Water Quality Status Within The Anchorage Space of Tema Harbour, Ghana

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Abstract

Marine pollution is attributable to anthropogenic introductions of contaminants above their natural background levels and being dispersed by ocean forcing. Assemblages of vessels within offshore platforms and seaport terminals could also be potential sources for marine water contamination. As such, nearshore perimeters of the Tema Port were assessed to review the vessel register and the seawater quality through Automatic Identification System (AIS), in-situ and laboratory analysis. The results of analysed satellite data suggested ~1,600 commercial vessels of over 50 flag states including Ghana were present in the West Africa territorial waters between 2016 and 2020. Bacterial load shows the following order: total heterotrophic bacterial [THB] (364-468 cfu/mL) > total coliform [TC] (26-73 cfu/100 mL) > faecal coliform [FC] (1-13 cfu/100 mL). Phytoplankton species abundances were in order *Ceratium spp*. (31.8%) >*Protoperidinium spp*. (30.1%) > *Dinophysis spp*. (9.3%) > *Coscinodiscus sp*. (7.3%) > *Lingulodinium polyedra* (6.9%) = *Nitzschia sp*. (6.9%). Water temperature ranged between 23.9 and 27.5 oC (surface to 25.4 m depth), salinity 36.03 ± 0.51‰, dissolved oxygen 6.54 ± 0.94 mg/L and pH 8.18 ± 0. 06. Phosphate, ammonia, Cd, As, and Pb levels were low (0.01 to 0.153 mg/L). Nitrate, silicate and Mg were relatively high (0.7 - 2.18 mg/L). Pearson correlation coefficient displayed 0.05 and 0.01 significant levels between total dissolved solids (TDS) and electrical conductivity and salinity, and dissolved oxygen and temperature and arsenic levels. Normalization physicochemical data suggested thermal stratification at 15 m depth. Nutrient and biological results indicated normal water quality conditions, however, relatively high levels of phytoplankton including harmful and toxic species suggested excess nutrient contamination in the study area. Further assessment is recommended to ascertain the link between phytoplankton and nutrient load at the anchorage space.

Keywords: anchorage; seawater; stratification; nutrient; Faecal-coliform; phytoplankton

Introduction

Nearshore continental shelves and ocean land space provide natural resources and fulcrum for global trade nodes for human growth and development. However, there are issues of increasing localized gross anthropogenic contaminations from plastic to sewage-related pollutants and vessel activities impacting the water quality in the nearshore spaces of marine ecosystems. The increases in the levels of nutrient loads in coastal waters do not only affect water quality but also leads to algal blooms and red tides as well as flourishing of opportunistic planktonic organisms resulting in fish kills, marine mammal death, outbreaks of shellfish poisoning, loss of bottom shellfish habitats, hypoxia and anoxia conditions (Rabalais et al., 1991; NRC, 2000; Byrnes and Dunn, 2020). Biological contaminations of the nearshore ecosystems of oceans and marginal seas through human activities are well documented (David et al., 2007; UNEP-CEP, 2020).

Marine organisms notably, the plankton communities including bacterioplankton are driven by nutrients and recognized as the net primary producers of the aquatic ecosystem. The phytoplankton communities plus holoplankton, meroplankton and their propagules are normally present in the marine ecosystems for food chain sustenance and energy transfer. It is important to note that, the quality of marine waters and their effects on human health becomes apparent through the rapid and exponential growths of the plankton communities due to availability of excess nutrients. Additionally, the transitional species of benthic planktonic larvae settling on or attaching to hard substrates, forming colonies and outgrowing niches will lead to water quality deterioration through depletion of dissolved oxygen. The early stages of hard substrates colonization by planktonic benthos are biofouling of harbour walls, shipwrecks, submerged ropes and offshore platforms. The later stages or climax of these colonies manifested as dead zones with the formation of hydrogen sulphide (H_2S) that leads to further water quality deterioration. Some of these colonies may survive the transition periods and evolve as cryptic or prevalence of none economic species of no predation mechanisms (Byrnes and Dunn, 2020).

Thus, water quality parameters within harbours and offshore platforms and installations should be a public concern amidst global industrialization and port development. This is because the continual growth of global trade (Alhouli, 2011) means possible increases in the number of ships at offshore platforms, terminals and anchorage spaces of the oceans. This will not only increase substrates (vessels' hulls) for biofouling but may also affect seawater quality through accidental or routine discharge of wastes and sewages (black waters) into the marine aquatic ecosystem including the anchorage space. Thus, there is a possibility of anchorage spaces that serve as temporal holding grounds for vessels, ships and other drafts becoming aquatic zones of potential threat to marine lives both local and global. Currently, there is limited work on water quality in the anchorage space measuring between 115 -200 km^2 offshore Tema Harbour (Botwe, 2017, Kpeglo 2016). This study, therefore, evaluated the status of marine water quality offshore the Tema Port, Ghana.

Study area

The study assessed water quality in the perimeters of the anchorage space of the Tema Port located at the southern section of the Greater Accra Region, Ghana. Since the port's inception in early 1962 (Botwe et al., 2017), the Tema Port has been serving as a receiving terminal and facilitator of trades in Ghana's economy and currently considered hub and spoke for national development (Kambase, 2020). At the sub-regional (West Africa) levels, the Tema Port is rated very high due to the volumes of ships and cargoes that arrived annually and ranked first in terms of efficiency (Boermann, 2016). Additionally, the port's location to landlocked countries like Burkina Faso, Niger, and Mali has also deepened the international trade services of the port (Boermann, 2016). The construction and commission of the current deep-water port (Figure 1A [2]) in addition to the existing port

Fig.1A Anchorage area of the Tema Port showing the sampling points (A-C) with cluster of moored vessels inserted images of ships taken at 19 GMT) indicated by arrow (photo by author)

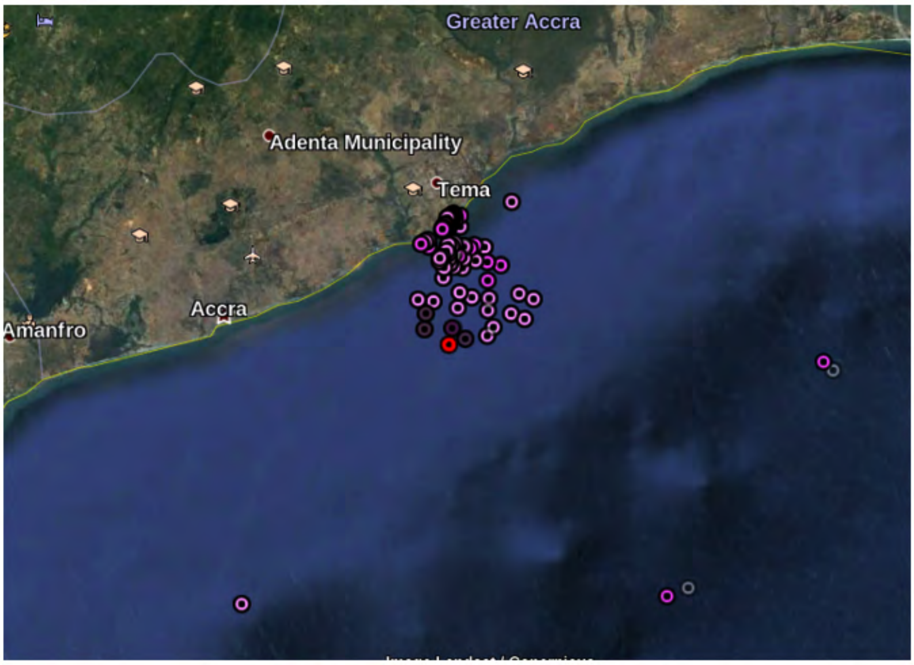

Fig. 1B Clusters of moored vessels at the Tema Anchorage space detected by automatic identification system (AIS)

(Figure 1A [1]) as well as the drydock base (Kambase, 2020), may offer the potential to increase vessel numbers and human activities at the anchorage space. Figures 1A and 1B show an overview of vessels clustering at the anchorage space of Tema Port at fine and coarse resolutions, respectively.

Sample and data collections

In-situ data collections were done between 5° 35'N; 0° 02'W and 5° 39'N; 0° 06'E (Fig.1). Specifically, samples were collected at points "A", "B" and "C" for water quality assessment whereas AIS data was obtained for the entire sub-region (detail is given in Section AIS vessel detection).

Direct measurements of hydrographic parameters; conductivity, total dissolved solids (TDS), salinity, temperature, pH, dissolved oxygen (DO) and turbidity were done at 2.5 m intervals based on barrier layer thickness (BLT) relationship with isothermal layer depth (ILD) and mix-layer depth [MLD] (Dossa et al., 2019) using a Multi-Parameter Probe (Horiba@52U) with a depth sensor deployed from an inshore vessel. A set of raw water samples were also collected into 500 mL high-density polystyrenes (HDPE) bottles from the three depths (0.5 m, 5 m, and 15 m) using a 2 L capacity Niskin water sampler (HYDRO-BIOS LTD., Germany).

The raw seawater samples collected were analysed for three groups of contaminants; Group one (1) comprised phosphate (PO_4^{3-}), ammonia (NH_3-N), silicate (SiO_4^{4-}), and sulphates (SO_4^{2-}); Group two (2) arsenic (As), zinc (Zn), cadmium (Cd), lead (Pb) and manganese (Mn); and Group three (3) microbes.

Minimizations of cross-contaminations of the HDPE bottles for groups 1 and 2 analyses were achieved through washing, using milled detergent and later soaked in a 1% nitric acid solution overnight and rinsed three times with distilled water. Further conditioning of the receptacles was done by rinsing three times with the collected raw water samples before filling to the brim. Group one (1) samples were directly placed in a thermally insulated container with ice packs whereas group two (2) samples were acidified with 65% analytical grade nitric acid solution using a 5 mL: 1 L approach APHA (1998). Group 3 samples were collected into 500 mL autoclave sterilized wide mouth dark bottles. The glass bottles were three-quarters filled with the samples collected at 0.5 m depth only. The samples were kept on ice, transported to the

laboratory and analysed within 24 hours.
Phytoplankton samples were collected through vertical hauling using a plankton net of mesh size 20 µm with a diameter of 0.6 m. The collected phytoplankton samples were backwashed from side to side, concentrated into the coden-end of the net and transferred into wide-mouth HDPE bottles and fixed with 4% formalin solution and analysed within two weeks.

Laboratory Analysis
Group 1 analysis was done calorimetrically using Hatch Spectrophotometer (HACH, DR 2800) following APHA (1998) standard protocols. The samples were allowed to thaw to room temperature overnight, and an aliquot of 10 mL was transferred into cleaned reaction vials and treated with HACH Reagents for colour development and later measured at a specific wavelength per treatment. Analytical details and procedures are shown in Klubi et al. (2019) and HACH (1992), as well as a summary outline below:

Summary of chemical analysis procedures
(A). *Nitrate; cadmium reduction method. 10 mL samples were transferred into a vial and NitrVer five (5) reagent containing cadmium was added and shaken vigorously. The cadmium reduced nitrate to a brownish nitrite and measured at 550 nm:* ***(B).*** *Phosphate; ascorbic acid method. 10 mL samples were transferred into a vial and PhosVer 3 reagent containing molybdate and ascorbic acid was added and mixed gently. Mixed complexes of phosphate and molybdate were formed, and ascorbic acid reduces the complex into molybdenum blue and then measured at 880 nm:* ***(C).*** *Silicate; Silicomolydate method. 10 mL samples were transferred into a vial and Silicate Reagent Set (Molybdate, Acid Reagent and Citric Acid) were added in turns. Molybdate ions react with silicate and phosphate in the sample to form yellow complexes silicomolybdic and phosphomolybdic acids. The addition of citric acid destroys phosphate complexes leaving the silicomolybdaic acid and measured at 452 nm:* ***(D).*** *Sulphate; USEPA Method 375.4. Due to high sulphate levels, the 1:50 ratio of sample to distilled water volumes were mixed. Total volume 10 mL was mixed with SulfaVer 4 reagent containing barium in a vial. The barium ion reacts with sulphate ions to form a white precipitate and was measured at 450 nm.*
Group 2 analysis was done using Atomic Absorption Flame Photometer (AAFP) while Group 3 analysis was done through pour plate and filtration methods (APHA, AWWA, WEF, 2012). The samples were filtered through a 0.45 membrane filter and placed on m-Endo, m-FC, and m-HC agar broth for total coliform, faecal coliform, and E. coli counts, respectively. For heterotrophic bacteria, pour plates were prepared by mixing one (1) ml volume of samples with molten agar (nutrient agar) in sterilized Petri dishes. The setups were then incubated at 37^{o}C for 24 hours and the number of bacteria growth was directly estimated and expressed as colony-forming units per 100 mL (cfu/100 mL) (APHA, AWWA, WEF, 2012).
Phytoplankton identification and abundance estimation were done after concentrating the sample volume to 50 mL aliquots. The 50 mL samples were thoroughly homogenized and wet mounts were prepared using a drop method. The wet mount was then examined under 100 magnification using a Leica Microscope and identification guides, respectively (Tomas et al., 1996).

Quality Assurance (QA) and Quality Control (QC)
In situ measurements were taken after the readings attained equilibrium. Additional weight was attached to the sensor guide to minimize drifting and maximize vertical profile against buoyancy. Distilled water was used for preparations of zero and blank solutions in addition to the analysis of split samples. Reactive phosphate was analysed before nitrate. This is to avoid false blue colour development between ascorbic acid and cadmium. Ascorbic and cadmium elements are active components of the Nitri@ Ver5 and Phos@Ver3 reagents for nitrate and

phosphate analysis, respectively. Dilution of samples for sulphate ions analysis was within a 50-80% factor ratio (Klubi et al., 2019). This was to avoid under or over-estimation of sulphate ion levels due to high error margins associated with the dilution factor (1:50). The precision and accuracy of the Atomic Absorption Flame Photometer were monitored during samples analysis by measuring prepared standard solutions of Pb, Zn, As, Mg, and Cd intermittently. A plot of absorbance and the standard readings show an intercept of -7 x 10^{-5}, which is close to the origin and can be considered negligible. The performances of the intermittent readings of the standard solutions (Pb, Zn, As, Mg, and Cd) were assessed using Equation 1;

$$yi = {}^{xi}/_{\sum xi/n}, \qquad (1)$$

where ***Yi*** is the normalized value of each element per repetition, xi is the obtained value of each repetition for the same element, and n is the total number of repetitions for each standard solution. The results indicated an excellent (100%) reproducibility of the readings for Zn, Mg, and Pb. Arsenic readings show reproducibility between 97-102% as compared to Cd, 92-102%. This suggested that the obtained results for the samples are consistent and did not drift as normally experienced with most AAS readings.

Statistical Analysis

Statistical analyses were performed using Minitab ® 18 for computing the arithmetic mean and standard deviation (SD) as well as multiple correlations and significant differences for physicochemical parameters using the Pearson Coefficient Correlation (PCC). The propagation of error and testing of homogeneity and intercomparison of results was by means of the Least Significant Difference (LSD) tests at 95% confidence levels (CL). The depth profiles of the water quality parameters (conductivity, temperature, pH, turbidity, TDS, and salinity) were plotted using Origin Probe Software.

Automatic Identification System (AIS) for vessels detection

The vessel data for the West Africa Sub-region were obtained using the Automatic Identification System (AIS). The data was made available through the GMES and Africa Project at the University of Ghana. The AIS data was downloaded via exactEarth's web-based viewing platform that allows users to access vessel traffic information. Navigational and positional information was extracted for individual vessels within the West Africa Sub-

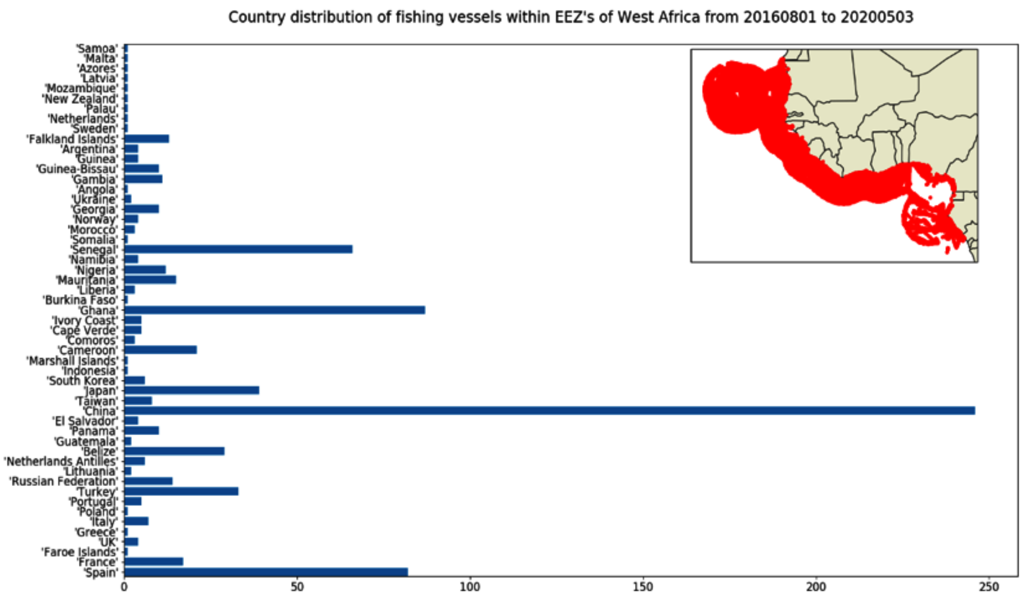

Fig. 2 Name of ship's flag states and number of fishing vessels between 2016 and 2020 within the West Africa waters respectively

region to have insight into the distribution and activities of vessels.

Results and Discussions

Fishing vessels assessed based on AIS

Figure 2 shows the number of fishing vessels and their routes within the Exclusive Economic Zones (EEZ) of the West African continental shelf of the Gulf of Guinean continuum. On the other hand, Fig. 1B shows the cluster of ships at the Tema anchorage space.

Analysis of Automatic Identification System (AIS) data over the region indicates that close to 1,600 industrial fishing fleets from over 50 countries operated within the EEZ between August 2016 and May 2020 (Fig. 2). China, Spain, Senegal, Turkey, Japan, Cameroon, France, Falkland Islands, Mauritania, Georgia, and Nigeria dominated the flag states of these fishing fleets (Fig. 2). This result suggested close to 11 industrial fishing were within the Wester Africa waters per day on average for the period. Compared to Kurekin et al. (2019), the average vessels per day could have been higher considering the 91% success of the AIS applications. This further suggested that the number of fishing fleets plus the local (inshore and canoes) drafts are not only contributing to the fishing efforts but may also lead to water quality deterioration through biofouling and introduction of non-native plankton species from other marine ecosystems.

Profile of in-situ physicochemical parameters

Profiles (approximately 0.5-25.4 m depth) of the water quality parameters at the anchorage area offshore Tema Harbour are shown in Fig. 3Ai-vii. Figures 3Aii, iii, and v displayed a general gradient for temperature, dissolved oxygen (DO), and pH with depth. Conductivity, salinity, and TDS levels showed sharp ascendants within 0.5 to 5 m depth and relatively increment with greater depth (Fig. 3Ai, IV and vii), respectively. Turbidity levels were, however, variable (Fig. 3Avi). Statistically, temperature levels ranged between 23.9 and 27.5 °C with a mean of 25.71 ± 1.55 °C at a 95% confidential interval (Table 1). pH was 8.18 ± 0.06. Salinity ranged between 34.22 and 37.84 ‰ with a mean of 36.03 ± 0.51‰ whereas conductivity varied between 52.61 and 56.23 mS/cm, and a mean of 54.42 ± 0.0.70 mS/cm, TDS between 30.83 and 34.48 g/l with a mean of 32.64 ± 0.42 g/l. Dissolved oxygen levels were between 4.73 and 8.35 mg/L, and a mean value of 6.54 ± 0.94 mg/L. Turbidity levels were between

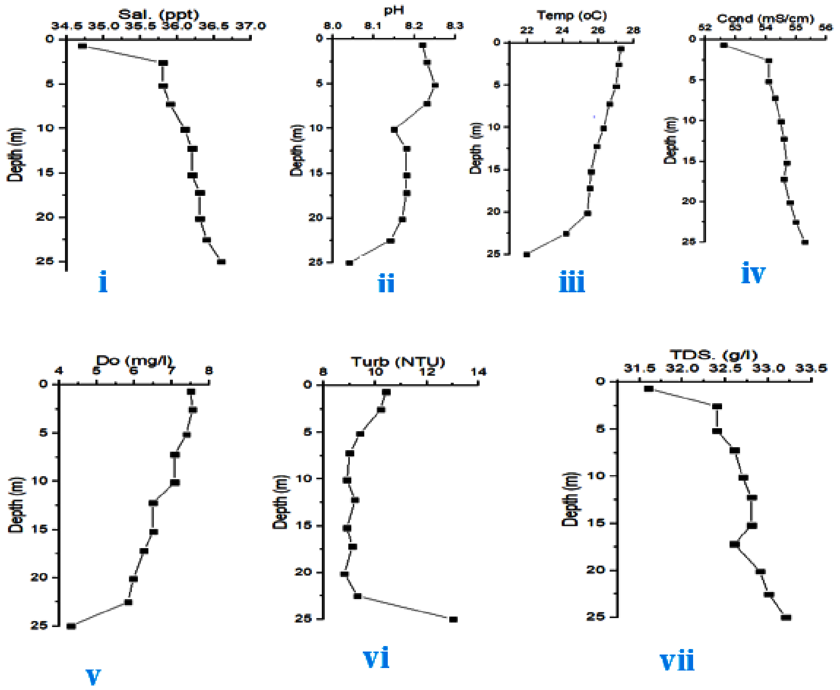

Fig. 3A: Profiles of physicochemical parameters at the anchorage offshore Tema

7.84 and 11.47 NTU, and a mean of 9.66 NTU as shown in Table 1.

Application of Dunnet's comparative test at 99.08% level of confidential interval (CI) suggested no significant variation in turbidity levels with depth (Table 2). However, significant ($p > 0.05$) differences were detected for pH, temperature, conductivity, salinity, TDS, and DO with depth (Table 2). This is expected in ocean basins and is normally associated with seasonal variabilities (wet and dry seasons) (Wiafe et al., 2008). As such, uniformity and apparent differences of the water quality parameters were evaluated through normalization and standardization of the raw data, applying equation 1. This is to do away with scale differences and centre the values at a unit for comparison.

The rescaled results are shown in Fig. 3B. Again, turbidity levels did not display any specific variation and could be best described as erratic. However, temperature values

TABLE 1

Mean levels, standard deviation, n=11; at 95% confidential intervals for the water quality parameters

Factor	Mean	StDev	95% CI
pH	8.1791	0.0580	(6.3690, 9.9892)
Temperature (°C)	25.714	1.547	(23.904, 27.524)
Salinity (ppt)	36.027	0.506	(34.217, 37.837)
Conductivity (mS/cm)	54.418	0.703	(52.608, 56.228)
Dissolved oxygen (mg/l)	6.537	0.956	(4.727, 8.347)
Turbidity (NTU)	9.655	1.227	(7.844, 11.465)
Total dissolved solids (g/l)	32.636	0.420	(30.826, 34.446)

TABLE 2

Dunnet's simultaneous tests for the mean levels of water quality parameters at 99.08% confidence levels

Parameters	Difference of Means	95% CI	T-Value	Adjusted P-Value
pH	-4.36	(-7.80, -0.92)	-3.39	0.007
Temperature (°C)	13.17	(9.74, 16.61)	10.24	0.000
Salinity (ppt)	23.49	(20.05, 26.92)	18.26	0.000
Conductivity (mS/cm)	41.88	(38.44, 45.31)	32.56	0.000
Dissolved oxygen (mg/l)	-6.00	(-9.44, -2.57)	-4.67	0.000
Turbidity (NTU)	-2.88	(-6.32, 0.55)	-2.24	0.136
Total dissolved solids (g/l)	20.10	(16.66, 23.53)	15.62	0.000

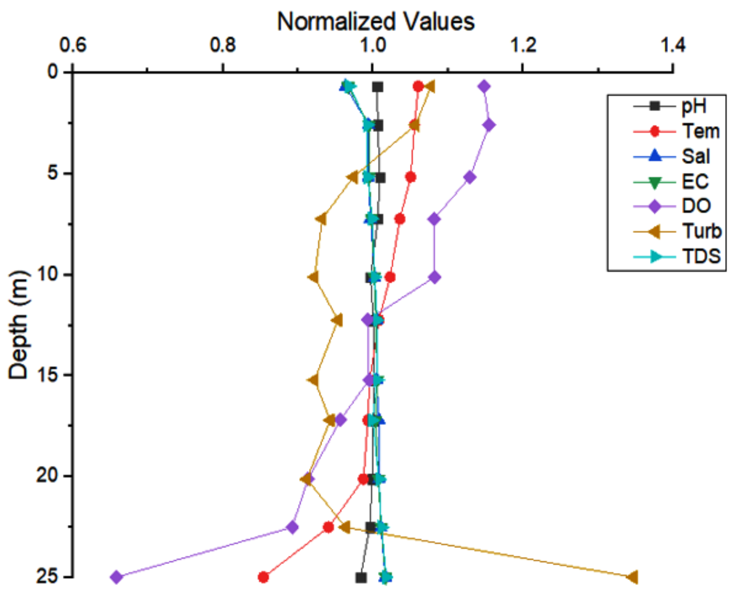

Fig. 3B: Normalized in-situ parameters at the anchorage area displaced a sharp gradient at 12.5 and 15 m depth and could be described as an isothermal region (Fig. 3B). This may be due to the abrupt changes in coastline geomorphology together with the extending of breakwaters into the depth of closure thereby increasing the residence time of the waters leading to stratification. The rescaled values of pH, conductivity, salinity, TDS, and DO also converged at 12.5 to 15 m depth (Fig. 3B). The decreasing levels of DO with depth could be associated with the euphotic zone, where wave-induced mixing effects is higher as well as phytoplankton activity. However, conductivity (EC), salinity, and TDS ascendants with depth (Fig. 3B) are expected (Klubi et al., 2019). This may be due to the settling velocity of coagulates and suspended solid particles of organic and inorganic origin.

Comparatively, the normalized data offered a better presentation of the water quality parameters than the raw data (Fig. 3a and Fig. 3b, respectively). Thus, the slight variation in the TDS values (Fig. 3avii) at 17.5 m depth compared to salinity and conductivity (Fig. 3ai and Fig. 3aiv respectively), did not influence the trend and could be ascribed as a mechanical error.

Descriptive analysis of water quality parameters against depth

Results of water quality parameters for nutrients (group 1) [phosphate, nitrate, ammonia, silicate, and sulphate], and trace metals (group 2) [Cd, Pb, Zn, As, and Mg] at the three depths (0.5, 5 and 15 m) are shown in Table 3 and Fig 4, respectively. Phosphate and ammonia as well as Cd and As levels were between 0.01

TABLE 3

Concentrations of nutrients and trace metals in 0.5 – 15 m water depth at the anchorage area offshore Tema Port

Station	Depth	PO_4^{3-}	NO_3^-	$NH_{3-}N$	$S_iO_4^{4-}$	SO_4^{2-}	Pb	Zn	Mg	Cd	AS
A	0.5	0.02	1.4	0.02	1.1	1750	0.129	<0.002	2.20	0.049	0.024
	5.0	0.05	1.4	0.02	0.8	1800	0.153	<0.002	2.18	0.059	0.030
	15	0.04	1.5	0.02	1.4	1950	0.149	<0.002	2.18	0.057	0.036
B	0.5	0.02	1.4	0.03	1.0	1850	0.143	<0.002	2.17	0.053	0.012
	5.0	0.03	1.5	0.03	0.9	1950	0.133	<0.002	2.18	0.053	0.018
	15	0.02	1.3	0.02	1.1	1850	0.142	<0.002	2.17	0.051	0.030
C	0.5	0.02	1.5	0.02	1.6	1750	0.122	<0.002	2.16	0.044	0.030
	5.0	0.02	1.4	0.02	1.1	1850	0.174	<0.002	2.17	0.054	0.036
	15	0.02	1.3	0.02	2.1	1850	0.147	<0.002	2.16	0.043	0.052

<0.002; below detection limit

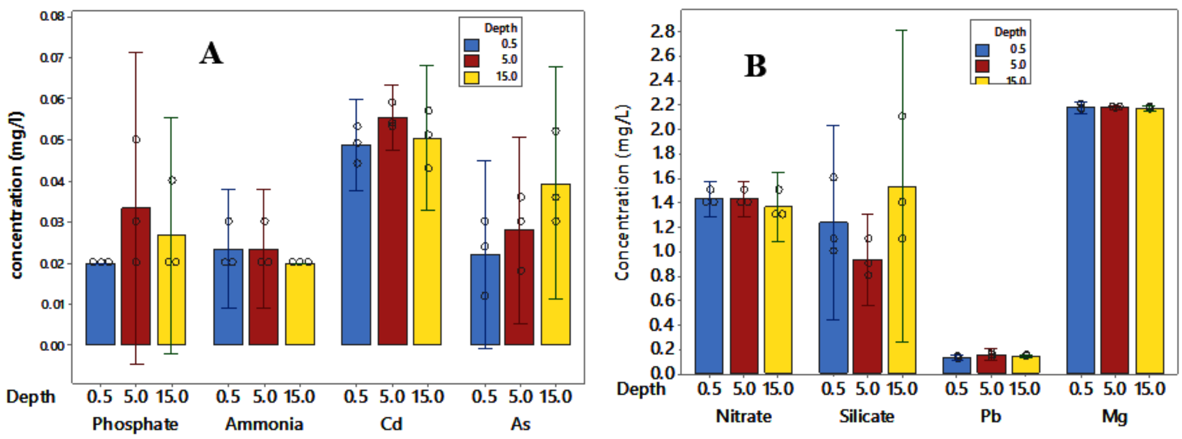

Fig. 4 Pulled data of the mean levels of nutrient and trace metal within the three layers of water mass

and 0.06 mg/L (Fig. 4). However, Cd and As levels were relatively high than the phosphate and ammonia levels. There were, however, no significant ($p > 0.5$) except arsenic (As) levels showing relative increase levels with depths (Fig. 4). Lead (Pb) levels were between 0.122 and 0.153 mg/L and uniform across the depth (Fig. 4). Nitrate and silicate levels ranged between 0.7 and 1.6 mg/L as shown in Table 3. Silicate and nitrate levels were erratic with depths (Fig. 4). Magnesium (Mg) levels were between 2.16 and 2.18 mg/L and comparably uniform across the depths (Table 3 and Fig. 4). Sulphate levels were relatively high and ranged between 1750 and 1950 (Table 3). Zinc (Zn) levels were below the detection limit of the analytical method of 0.002 mg/L as such there was no further discussion.

Largely, salinity, conductivity, and total dissolved solids (TDS), magnesium (Mg) and sulphate (SO_4^{2-}) levels were fairly constant and could be associated with a homogeneous environment. However, the general increases in salinity, conductivity, TDS, and sulphate with depth could be attributed to dissolved ions (sodium, calcium, chloride, sulphate, and magnesium). Minor but essential ions and nutrients (nitrate, phosphate, ammonia, and zinc) are deemed to be biologically driven as such their levels are highly influenced by seasonality (Blain et al., 2007: Safaa and Ghani, 2015). The results of the nutrients and other elements were randomly distributed and could be of diffused sources, namely possible biological activities, and anthropogenic impacts (Klubi et al., 2021). The influences of upwelling on the nutrient availability within the water column offshore the anchorage area could be described as limited due to the isothermal region as explained above. On the other hand, the presence of trace elements such as arsenic, lead, and cadmium, although at relatively low levels in the water columns could be assigned to anthropogenic impacts rather than land-based sources. It is important to note that nutrients associated with sediment plumes discharged to coastal waters are rapidly depopulated into the sediment beds due to absorption and percolation mechanisms except areas of relatively high discharges. As such, influences of river discharges may be confined to the littoral zone as a result of limited outflows from the Accra-Tema metropolis of the Greater Accra Region of Ghana. Thus, nutrient loads within the water columns could be solely ascribed to anthropogenic activities within the anchorage space offshore Tema Port.

Pearson correlation coefficient analysis of water quality parameters

Further analysis of the nutrients and depth profile data were centred at the three levels (surface, middle, and bottom) for evaluation of the distribution and correlations. Average values for temperature, TDS, pH, salinity, conductivity, turbidity, and DO were calculated between 0.5 and 5 m depths (this is assigned as surface water column, 0.5 m), between 5 and 15 m depths; mid-water column (5 m) and from 15 to 25 m depths as bottom water column (15 m). A pooled data of the nutrient and trace metal levels were also averaged for each water column (0.5, 5, and 15 m). The rescaling profiles (Fig. 3B) of the physicochemical data proved that most of the water quality parameters either decrease or increase with depth and could, therefore, be grouped for multivariate analysis (Klubi et al., 2019). Although the water circulation is considered as orbiting and more like a stationary rotating medium, there could be diffusions and advection processes as well as differences in settling velocity of dissolved solid particles. This could cause special patterns of distribution of elements of similar properties and may enhance the understanding of nutrient source and transport within the ocean basins.

According to Lee and Lee (2018), multivariate analysis helps to reduce complex data and yet retain the individual variabilities for information gathering. Results of the Pearson correlation coefficient (PCC) and the p-values are shown in Table 4 indicating various forms of correlation and significance levels. Turbidity levels show a strong but negative correlation between NO_{3-}, $NH_{3-}N$, Mg, pH, temperature

TABLE 4
Pearson coefficient correlations (PCC) values and their respective p-values

	PO_4^{3-}	NO_{3-}	NH_4-N	$S_1O_3^{2-}$	SO_4^{2-}	Pb	Mg	Cd	As	pH	Temp.	Sal.	EC	DO	Turb
NO_{3-}	-0.00														
	1.00														
NH3-N	-0.00	1.00													
	1.00	*													
$S_1O_3^{2-}$	-0.50	-0.87	-0.87												
	0.67	0.33	0.33												
SO_4^{2-}	0.78	-0.63	-0.63	0.16											
	0.43	0.57	0.57	0.90											
Pb	0.98	-0.19	-0.19	0.88	-0.33										
	0.12	0.88	0.88	0.79	0.31										
Mg	-0.00	1.00	1.00	-0.87	-0.63	-0.19									
	1.00	*	*	0.33	0.57	0.88									
Cd	0.96	0.28	0.28	-0.72	0.57	0.89	0.28								
	0.18	0.82	0.82	0.49	0.61	0.30	0.82								
As	0.34	-0.94	-0.94	0.64	0.86	0.51	-0.94	0.07							
	0.78	0.22	0.22	0.56	0.35	0.66	0.22	0.96							
pH	-0.48	0.88	0.88	-0.52	-0.92	-0.64	0.88	-0.22	-0.99						
	0.68	0.32	0.32	0.65	0.25	0.56	0.32	0.86	0.10						
Temp.	-0.35	0.93	0.94	-0.63	-0.86	-0.52	0.94	-0.08	-1.00	0.99					
	0.77	0.23	0.23	0.56	0.34	0.65	0.23	0.95	0.01	0.09					
Sal.	0.67	-0.74	-0.74	0.30	0.99	0.80	-0.74	0.44	0.92	-0.97	-0.93				
	0.53	0.47	0.47	0.80	0.10	0.41	0.47	0.71	0.25	0.15	0.24				
EC	0.68	-0.73	-0.73	0.29	0.99	0.81	-0.73	0.45	0.92	-0.97	-0.93	1.00			
	0.52	0.48	0.48	0.81	0.09	0.40	0.48	0.70	0.26	0.16	0.25	0.01			
DO	-0.36	0.93	0.93	-0.63	-0.87	-0.53	0.93	-0.09	-1.00	0.99	1.00	-0.93	-0.93		
	0.76	0.24	0.24	0.57	0.33	0.64	0.24	0.94	0.02	0.08	0.01	0.23	0.24		
Turb	-0.18	-0.98	-0.98	0.94	0.48	0.01	-0.98	-0.44	0.87	-0.78	-0.86	0.61	0.60	-0.85	
	0.89	0.11	0.11	0.22	0.68	0.99	0.11	0.71	0.34	0.43	0.34	0.58	0.59	0.35	
TDS	0.72	-0.70	-0.70	0.24	1.00	0.84	-0.70	0.50	0.90	-0.96	-0.90	1.00	1.00	-0.91	0.56
	0.49	0.51	0.51	0.84	0.06	0.37	0.51	0.67	0.29	0.19	0.28	0.04	0.03	0.27	0.62

Data are presented as;
Pearson correlation value
P-Value

(Temp), DO, and Cd (Table 4). This suggested an opposite trend in the levels of turbidity with the above parameters. However, in all cases, the p-values ($p > 0.05$) suggested no statistical significance. On the contrary, silicate (SiO_4^{4-}) and arsenic (As) showed a strong positive correlation with turbidity levels, while salinity (Sal.), TDS, conductivity (EC) and sulphate (SO_4^{2-}) displayed a moderate positive correlation (Table 4). Although the p-values ($p > 0.05$) did not demonstrate any significant difference as was expected, it can be inferred that silicate and arsenic have a higher affinity for turbidity as well as salinity, TDS, conductivity, and sulphate.

Nitrate (NO_{3-}) levels, on the other hand, demonstrated a strong positive PCC between $NH_{3-}N$, Mg, pH, temperature (Temp), and dissolved oxygen (DO) levels [Table 4]. It can be inferred also that nitrate and ammonia levels are likely to decrease with depth as compared to temperature, pH, and DO levels respectively (Fig. 3b). The strong correlation between nitrate and ammonia could be considered as microbial oxidation of ammonia to nitrite and finally to nitrate, which is enhanced by ammonia-oxidizing bacteria (Isnansetyo et al., 2014). Phosphate (PO_4^{3-}) also shows a strong positive PCC between Pb and Cd as well as a moderate correlation between SO_4^{2-}, salinity,

TABLE 5A

Results of bacterial contamination within the anchorage of Tema Port

Sites	*Total Coliform (TC) (cfu/100 ml)*	*Faecal coliform (cfu/100 ml)*	*E. coli (cfu/100 ml)*	*THB (cfu/ml)*
A	72	13	0	468
B	26	1	0	364
C	35	5	0	416

Key: E. coli; Escherichia coli, THB; Total heterotrophic bacteria

TABLE 5B

Individual levels and percentage composition of dominant bacterial contamination offshore of Tema Port

Sampling Site	Total Coli		Faecal Coli		THB	
	Count	Percent	Count	Percent	Count	Percent
A	72	54.14	13	68.42	468	37.50
B	26	19.55	1	5.26	364	29.17
C	35	26.32	5	26.32	416	33.33
Total	133	100.00	19	100.00	1248	100.00

conductivity and TDS (Table 4). Salinity, conductivity, and TDS levels increased with depth (Fig. 3b), this suggested that phosphate levels are more likely to increase with depth. This also implies that there would be less phosphate in the euphotic zone, which supports the idea that phosphate is a limiting factor in the open oceans for primary productivity (Gadea et al., 2013). TDS levels show a significant ($p < 0.05$) and a perfect positive correlation between conductivity, salinity, and sulphate levels (Table 4). There were, however, a moderately positive correlation between TDS, and Pb, As, Cd, PO_4^{3-} and turbidity levels. This suggested that Pb, As, Cd, and PO_4^{3-} are likely to increase with depth since TDS values increase with depth (Table 4 and Fig. 3). There were also strong to moderate but negative correlations between TDS levels and NO_{3-}, $NH_{3-}N$, Mg, pH, DO, and temperature levels (Table 4). This is a further confirmation of NO_{3-}, $NH_{3-}N$, Mg, pH, DO, and temperature levels being high in the upper water column compared to high levels of TDS in greater depths. This is a pure reversal relationship and a demonstration of the relatively high levels of nutrients at the upper water column could be due to anthropogenic sources.

Microbial load

Results of the microbial analysis within the anchorage space offshore Tema Harbour suggested relatively high levels of bacteria concentrations across the three sampling points (Table 5). For example, Total coliform (TC) ranged between 26 and 73 cfu/100 mL, Faecal coliform (FC) between 1 and 13 cfu/100 mL, Total heterotrophic bacteria (THB) between 364 and 468 cfu/100 mL whereas, Escherichia *coli* (*E. coli*) was not detected (Table 5A). The occurrences of the bacterial load can be ranked in the order; THB > TC > FC for the anchorage space of the Tema Port. Comparatively, the sample points "A" and "C" recorded the highest concentrations of bacterial levels compared to point "B" (Table 5B). This could be assigned to the location differences (sites "A" and "C" were located within the midsection where most of the vessels were anchored to the bottom bed whereas site "B" is located further seawards of the anchorage area with fewer vessels (Fig. 1 and 3).

The possibility that the levels of bacterial load could be due to land-based activities may be minimal since sample locations were further (about 5.5 Km) from the shore. Additionally, the normalized in-situ parameters (as shown in Fig. 3B) suggested thermal stratification which precludes mixing of upper layers and bottom nutrient-rich waters, and hence upwelling may not be a contributing factor. This, therefore, left with the option that the possible source of bacterial levels could be due to immediate anthropogenic impact. Thus, the levels of bacteria in the anchorage area may be confirming the nutrient load which might be associated with anthropogenic activities and the number of vessels. It is, however, prudent to indicate that the levels of bacteria were below the USEPA recommended standard of 100 cfu/100ml for recreational purposes (USEPA, 1986). On the other hand, THB levels (364-468 cfu/ml [Table 5A]) were almost close to the WHO recommended concentration of 500 cfu/ml and could be considered as a public concern (USEPA, 1986). It is important to note that, the regeneration period of heterotrophic bacteria is less than ten minutes or faster (Pomeroy et al., 2007). Also, the lag phase or cryptic stage of bacterial growth are adaptive mechanisms for survival (Roszak and Colwell, 1987). Thus, there is a high possibility of THB levels exceeding the WHO recommended level concerning the trend in nutrient levels at the anchorage space. Although statistical testing of the occurrence of bacteria with nutrient levels was not considered in this work, according to Kalkan and Altug (2015), Vraspir and Butler (2009), there are significant correlations between nutrient levels and bacteria occurrences. This, therefore, suggested that the anchorage space could be a hotspot for bacterial growth with possible impacts on seawater quality and spreading across marine ecosystems through vessels' routes and assembly points.

Main phytoplankton occurrence

Results of phytoplankton analysis revealed three main taxa dominances offshore the Tema port (Table 6). A total of 4.09×10^9 cells per cubic meter were estimated. These individual cells belonged to thirteen (13) species, seven (7) taxonomic families, six (6) order and three (3) taxonomic classes. Dinophyceae formed the highest species diversity group and constituted the highest percentage abundance (80%) of the total species composition (Table 6). The Dinophyceae group was further dominated by *Ceratium spp*. (31.8%), *Protoperidinium spp*. (30.1%) and *Dinophysis spp*. (9.3%) as well as *Lingulodinium polyhedra* (6.9%) [Table 6). Bacillariophyceae formed the second-highest diverse species group with *Coscinodiscus sp*. (7.3%) and *Nitzschia sp*. (6.9%) being the major species. The Cynophyceae group was represented by *Oscillatoria sp*., contributing about 5% of the total species composition of the estimated phytoplankton abundance (Table 6). It is also important to indicate that some of the plankton species identified in this work (Table 6) are harmful and toxic (Figueras et al., 1995; Amorim et al., 2004; Sellner et al., 2003) and calls for public concerns.

On the other hand, the plankton community composition and abundance varied greatly and this is normally associated with the

TABLE 6

Estimation of phytoplankton abundance from offshore Tema coast

Dominate Species	No. of cell/ $m^3 \times 10^7$	% abundance
Ceratium furca[a,3]	7	1.7
Ceratium tripos[a,3]	35	8.6
Ceratium sp [a]	88	21.5
Protoperidinium crassipes[3]	53	12.9
Protoperidinium depressum[3]	42	10.3
Protoperidinium divergens[3]	28	6.9
Dinophysis caudate [b,3]	35	8.6
Coscinodiscus sp[1]	30	7.3
Dinophysis mitra [b]	3	0.7
Gonyaulax spinifera complex [b,3]	11	2.6
Lingulodinium polyedra[b,3]	28	6.9
Nitzschia sp[1]	28	6.9
Oscillatoria sp[2]	21	5.0

a harmful algae species; b, toxic algae species; 1, Bacillariophyceae; 2, Cynophyceae; 3, Dinophyceae seasons and nutrient availability (Amorim et al., 2004; Vraspir and Butler, 2009; El Gammal et al., 2017; Oseji et al., 2019). The Gulf of Guinea, a continuum of Guinea Current Large Marine Ecosystem (GCLME), is noted for high plankton biomass due to its seasonal upwelling phenomenon (Wiafe et al., 2008; Lazar et al., 2017). The oceanographic parameters measured suggested no upwelling period hence influence from nutrient-rich bottom waters could not be implicated. As such, the relatively high abundance of the plankton and the occurrences of harmful and toxic species identified (Table 6), suggested human-induced contamination of nutrients at sampling locations. This could also be linked with the relatively high concentrations of TC, FC, and THB (Table 5), which are considered biological indicators of marine pollution. The relatively high levels of nutrients as a result of anthropogenic activities and the concentrations of bacteria and phytoplankton levels within the anchorage environment of the Tema Port may therefore have water quality implications for the marine ecosystem and human health issues.

Conclusion

The study has demonstrated that water quality assessment using physicochemical parameters and biotic characteristics at anchorage space offshore Tema Harbour falls within the marine tropic climatic conditions with anthropogenic impact. The physicochemical parameters estimated suggested no upwelling event but rather stratification at the 15 m depth. Thus, measured nutrient loads suggested anthropogenic activities which could be ascribed to the human impact associated with vessels in the anchorage space offshore the Tema Port. The identification and quantification of harmful and toxic algae species, as well as bacteria load, signify the possibility of marine pollution and contamination. This could affect the immediate environment, fisheries resources, human health and possible spreading of invasive species by vessels' movement. It is, therefore, recommended that further studies should be conducted to establish the link between nutrient load and the anthropogenic activities within the anchorage space offshore Tema Port.

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