



***In-situ* Physico-chemical Properties of the Deep Atlantic Ocean Water Column and their Implications on Heterotrophic Bacterial Distribution in the Gulf of Guinea**

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ABSTRACT

The in-situ parameters of water have in the time past been determined by collection of water samples, followed by use of common probes and indirect calculations. This work however, presents the in-situ physico-chemical properties of the deep Atlantic Ocean water column using Conductivity, Temperature, Depth (CTD) profilers and their implications on the Atlantic Ocean's heterotrophic bacterial distribution. Measurement was done at 1 m depth intervals from surface to bottom (about 2,774 m) in four (4) locations. ASTM, APHA and other international methods were adapted for NO₃, PO₃, SO₄ and CO₃. Quantitative analysis of the total heterotrophic bacteria (THB) was conducted using culture-dependent technique. The in-situ physico-chemical parameters are in the range of 7.96 – 8.14 for pH, 3.09 – 29.0 °C for temperature, 32,700 – 54,000 μS/cm for conductivity, 32.3 – 34.9 g/l for salinity and 2.62 – 7.44 mg/l for dissolved oxygen (DO). The nutrient characteristics of seawater provide an insight into the existing health status of the deep sea environment of the Atlantic Ocean with average range of 0.31 – 0.49 mg/l for NO₃, 0.97 – 1.91 mg/l for PO₃, 2,525 – 2,735 mg/l for SO₄ and <1.00 – 32.0 mg/l for CO₃. THB count is in the range of 1.91 x 10³ – 2.45 x 10³ cfu/ml in surface seawater, 1.28 x 10³ – 2.19 x 10³ cfu/ml in middle seawater and 0.93 x 10³ – 1.74 x 10³ cfu/ml in bottom seawater. The THB population of the seawater column is in the order surface>middle>bottom. Difference in THB values observed at various depths was significant (p<0.05) but values were consistent across sample stations (p>0.05). Phenotypic characterization based on key morphological and biochemical traits showed that all of the deep seawater isolates showed taxonomic affinities to the genus Pseudomonas.

Key words: Deep Atlantic Ocean, Gulf of Guinea, In-situ Physico-chemical Properties, Seawater, Marine Water, Heterotrophic Bacterial Distribution.

INTRODUCTION

Covering approximately 20% of Earth's surface, the Atlantic Ocean is second only to the Pacific in size. With its adjacent seas it occupies an area of about 106,400,000 square kilometres; without them, it has an area of 82,400,000 square kilometres. The land area that drains into the Atlantic is four times that of either the Pacific or Indian oceans. The volume of the Atlantic Ocean with its adjacent seas is 354,700,000 cubic kilometres and without them 323,600,000 cubic kilometres [1].

The average depth of the Atlantic, with its adjacent seas, is 3,332 metres (10,932 ft); without them it is 3,926 metres (12,881 ft). The greatest depth, 8,605 metres (28,232 ft), is in the Puerto Rico Trench. The width of the Atlantic varies from 2,848 kilometres (1,770 miles) between Brazil and Liberia to about 4,830 kilometres (3,000 miles) between the United States and northern Africa. Nigeria is located on the West-coast of Africa, at the interior-most corner of the Gulf of Guinea. It bordered to the south by the Atlantic Ocean (Gulf of Guinea) [2].

Horizontal and vertical distribution of microbial populations in seawater and sediments is influenced by various factors, such as the physico-chemical nature of the sea and the presence of high organic matter concentrations. Previous in-situ parameters measurements have in the time past been determined by collection of water samples, followed by use of common probes and indirect calculations. A more precise instrument is currently in use by oceanographers for the determination of oceanic in-situ physico-chemical properties.

A CTD measures Conductivity, Temperature, and Depth [3]. Despite the name, all CTDs actually measure pressure, which is not quite the same thing as depth. The relationship between pressure and depth is a complex one involving water density and compressibility as well as the strength of the local gravity field. The CTD data can be used to calculate salinity, density, sound velocity, and other parameters of interest.

The term *CTD* is often used today to describe a *package* that includes the actual CTD as well as auxiliary sensors to measure other parameters (such as dissolved oxygen, pH, turbidity, fluorometer, altimeter, etc.) and a water sampler to collect water samples for later analysis in the laboratory. A *Profiling* CTD measures water parameters as it travels through the water, whether lowered over the side of a ship with a winch to take measurements of a vertical column of water or integrated with an autonomous vehicle or glider [3].

Profiling CTDs are built to perform under the unique dynamic conditions found on varying measurement platforms. They pumped and ducted constant flow for matched temperature and conductivity response while measurements are made on the same sample of water with a predictable delay and predictable flow effects. Aligning and coordinating measurements either done with software or automatically.

All previous ecological studies on Nigeria deep Atlantic Ocean water however were done in fulfillment of legal/regulatory framework prior to commencement of crude oil related activities and are mostly limited to the near shore and coastal areas. This was largely due to the enormous resources and sophistication of sampling equipment involved in deep ocean study.

There is also need to study the Nigeria deep Atlantic Ocean in-situ parameters using modern technologies as this will give a comprehensive and detailed description of the in-situ parameters for a better understanding of microbial distribution in the deep Atlantic Ocean of the Gulf of Guinea.

MATERIALS AND METHODS

Study Area:

The study area is located at approximately 150 – 170km from the nearest Nigerian shoreline and within seawater depths of 2,450 – 2,774 metres (**Figure 1**). Four sampling stations were established as W1 (4.370641667⁰N, 3.839308333⁰E), W2 (4.230655000⁰N, 3.849308333⁰E), W3 (4.370641667⁰N, 3.979310000⁰E) and W4 (4.130665000⁰N, 3.969310000⁰E).

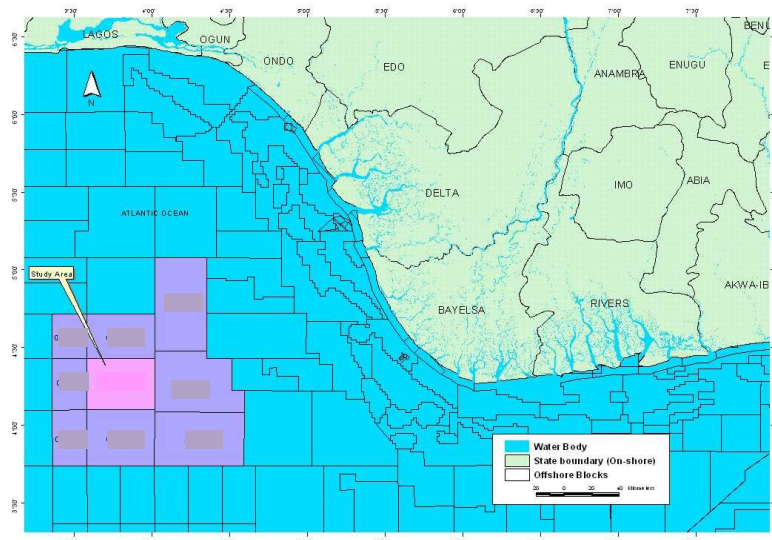


Figure 1: Map of the Study Area in the Deep Atlantic Ocean of the Gulf of Guinea.

Sample Collection

The field data gathering exercise was conducted using a specialized survey vessel, R/V GeoExplorer Type OSV/Research owned by TDI Brooks International. Seawater column samples were collected at the surface, middle and bottom using SBE 32 Carousel Water Sampler manufactured by Sea-Bird Electronics (SBE), Inc. USA. This is specialized equipment comprising twelve (12) water sampling bottles (8 litres size) and an automatic fire module (model AFM 6800m). Six (6) out of the twelve bottles were used for sampling. The AFM is programmed to trigger the bottles for sample collection at desired depths using a special computer programme (SeaTermAF Version 1.1.3).

A SeaCAT Water Profiler (SWP) with CTD model SBE 19 plus 7000m attached to the carousel was used to carry out *in situ* measurement of seawater temperature, conductivity, salinity, DO and depth at 1meter depth intervals from surface to bottom. On reaching the desired depth, the carousel together with the CTD was retrieved from the sea, the CTD was reconnected to the laptop computer and results uploaded using SeaTermAF version 1.31. The results were subsequently converted to common display units, displayed and checked for reasonability before

storing in database. The generated data was erased from the instrument's internal memory to avoid mix up during subsequent profiling.

The seawater samples collected at each station were also analyzed immediately for pH, nitrate (NO₃), phosphate (PO₃), sulphate (SO₄) and total heterotrophic bacteria (THB) while sub-samples were obtained and appropriately preserved for further studies in the laboratory.

Analysis of Seawater Samples

pH was determined *in situ* using 340i WTW multimeter calibrated with pH 7.0 and 10.0 buffer solutions. Turbidity of seawater samples was measured *in situ* using T930712 turbidity meter. Nitrate, phosphate and sulphate in seawater samples were determined colorimetrically by UV4-100 Unicam UV/VIS spectrophotometer at wavelengths of 410nm, 690nm and 420nm respectively [4, 5, 6] while carbonate was determined titrimetrically.

Total aerobic heterotrophic bacteria (THB) in seawater samples were determined using culture-dependent technique. 1ml of the seawater sample was transferred into 9ml of diluent (sterile Ringer's solution) and further dilutions were made accordingly. 0.1ml aliquot of 10¹ dilutions as well as 1ml of the seawater sample were then spread plated on marine agar (MA) plates (Difco 2216) in triplicates [7, 8, 9]. All plates were incubated at 25 ± 2°C in inverted position for 24 – 48 hours. Plates with 30 - 300 colonies were counted at the end of incubation and reported as colony forming units per ml (cfu/ml) of sample analyzed. Isolates were sub-cultured on fresh MA plates to obtain pure cultures of THB and finally onto nutrient agar (NA) slants, stored at 4°C prior to identification and characterization.

Identification and characterization of all bacterial isolates to specie level were done on the basis of their cultural, morphological and physiological characteristics by the identification schemes and methods described by [10 – 17].

RESULTS AND DISCUSSION

Continuous measurement (profiling) of water characteristics (temperature, conductivity, salinity, and dissolved oxygen) was carried out from surface to bottom at intervals of 1m at four (4) stations namely W1, W2, W3 and W4. The representative profile data (W1) are presented graphically using Sea Plot Beta 1.1 Software (Figure 1).

The typical temperature profile of the deep Atlantic Ocean of the Gulf of Guinea is presented in Figure 1a. The profile showed that within 0 – 50m depth, seawater temperatures in the area ranged between 25°C and 29°C. However, within 50m - 60m a region of discontinuity or thermocline was observed. Within this depth range, temperature declined rapidly (at the rate of 0.58°C/m) from 25°C to about 20°C. Also, within 70 – 100m depth another region of slight discontinuity was also observed, with temperature decreasing to about 16.8°C at the rate of between 0.05 and 0.08°C/m. Thereafter, the temperature decreased steadily at a constant rate (0.02°C/m) to about 5°C within 800m depth and subsequently at a slower rate (0.002 – 0.004°C/m) towards 4°C near the bottom.

Data obtained from continuous measurement of conductivity from sea surface to bottom in the study area is presented graphically as Figure 1b. Within 20m depth, seawater conductivity increased (with several inflexions) from about 53,597 μ S/cm at the surface to 56,623 μ S/cm. Thereafter, it decreased gradually, reaching 45,769 μ S/cm at about 100m depth. The conductivity further decreased to about 34,633 μ S/cm at 600m depth and then to 32,705 μ S/cm at the maximum depth measured. The observed trend was similar across profiled stations and fairly consistent with salinity trend in the study area.

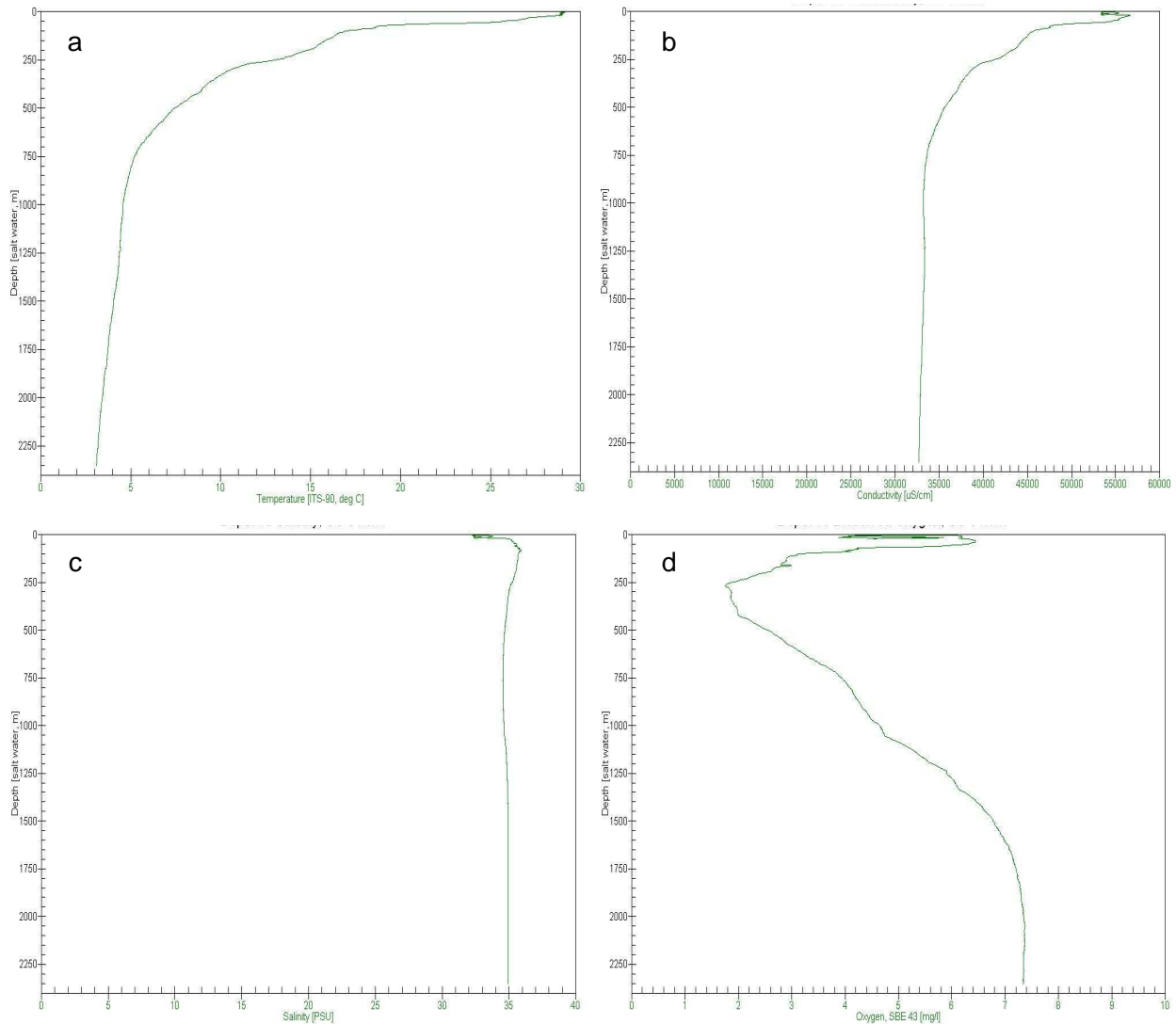


Figure 1: Representative Profile Data for W1 Sample Station a) Depth vs Temperature, b) Depth vs Conductivity, c) Depth vs Salinity, d) Depth vs DO

The salinity of surface seawater in the study area ranged between 32.3ppt and 33.2ppt with a mean of 32.8ppt while the salinity of middle is between 34.6ppt and 34.7ppt with an average of 34.6ppt. Bottom seawater salinity maintained a value of 34.9ppt. Data obtained from continuous

measurement of salinity from sea surface to bottom in the study area is presented graphically as Figure 1c.

The seawater profile at the study area showed that salinity was about 32.3ppt within 10m depth. Thereafter, salinity increased with several inflexions to a maximum of about 35.9ppt within 80m depth. It then decreased steadily (at the rate of 0.002 – 0.004ppt/m) to about 34.6ppt at 600m depth and then much more slowly (0.001 – 0.004ppt/m) to about 34.5ppt at 800m depth. Thereafter, salinity increased slowly and steadily (0.0001 – 0.0006ppt/m), reaching 34.9ppt near the seabed. This trend was again consistent across profiled stations in the area.

The dissolved oxygen of surface seawater in the study area ranged between 5.98mg/l and 7.88mg/l with a mean of 6.35mg/l while of middle and bottom is in the range of 2.62 – 4.66mg/l and 7.33 – 7.44mg/l with mean values of 3.96mg/l and 7.38mg/l respectively. Data obtained from continuous measurement of dissolved oxygen from sea surface to bottom in the study area is presented graphically as Figure 1d.

The profile showed that the dissolved oxygen concentration was fairly constant (4.0 – 6.7mg/l) within 50m depth. The concentration thereafter declined sharply to about 2.9mg/l between 40m and 140m depth. The dissolved oxygen levels continued to decline with several inflexions beyond the 140m depth, reaching 1.76mg/l at 270m. Beyond this depth, the dissolved oxygen level started to increase (with several inflexions) and continued steadily, reaching 7.3mg/l towards the seabed.

The *in situ* measurements of profiled seawater samples from the study site are as shown in **Table 1**.

Table 1: *In situ* Physico-chemical Characteristics of Profiled Seawater Samples

Sample Points	Chemical Parameters (mg/l)								
	pH	Turbidity (NTU)	Eh (mV)	TDS	TSS	NO ₃	PO ₃	SO ₄	CO ₃
W1 Surf	8.14	<1.00	+227	39,600	6.00	0.31	1.03	2,551	32.0
W1 Mid	8.05	<1.00	+233	23,400	7.00	0.46	1.91	2,617	<1.00
W1 Bot	8.04	<1.00	+215	23,400	8.00	0.37	1.47	2,715	<1.00
W2 Surf	8.16	<1.00	+247	39,800	6.00	0.31	0.97	2,541	32.0
W2 Mid	8.06	<1.00	+253	23,400	7.00	0.46	1.60	2,652	<1.00
W2 Bot	8.05	<1.00	+233	23,400	9.00	0.38	1.40	2,733	<1.00
W3 Surf	8.02	<1.00	+225	39,800	6.00	0.31	0.98	2,525	30.0
W3 Mid	8.00	<1.00	+223	23,300	7.00	0.47	1.77	2,650	<1.00
W3 Bot	7.96	<1.00	+226	23,300	8.00	0.38	1.39	2,709	<1.00
W4 Surf	8.08	<1.00	+219	39,600	6.00	0.31	1.11	2,533	32.0
W4 Mid	8.04	<1.00	+237	23,400	8.00	0.49	1.74	2,637	<1.00
W4 Bot	8.02	<1.00	+244	23,400	8.00	0.39	1.39	2,735	<1.00

The pH of surface seawater in the study area ranged between 8.0 and 8.2 with a mean of 8.1 while the pH of middle and bottom is in the range of 8.0 – 8.1 with mean values of 8.0 respectively. The turbidity levels in the seawater were below equipment detection limit of 1.00NTU.

The redox potential (Eh) of surface seawater in the study area ranged between +176mV and +256mV with a mean of +221mV while the redox potential of middle and bottom is in the range of +223 to +253mV and +215 to +244mV with mean values of +237mV and +230mV respectively. Figure 4.9 below shows the redox potential values of the surface, middle and bottom of seawater profile stations (SS 01, 03, 10 and 15). The Eh of the sediments in the study area ranged between, -94mV and -59mV with a mean of -69.4mV. This trend was consistent across sampling stations.

The total dissolved solids (TDS) of surface seawater in the study area ranged between 39,500mg/l and 40,300mg/l with a mean of 39,800mg/l while the TDS of middle and bottom is in the range of 23,300 – 23,400mg/l with mean values of 23,400mg/l. Figure 4.6 shows the TDS values of the surface, middle and bottom of seawater profile stations (SS 01, 03, 10 and 15).

The total suspended solids (TSS) of surface seawater in the study area ranged between 6mg/l and 7mg/l with a mean of 6.4mg/l while the TSS of middle and bottom is in the range of 7 – 8mg/l and 8 – 9mg/l with mean values of 7.3mg/l and 8.3mg/l respectively. Figure 4.7 shows the TSS values of the surface, middle and bottom of seawater profile stations (SS 01, 03, 10 and 15).

The nitrate of surface seawater in the study area ranged between 0.30mg/l and 0.44mg/l with a mean of 0.32mg/l while the nitrate of middle and bottom is in the range of 0.46 – 0.49mg/l and 0.37 – 0.39mg/l with mean values of 0.47mg/l and 0.38mg/l respectively.

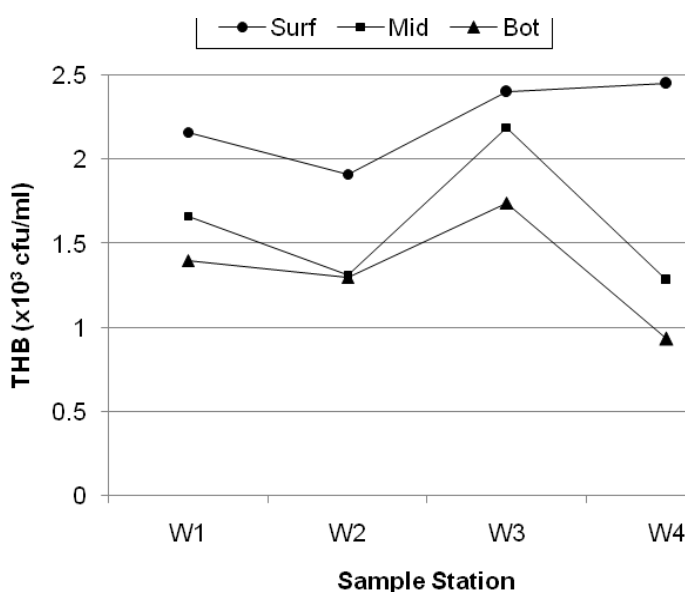


Figure 2: THB counts of the seawater column samples

The phosphate of surface seawater in the study area ranged between 0.97mg/l and 1.16mg/l with a mean of 1.05mg/l while the phosphate of middle and bottom is in the range of 1.60 – 1.91mg/l and 1.39 – 1.47mg/l with mean values of 1.75mg/l and 1.41mg/l respectively.

The sulphate of surface seawater in the study area ranged between 2,514mg/l and 2,622mg/l with a mean of 2,582mg/l while the phosphate of middle and bottom is in the range of 2,617 – 2,652mg/l and 2,709 – 2,735mg/l with mean values of 2,639mg/l and 2,723mg/l respectively.

The carbonate of surface seawater in the study area ranged between 30mg/l and 32mg/l with a mean of 31.5mg/l while the middle and bottom seawater maintained a carbonate concentration of <1.00mg/l.

Total heterotrophic bacterial (THB) count of the surface, middle and bottom of seawater profile stations (W1, W2, W3 and W4) are presented in Figure 2.

Surface seawater samples from the four profile stations have the highest values of THB which ranged from 1.91×10^3 cfu/ml in sample station W2 to 2.45×10^3 cfu/ml in sample station W3. This was followed by the middle seawater samples with a mean value of 1.61×10^3 cfu/ml and bottom water samples with a mean value of 1.34×10^3 cfu/ml.

DISCUSSION AND CONCLUSION

The pH results of profiled seawater which ranged from 7.96 to 8.14 are indicative of alkaline with observed trend reported for tropical Ocean waters [7, 18, 19]. The highest pH values were reported for the surface seawater followed by middle and bottom in that order. [19] reported that seawater pH varies between 7.5 and 8.4 with the highest values occurring in the surface during periods of high productivity when carbon dioxide is withdrawn during photosynthesis. The presence of organic acids, biological processes (photosynthesis and respiration) and physical processes (turbulence and aeration), which can alter concentration of dissolved carbon dioxide affect pH level in the sea.

Temperature in tropical surface ocean waters is usually between 27°C and 28°C. Values of between 28°C and 32°C have been recorded where there is large area of shallow water. The seawater column temperature was consistent with trend in tropical ocean waters. This observed trend (defined thermoclines) was consistent across all the profile stations in the study area. This is in agreement with [1] who stated that in the upper 100m of the sea, the water is almost as warm as at the surface. From 100m to approximately 1000m, the temperature drops rapidly to about 5°C, and below this it drops gradually about another 4°C to barely above freezing. [18] also stated that the temperatures in the deep seas are around 2°C to 5°C.

The highest conductivity values were reported for the surface seawater with a mean of 52,941µS/cm followed by middle and bottom in that order with mean values of 33,660µS/cm and 32,733µS/cm respectively. The conductivity of an aqueous medium is an indication of its ability to conduct an electric current. The conductivity of seawater in any season is determined by the presence of total concentration ions, mobility, valence, relative concentrations and the temperature of the system.

The salinity of seawater from the study area ranged between 32.2ppt and 34.9ppt. This is consistent with the result of [7, 20] who reported salinity of up to 37.8ppt and 33.8ppt respectively for seawater samples collected from different sites. Natural concentrations of

salinity for open seas in the tropical regions is usually between 33ppt and 35ppt, but could be as high as 37ppt where rainfall is low and evaporation is high. The value is lower where large rivers enter the sea [21]. The average salinity of deep seas according to [18] is 34–35ppt. The salinity of seawater gives a measure of the total amount of sodium, chloride and other salts dissolved in it. Sodium and chloride are known to comprise about 86 percent of the ions present in seawater by weight. The combination of salinity and temperature has profound effect on ocean density and its circulation, though density of seawater depends more on salinity than on temperature. As salinity increases, vapour pressure decreases and osmotic pressure increases. It is important in marine ecosystems because changes in salinity can cause changes in the relative diversity and abundance of marine organisms. This may lead to degradation of the food and energy chains in the ecosystem. Slight increase in salinity was observed towards the seabed. A great diversity of microorganisms has been isolated from high-salinity environments, including aerobic and anaerobic microorganisms [22].

Dissolved oxygen (DO) is the measure of the amount of gaseous oxygen dissolved in an aqueous solution. It is one of the most important parameters in aquatic life as it is an absolute requirement for the metabolism of aerobic organisms and also influences inorganic chemical reactions. Ocean surface waters as observed in this study are kept supersaturated with oxygen (5.98mg/l and 7.88mg/l range) primarily by waves and photosynthesis (to few meters depth). This dissolved oxygen range is in agreement with [7]. The concentration at the sea surface becomes slowly reduced with depth and acts as a pointer to the movement of oceanic water masses. Between 40m and 140m depth is the zone where light penetration is sufficient for photosynthesis (photic zone). The 100m water depth (called compensation depth) defines the bottom of the photic zone, where a balance exists between the oxygen produced photosynthetically and that consumed by respiration (i.e. balance between carbon taken up and that dispersed). Photosynthesis does not cease below the compensation depth, but there can be no net phytoplankton growth below it. Decline in dissolved oxygen between 40m and 270m (down to 1.76mg/l at 270m) could be attributed to consumption of dissolved oxygen due to the respiratory needs of both plants and animals and by the microbial oxidation of settling organic detritus. However, at deeper depths, oxygen level rises reaching 7.3mg/l towards seabed, owing to the input of cold dense oxygenated water sinking in Polar Regions. The sustenance of the benthic/bottom dwelling organisms in deep ocean water may be attributed to the observed trend in dissolved oxygen concentration which is rarely limiting (higher concentrations towards the seabed). Among other factors, the amount of oxygen water can hold is dependent on temperature. The basic rule of thumb is colder water has the ability to hold higher amounts of dissolved oxygen than warmer water. The pattern of dissolved oxygen observed is also consistent across profiled stations. Contrary to popular belief, the bottom waters in most of the seas are well oxygenated due to the flow of nutrient and oxygen-rich deep and bottom waters by the South Equatorial Currents and the Pacific through-flow [18].

Turbidity is a unit of measurement quantifying the degree to which light travelling through a water column is scattered by suspended organic (including microorganisms) and inorganic particles. It can be termed as a measure of “cloudiness” in water. The causes of seawater turbidity include waste discharge, urban run-off, bottom feeders that stir up sediments, wave and current actions (especially in less deep areas). In water bodies, turbidity may impart a brown or other colour depending on the light absorbing properties of the solids and may interfere with

light penetration and photosynthetic reactions [23]. The turbidity level of <1.00NTU observed in the study area was consistent with the low TSS levels recorded and indicates that seawater in the area was clear to sight and would permit maximum light penetration into the photic zone for photosynthetic activity.

The chemical characteristics of seawater provide an insight into the existing health status of the marine environment of Gulf of Guinea. Nitrate ions (NO_3^-), phosphate ions (PO_4^{3-}) and sulphate ions (SO_4^{2-}), are the ionic forms of the essential nutrients nitrogen, phosphorous and sulphur respectively, which are essential to growth and reproduction of plants and animals. Generally, nutrients enter the marine environment through urban storm water run-off, irrigation drainage, agricultural run-off, etc. via creeks, rivers and estuaries.

Aquatic species depend on the surrounding water to provide their nutrients. Although a wide variety of minerals and trace elements can be classified as nutrients, those required in most abundance by aquatic species are nitrate and phosphate [23]. While nitrogen and phosphorus occur in nature and are critical to plant life in the marine environment, too much of the nutrients cause an excessive growth of phytoplankton and other organisms, which deprive marine life including fish and plants of oxygen. The natural concentration of nitrate in seawater is between 0.01mg/l at the surface, to 0.70mg/l at lower depths [24].

The nutrient concentrations in the seawater of the study area were consistent across sampling stations ($p > 0.05$). Compared to natural levels in surface seawater, the nutrient levels in seawater of the area were high and may lead to high phytoplankton abundance as well as bloom in certain microbial species in the area. NO_3^- , PO_4^{3-} and SO_4^{2-} concentrations are highest in the middle followed by the bottom while the lowest concentrations of these nutrients were recorded in the surface water samples. This variation in nutrient values of surface, middle and bottom seawater samples is however significant ($p < 0.05$). NO_3^- , PO_4^{3-} and SO_4^{2-} concentrations in all the seawater samples tested appeared in the order $\text{SO}_4^{2-} > \text{PO}_4^{3-} > \text{NO}_3^-$ with low N:P ratio of 1:3 at the surface and 1:4 at the middle and bottom seawater. This is contrary to the work of [25] who reported up to 100:1 of N:P ratio in open oceans. The result confirmed the work of [26, 27] who observed that sulphate is abundant in seawater while nitrate concentrations are typically low. [28] in his review also reported that sulphate is one of the major anions in seawater and is present in excessive quantity. [29] reported nitrate concentration of as low as 0.049mg/l in seawater. The difference observed could be attributed to difference in methodologies used.

Approximately 50% of the world's known petroleum reservoirs are present in carbonate rocks [30]. Carbonate is utilized by marine organisms, in combination with calcium to form their skeletons of CaCO_3 . Carbonate is primarily ion paired in solution with only about 15% of it actually present as free CO_3^{2-} at any given point in time. This is very important to the maintenance of calcium and alkalinity levels in the seawater column, as the free carbonate concentration has the tendency to precipitate with calcium as calcium carbonate [31]. Except at the sea surface where a mean carbonate concentration was 31.5mg/l recorded, the carbonate concentration of seawater column was below the detection limit.

The results revealed that aerobic heterotrophic bacteria were present in all the surface, middle and bottom seawater samples obtained from the Nigeria deep Atlantic Ocean (Gulf of Guinea).

Several previous studies have revealed the presence of aerobic heterotrophic bacteria in ocean sites and in different coastal areas of temperate, tropical and polar zones [7, 32 – 36].

The density of heterotrophic bacterial populations in surface, middle and bottom seawater samples from the study area is in the range of 9.30×10^2 cfu/ml and 7.80×10^3 cfu/ml. [7] stated that the density of bacterial populations in seawater usually ranges from 10^3 to 10^6 cfu/l when cultured on artificial medium. Heterotrophic bacterial density of up to 10^7 has also been reported in seawater samples when direct microscopic method was used [37]. This implies that conventional culture methods usually detect only about 10 percent of the viable aerobic heterotrophic bacterial population but the microscope cannot distinguish living from dead bacteria.

Seawater exhibits antibiotic properties to most terrestrial bacteria. This property of seawater is as a result of factors, such as exposure to daylight, sedimentation reactions, nutrient deficiencies, high salt content and the presence of antibiotic compounds produced by algae, as well as the grazing activities of zooplankton [38]. Low heterotrophic bacterial density thus observed in the seawater from the study area could be attributed to the distance from the nearest Nigerian shore as well as depth and physico-chemical properties of the seawater.

The aerobic heterotrophic bacterial population of the seawater column is in the order surface>middle>bottom. This order supports the work of [39] who concluded that the bacterial population in the water column decreases with depth. Difference in total heterotrophic bacterial values observed at various depths was significant ($p < 0.05$) but values were consistent across sample stations ($p > 0.05$).

Phenotypic characterization based on key morphological and biochemical traits showed that all of the offshore isolates showed taxonomic affinities to genus *Pseudomonas*. Morphological and biochemical characteristics of *Pseudomonas* isolated in this study are similar to those described by various authors [16, 40 – 43]. *Pseudomonas* is a well-known and widespread microorganism, which have been isolated from a variety of natural sources and characterized by a high level of metabolic diversity [44, 45, 46]. *Pseudomonas* has also been isolated in the deepest recorded part of the ocean at 11,033m which lies in the Mariana Trench in the Pacific Ocean [47]. *Pseudomonas* is known to possess physiologic and genetic capabilities for surviving and proliferating under extreme environmental conditions such as alkaline and acidic conditions, high and low temperatures and very high pressure under the deep sea [16]. Possession of multiple genes coding for all the three classes of ribonucleotide reductases in *Pseudomonas* species is another adaptive feature for their survival both in oxic and anoxic environments [46, 48]. Seawater environment is known to exhibit antimicrobial effects on many bacterial species.

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