 1 and 2 possessing similar levels of BOD as the control spot in the dry season would suggest they are safer than the rest in terms of oxygen availability. On the other hand, the wet season seemed to pose more of a life-threatening problem to all tested sites, bar site 10, the control site. This deduction, of course, can be tentatively attributed to the dissolution of aerial toxic compounds by rainwater, which adds to the contamination level supposedly existent during the dry period.

Measurements of the ammonia content of the water samples also showed high levels of the gas in all of the sampling sites compared to control, particularly during the dry season, where values were enormously elevated. Ammonia levels in the water samples during the wet period were also comparatively higher in experimental samples when compared with specimens from the control region at the same period. It is entirely evident that a dissolution of the gas during the wet season slightly reduces its toxicity but not enough to warrant safety. Existent minor differences in the levels of ammonia in the experimental regions during both the dry and wet periods only serve to highlight and differentiate the proximity of each tested site to the source of contamination. In the sediment areas, ammonia levels in the dry period were identical in all tested sites, while levels of the gas in the nine experimental regions were only marginally different from the control amount. The vast existential difference between ammonia levels in water samples and sediments are status-related. Aqueous ammonia is known to last longer than its gaseous form. Relating back to oxygen demand, the complete oxidation of one mole of reduced nitrogen (for example, ammonia) requires two moles of oxygen [3,29]. Therefore, the presence of excess ammonia also contributed to high oxygen demand of the water samples. Moreover, the presence of excess ammonia in the water samples can be hazardous to marine life including most fishes [31-34] and therefore, adversely affect the fish production in the region as well.

The bacterial population dynamics study did not reveal the presence of any major ammonia-oxidising microorganisms in the water samples, which also prevented its adequate removal. In turn, many facultative anaerobic bacteria can utilise nitrate as an exogenous electron acceptor during anaerobic metabolism. Thus, a wide range of organic compounds that are typically found in domestic wastewater can be oxidised by the plethora of anaerobic bacteria that was found in the water samples during this study. The nitrate amounts were significantly abundant over both test periods in all tested areas in comparison with control, but when compared to each other, some sites had considerably more nitrate availability than others. Sediment organic matter is closely concomitant with soil minerals and is imperative for the maintenance of aggregate stability [35]. Organic matter in sediments also escalates the water retention capacity and influences the thermal properties of sediments [35], as well as buffering their pH and being responsible for other properties of the sediment environment. Our results indicated that the organic matter content of the sediment is around 6 %, which shows that the sediment was hydric [36-39].

The presence of excess phosphorus in the water samples in all examined experimental sites during the dry and wet seasons may greatly favour eutrophication of the coastal ecosystem. This process leads to increased productivity of photoautotrophic organisms like algae and phytoplankton and a decrease in the capability of other higher organisms, like fishes, to survive, which eventually culminates in a major extinction event in the ecosystems [18,40].

Sites 1 to 3 seem particularly phosphorus-rich in the wet season, while every single contaminated site in the dry season had significantly more elevated phosphorus levels than the control.

Sulphur cycling in wastewater-contaminated aquatic ecosystems, like coastal regions, is an important process owing to its considerable presence in all forms of wastewater [41-43]. The identification of excess sulphur in the sampling sites also indicates the loading of untreated wastewater in the region. Unlike in water samples, sediments did not contain overly significant levels of phosphorus and sulphur in both the rainy and dry seasons in comparison to control. Phosphorus was slightly higher over both periods compared to control, but there were no differences between levels of the gas when compared with each other. Sulphur in the dry season was identical in all 10 regions but marginally different between experimental sites and the control area in the wet season.

Concentrations of Ca and Mg were lower than detected by [44]. Concentrations of Fe (0.52 - 1.82 mg/l) were similar to [44] (0.07 - 6.63 mg/l) but, much less than measured by Asaolu and Olaofe (2005) (29 - 197 ppm) and greater than the FEPA guidelines for water (0.3 mg/l) [45]. The high concentrations of Fe measured are likely natural in origin as Nigerian soils have high concentrations of Fe [46,47]. The elements calcium, sodium, potassium and magnesium are vital nutrients that are involved in several metabolic pathways in cellular metabolism and thus form an essential part of cellular physiology. Sodium and potassium are involved in ATP synthesis in living cells, while calcium and magnesium are essential cofactors in the wide range of metabolic pathways [48]. Therefore, the availability of these nutrients within the water samples as well as in the sediment samples, ensures proper functioning of the diverse microbial population found in the coastal ecosystem. In water samples, mineral levels in the experimental areas are somewhat different from mineral levels in the control regions, but are almost identical to each other, with very few exceptions. In the sedimented sites, except for calcium (6.50 mg/l, dry season and 5.65 mg/l, wet season) and magnesium (8.89 mg/l, dry season and 7.71 mg/l, wet season), the levels of these essential metals at the pilot sites are relatively equal to those at the control site in both the dry and wet seasons, especially in the case of potassium. However, sodium levels are much higher at site 10 than at contaminated sites in the dry season, meaning that an already existing critical situation owing to the lack of oxygen is further compounded by the suppression of sodium.

All metals measured were detected in samples from the Ilaje community, Ondo State, Nigeria. In general, site 10 had the lowest concentrations of heavy metals of all sites sampled and supports its use as a reference site for comparison with other sites used in this study. Heavy metals have the potential to exert toxicity on human beings and other living organisms in a plethora of ways [49]. These metals can have harmful toxic effects on key organ systems of human beings such as the digestive, reproductive, nervous and skeletal systems [18] even upon very low exposure.

Concentrations of Pb in water samples were similar to that reported by Ajayi., *et al.* [44] and Asaolu and Olaofe [50]. Concentrations of Pb in water (0.01 - 0.41 ppm) throughout the Ilaje community were higher than FEPA guidelines [45]. The concentrations of lead (Pb) in sediment samples were lower than detected by Ololade., *et al.* [51] but similar to that reported by Asaolu and Olaofe [50].

Concentrations of chromium (Cr) and cadmium (Cd) were similar to that measured by Ajayi., *et al.* [44], while concentrations detected by Asaolu and Olaofe [50] were significantly higher from those measured in this study. Concentrations of Cr in sediment samples were lower than concentrations measured Asaolu and Olaofe [50], and Cd concentrations were similar to Ololade., et al. [51] and Asaolu and Olaofe [50]. This might be as a result of climate change that may lead to significant changes in the physical (temperature), chemical (increased nutrients) and biological (migration of species) variables that affect water quality and freshwater biodiversity [52]. Compared to guidelines, concentrations of Cr exceeded WHO guidelines (0.05 mg/l) at all sites sampled except sites 9 and 10 during the wet season [53]. Additionally, the FEPA guideline of 0.12 ug/l in marine environments for Cd was exceeded at all sites except site 10 where it was not detected [45].

Concentrations of nickel (Ni), copper (Cu) and zinc (Zn) in water samples were similar to those measured by Asaolu and Olaofe [50]. Additionally, concentrations of Ni and Zn in sediment samples were similar to the concentrations measured by [51] and Asaolu and Olaofe [50]. Copper concentrations were much less than Ololade., *et al.* [51] but similar to Asaolu and Olaofe [50]. However, all samples were near or below the lower limit of FEPA guidelines during the wet season [45]. This may be ascribed to increased volume and subsequently dilution of water body from rainfall during the wet season.

Concentrations of vanadium (V) were higher than WHO standards in sites 1 - 9 in the dry season [53]. Vanadium can be found in phosphate rock and some crude oils [54]. Therefore, the vanadium detected may be attributed to by-products discharge into water body after production and reduced water volume and high rate of evaporation during dry season. However, vanadium was not detected in Site 10 in all seasons which may be due to less industrial activities in this area.

The results showed that there is a diverse population of bacteria and fungus present in the water samples as well as in the sediment samples. Many of the bacteria present in the ecosystem such as Enterobacter, *Escherichia coli* and several Firmicutes are of faecal origin, indicating the presence of this type of contamination in the area. Several of the identified microorganisms are well-known pathogens that are widely associated with enteric diseases [55]. The presence of enteric disease-causing agents due to faecal contamination results from the lack of adequate wastewater treatment facilities and irresponsible disposal practices. Many of the bacteria found in the ecosystem are anaerobic microorganism (facultative) in nature, which can be attributed to the high oxygen demand associated with the water. The microorganisms found represented diverse taxonomic and functional groups that are capable of performing a range of diverse ecological functions within the coastal marine ecosystem. Most of the fungi belonged to the Ascomycota, which produce microscopic spores inside specialised, elongated sac-like cells also known as 'asci'[48]. The prevailing acidic environment greatly favoured the growth of this diverse population of fungi identified. Most of the fungi that were detected during this study were heterotrophic, much like the bacterial population that was observed, which relies on the presence of organic compounds in both the water samples and the sediment samples.

## Conclusion

This study explored several different facets of the complex, diverse, sensitive and vulnerable marine coastal ecosystem. The region is the site for both offshore and onshore crude oil drilling operations conducted by several multinational corporations. Moreover, due to inadequate large-scale treatment facilities in the area, much of the domestic wastewater from the surrounding region makes its way into this sensitive ecosystem through a network of rivers. The findings of this study demonstrated that the region was contaminated by domestic wastewater as indicated by the high oxygen demand and presence of bacteria of enteric origin. The ecosystem was found to be contaminated with other toxic pollutants including toxic heavy metals like cadmium, chromium, lead and arsenic. There was a clear pattern of seasonal variation in most of the contaminants and other metrics since several parameters such as the concentration of most of the pollutants were demonstrably higher during the dry season in comparison to the values assessed during the wet season. Moreover, the concentration of all the pollutants was much higher in the sediment samples compared to the water samples. Nonetheless, some parameters proved equally efficient over both periods, with only slight differences reported, while some toxins were more water-persistent than sediment-dogged. In conclusion, this was a comprehensive study that explored various aspects of this coastal marine ecosystem including environmental issues such as the potential ecotoxicity, which poses a serious threat to the socio-economic and health of the local people. In combination and singly, the various tested parameters seem to condemn the oil-producing areas of Ilaje to a deteriorating fate and the thin balance keeping the environment together appears to be wearing out finally. Thus, if further studies can confirm our experimental findings, stemming from a long-held suspicion, then a lot of effort would be required to save the social and economic lives of the inhabitants of the areas.

## Acknowledgements

The authors would like the staff of the Department of Microbiology, Federal University of Technology for their unwavering guidance and support.

## Conflict of Interest

The authors declare no conflict of interest.

## Bibliography

1. Mitsch WJ and Gosselink JG. "Wetlands". John Wiley and Sons, New York (2010).
2. Vallentyne JR and Beeton AM. "The 'Ecosystem' Approach to Managing Human Uses and Abuses of Natural Resources in the Great Lakes Basin". *Environmental Conservation* 15.1 (1988): 58-62.
3. Wetzel RG. "Limnology: Lake and River Ecosystems". Elsevier B.V, New York (2001).
4. Naser HA. "Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review". *Marine Pollution Bulletin* 72.1 (2013): 6-13.
5. Kivaisi AK. "The potential for constructed wetlands for wastewater treatment and reuse in developing countries: A review". *Ecological Engineering* 16.4 (2001): 545-560.
6. Geist J and Hawkins SJ. "Habitat recovery and restoration in aquatic ecosystems: current progress and future challenges". *Aquatic Conservation: Marine and Freshwater Ecosystems* 26.5 (2016): 942-962.
7. Olujimi JA., *et al*. "Environmental implications of oil exploration and exploitation in the coastal region of Ondo State, Nigeria: regional planning appraisal". *Journal of Geography and Regional Planning* 4.3 (2011): 110-121.
8. Ajayi AO., *et al*. "Microorganisms in the crude oil-producing areas of Ondo State, Nigeria". *Scientific Research and Essays* 3.5 (2008): 174-179.
9. City Population. "NIGERIA: Administrative Division" (2015).
10. Omonijo AG and Matzarakis A. "Climate and bioclimate analysis of Ondo State, Nigeria". *Meteorologische Zeitschrift* 20.5 (2011): 531-539.
11. World Weather Online. "Ilaje, Ondo State" (2016).
12. APHA. "Standard Methods for the Examination of Water and Wastewater". American Public Health Association, Washington D.C (2012).
13. Ahmad AK., *et al*. "Water quality and heavy metal concentrations in sediment of Sungai Kelantan, Kelantan, Malaysia: A baseline study". *Sains Malaysiana* 38.4 (2009): 435-442.
14. Alef K and Nannipieri P. "Methods in Applied Soil Microbiology and Biochemistry". *The Journal of Applied Ecology* (1995): 178.
15. APHA. "Standard Methods for the Examination of Water and Wastewater". American Public Health Association, Washington D.C (1998): 552.
16. APHA/AWWA/WEF. "Standard Methods for the Examination of Water and Wastewater". American Public Health Association (APHA), American Water Works Association (AWWA), and the Water Environment Federation (WEF), Washington D.C (2012): 541.
17. Buchanan JB. "Sediment analysis". Methods for the study of marine benthos. Blackwell Scientific Publications, Oxford, UK (1984): 41-65.
18. Das Gupta A., *et al*. Microbes: "Potential Arsenal to Combat Metal Toxicity". In: Das S, Dash HR (eds) Handbook of Metal-Microbe Interactions and Bioremediation. CRC Press, Boca Raton (2017): 813.
19. Mylavarapu R. "Walkley-Black method". In: Soil Test Methods from the Southeastern United States. University of Kentucky, Lexington 419 (2014): 158-161.
20. APHA. "Standard Methods for the Examination of Water and Wastewater". American Public Health Association, Washington D.C. (2005).
21. Taylor VF., *et al*. "Acid digestion of geological and environmental samples using open-vessel focused microwave digestion". *Analytical and Bioanalytical Chemistry* 372.2 (2002): 360-365.
22. Ben-David A and Davidson CE. "Estimation method for serial dilution experiments". *Journal of Microbiological Methods* 107 (2014): 214-221.
23. Bergey DH., *et al*. "Bergey's Manual of Determinative Bacteriology" (9th editon)". Lippincott Williams and Wilkins, Philadelphia (1994): 9-10.
24. Burnett JH. "Fundamentals of Mycology" (2nd edition). Edward Arnold, London (1976).
25. Luce E. "Koneman's Color Atlas and Textbook of Diagnostic Microbiology (6th edition). *Plastic and Reconstructive Surgery* 125 (2010): 414-415.

26. Wang TY., *et al*. "A simplified universal genomic DNA extraction protocol suitable for PCR". *Genetic Molecular Research* 10 (2011): 519-525.

27. White TJ., *et al*. "Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics". PCR Protocols: A Guide to Methods and Applications (1990): 315-322.

28. Pereira-Santana A., *et al*. "Comparative genomics of NAC transcriptional factors in angiosperms: Implications for the adaptation and diversification of flowering plants". *PLOS One* 10 (2015): e014866

29. Das Gupta A., *et al*. "Nitrogen dynamics of the aquatic system is an important driving force for efficient sewage purification in single pond natural treatment wetlands at East Kolkata Wetland". *Chemosphere* 164 (2016): 576-584.

30. Tang CJ., *et al*. "Enhanced nitrogen removal from ammonium-rich wastewater containing high organic contents by coupling with novel high-rate ANAMMOX granules addition". *Chemical Engineering Journal* 240 (2014): 454-461.

31. Smith VH. "Eutrophication". In: Encyclopedia of Inland Waters. Elsevier Ltd, Oxford (2003): 61-73.

32. Smith VH and Schindler DW. "Eutrophication science: where do we go from here?" *Trends in Ecology and Evolution* 24.4 (2009): 201-207.

33. Andersen JH., *et al*. "Coastal eutrophication: Recent developments in definitions and implications for monitoring strategies". *Journal of Plankton Research* 28.7 (2006): 621-628.

34. Rabalais NN., *et al*. "Global change and eutrophication of coastal waters". *ICES Journal of Marine Science* 66.7 (2009): 1528-1537.

35. Essington ME. "Soil and water chemistry: an integrative approach". (2nd edition). CRC Press, Boca Raton (2015).

36. Mitsch WJ and Gosselink JG. "Wetlands". John Wiley and Sons, New York (2015).

37. Vepraskas MJ and Faulkner SP. "Redox chemistry of hydric soils". In: Wetland soils: Genesis, hydrology, landscapes, and classification (2001): 85-106.

38. Moorhead KK. "Evaluating wetland losses with hydric soils". *Wetland Ecology Management* 1.3 (1991): 123-129.

39. Vasilas LM and Vasilas BL. "Hydric soil identification techniques". In: *Wetland techniques* (2013): 227-272.

40. Ryther JH and Dunstan WM. "Nitrogen, phosphorus, and eutrophication in the coastal marine environment". *Science* 171.3975 (1971): 1008-1013.

41. Janssen AJH., *et al*. "Industrial applications of new sulphur biotechnology". *Water Science and Technology* 44.8 (2001): 85-90.

42. Faulwetter JL., *et al*. "Microbial processes influencing performance of treatment wetlands: A review". *Ecological Engineering* 35.6 (2009): 987-1004.

43. Wu S., *et al*. "Sulphur transformations in constructed wetlands for wastewater treatment: A review". *Ecological Engineering* 52 (2013): 278-289.

44. Ajayi A., *et al*. "Microbes and Mineral Elements in Oil Producing Areas of Ondo State, Nigeria". *American-Eurasian Journal of Scientific Research* 4.3 (2009): 204-212.

45. FEPA. "Guidelines and Standards for Environmental Pollution Control in Nigeria". Taylor and Francis, Nigeria (2003).

46. Okoye BCO. "Heavy metals and organisms in the Lagos Lagoon". *International Journal of Environmental Studies* 37.4 (1991): 285-292.

47. Oyakhilome GI., *et al*. "Heavy Metals Concentration in Sediment and Fish Samples from Owena Multi-Purpose Dam, Ondo State, Southern Nigeria". *British Journal of Applied Science and Technology* 3.1 (2013): 65-76.

48. Prescott LM., *et al*. "Microbiology". McGraw-Hill Education, New York (2008).

49. Duruibe JO., *et al*. "Heavy metal pollution and human biotoxic effects". *International Journal of Physical Sciences* 2.5 (2007): 112-118.

50. Asaolu SS and Olaofe O. "Biomagnification of some heavy and essential metals in sediment fishes and crayfish from Ondo State Coastal Region". *Pakistan Journal of Scientific and Industrial Research* 48.2 (2005): 96-102.

51. Ololade IA., *et al*. "Seasonal metal distribution in Ondo coastal sediment, Nigeria". Journal of Applied Science and Environmental Management 12.4 (2008): 11-18.

52. Solheim A., *et al*. "Climate change impacts on water quality and biodiversity". *European Environment Agency* 6.1 (2010): 1-68.

53. World Health Organization. "Microbial aspects". In: In Guidelines for drinking-water quality. World Health Organization, Geneva (2017): 518.

54. Pedersen T. "Facts about vanadium" (2017).

55. Yurist-Doutsch S., *et al*. "Gastrointestinal Microbiota-Mediated Control of Enteric Pathogens". *Annual Review of Genetics* 48 (2014): 361-382.

**Volume 1 Issue 6 June 2018**