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SHORT RESEARCH AND DISCUSSION ARTICLE

A baseline study of spatial variability of bacteria (total coliform, *E. coli*, and *Enterococcus* spp.) as biomarkers of pollution in ten tropical Atlantic beaches: concern for environmental and public health

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Abstract

Coastal water quality in urban cities is increasingly impacted by human activities such as agricultural runoff, sewage discharges, and poor sanitation. However, environmental factors controlling bacteria abundance remain poorly understood. The study employed multiple indicators to assess ten beach water qualities in Ghana during minor wet seasons. Environmental parameters (e.g. temperature, electrical conductivity, total dissolved solids) were measured in situ using the Horiba multiple parameter probe. Surface water samples were collected to measure total suspended solids, nutrients, and chlorophyll-a via standard methods and bacteria determination through membrane filtration. Environmental parameters measured showed no significant variation for the sample period. However, bacteria loads differ significantly ($p = 0.024$) among the beaches and influenced significantly by nitrate (55.3%, $p = 0.02$) and total dissolved solids (17.1%, $p = 0.017$). The baseline study detected an increased amount of total coliforms and faecal indicator bacteria (*Escherichia coli* and *Enterococcus* spp.) in beach waters along the coast of Ghana, suggesting faecal contamination, which can pose health risks. The mean ± standard deviations of bacteria loads in beach water are total coliforms ($4.06 \times 10^3 \pm 4.16 \times 10^3$ CFU/100 mL), *E. coli* ($7.06 \times 10^2 \pm 1.72 \times 10^3$ CFU/100 mL), and *Enterococcus* spp. ($6.15 \times 10^2 \pm 1.75 \times 10^3$ CFU/100 mL). Evidence of pollution calls for public awareness to prevent ecological and health-related risks and policy reforms to control coastal water pollution. Future research should focus on identifying the sources of contamination in the tropical Atlantic region.

Keywords Beach water quality · Faecal indicator bacteria · *Escherichia coli* · Pollution · Environmental factors · Public health policy

Introduction

Life is refreshing at the beach, but pollution of the water is a risk to human health.

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Coastal water bodies are impacted through pollution, deteriorating urban sanitation, land use, and hydrological changes (Armah et al. 1997, Berendesa et al. 2020, Pommepuy et al. 2005, Shuval 2006, Stewart et al. 2008). The human activities in Ghana's urban coastal regions are increasingly contributing to coastal water pollution (Akita et al. 2020, Gretsch et al. 2015, Labite et al. 2010, Lawson 2014). About 50% of the world's population lives in towns and cities within 100 km of the coast (Monney et al. 2013, Shuval 2006, Stewart et al. 2008). Many people do not have access to clean drinking water, and numerous people die of waterborne bacterial infections (e.g. cholera, typhoid, diarrhoea) (Cabral 2010, Ecklu-Mensah et al. 2019, Gretsch et al. 2015, Igobinosa and Okoh 2009, McGarvey et al. 2008, Osiemo et al. 2019). In developing countries, especially in Africa, water-borne diseases infect millions, especially children (Fenwick 2006, Osiemo et al. 2019, WHO 2015, Yang et al. 2012).

Ghana is a low-lying region (on average, 30 m above sea level) and bordered by the Gulf of Guinea between 4 and 12° N (Figure 1). The coastline is about 550 km long, and the continental shelf (about 75–120 m deep) is narrow and covers approximately 26,000 km^2 (Armah and Amlalo 1998, Armah et al. 2005, Lawson 2014). The Ghanaian coastal shore is categorised into the western, central, and eastern coastlines (Armah 1991, Armah et al. 2005, Ly 1980). The west coast covers 95 km of the stable shoreline and extends from Ghana's border with Côte d'Ivoire to the Ankobra River's estuary (Lamptey et al. 2010, Wiafe et al. 2013). The central zone includes 321 km of shoreline and extends from the Ankobra River's estuary, near Axim to Prampram on the eastern coast (Lamptey et al. 2010, Wiafe et al. 2013). The east zone covers 139 km of the shoreline, which extend from Prampram to Aflao, at the border to the Republic of Togo, and characterised by sandy beaches with a central deltaic estuary (e.g. Ada, Volta, Densu) and coastal lagoons (e.g. Keta and Songor) (Akita et al. 2020, Klubi et al. 2019, Lamptey et al. 2010, Larbi et al. 2018, Wiafe et al. 2013).

The Gulf of Guinea Coast is characterised by current and dynamic hydrodynamic conditions (Acheampong et al. 2021, Hardman-Mountford and McGlade 2003). The coast resources serve as a source of seafood, recreational, educational, medicinal, and an important social and economic value to the well-being of coastal communities (McGlade et al. 2002, Okafor-Yarwood 2018).

Human activities in the Gulf of Guinea (GOG) coast have caused deterioration, eutrophication, and oxygen depletion in the coastal waters in the urban cities, resulting in biodiversity loss and waterborne diseases (Pabis et al. 2020, Scheren et al. 2002, Yeleliere et al. 2018a). Therefore, the discharge of effluents without inadequate treatments into nearshore waters is a critical environmental issue. However, monitoring of coastal waters in Africa using multiple indicators and lack of continuous oceanographic observational data from the sub-Sahara region is still scarce (Akita et al. 2020, López-López and Sedeño-Díaz 2015, Parmar et al. 2016, Zaghloul et al. 2020). Moreover, there is a lack of knowledge on bacteria distribution in beach water in West Africa, Ghana, and their environmental factors are unknown.

Beaches and bathing areas worldwide are dynamic zones in urban cities and contribute to coastal economics (Abdelzaher et al. 2013, Efstratiou 2001, Tiwari et al. 2021). However, the

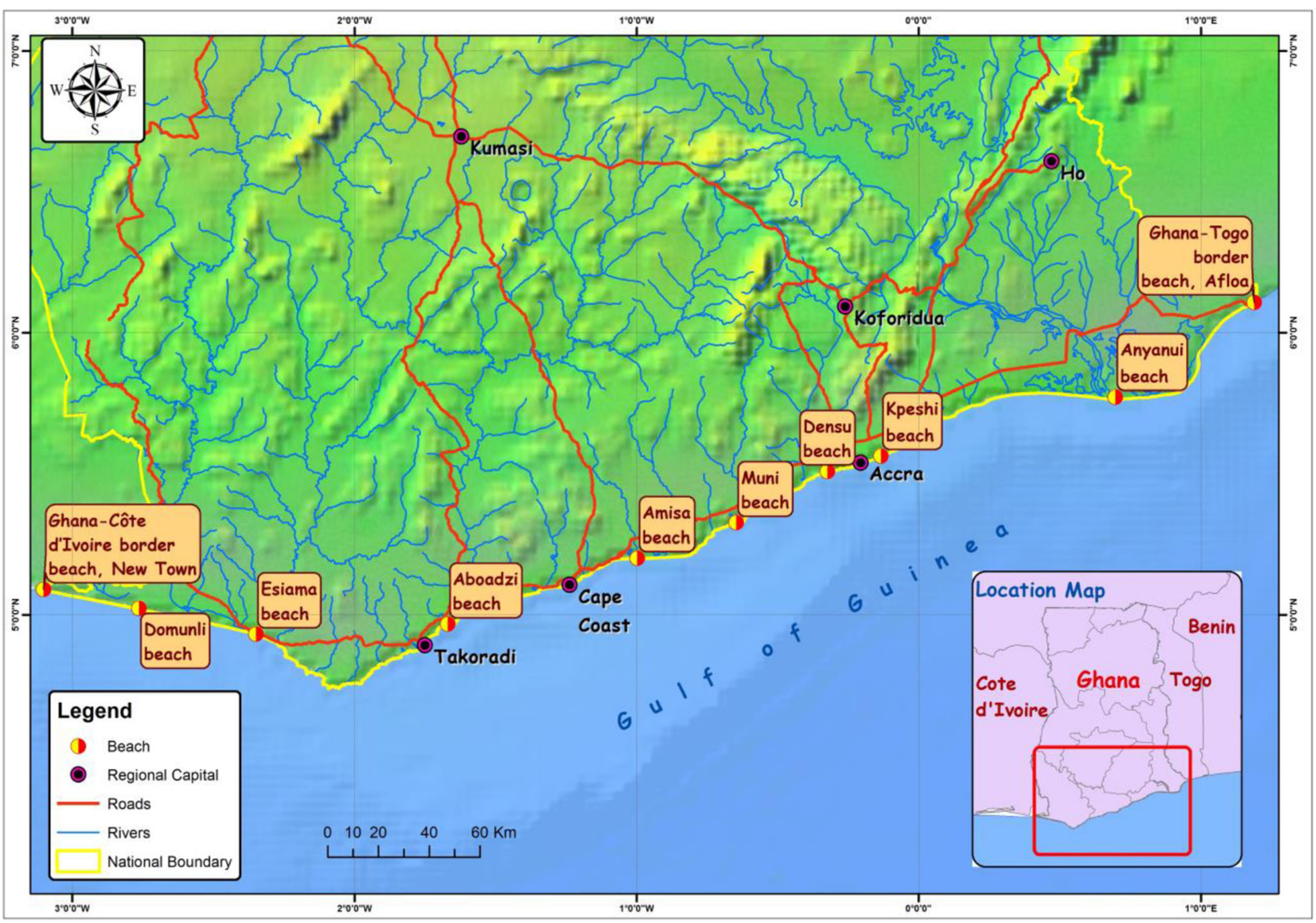

Fig. 1 **A** A map of sampled ten selected coastal beaches in Ghana. **B** Some of study beaches in the coast of Gulf of Guinea, Ghana (Ghana-Côte d'Ivoire border, Amisa, Muni,Aboadzi, Densu, Kpeshi, Anyanui, Ghana-Togo border)

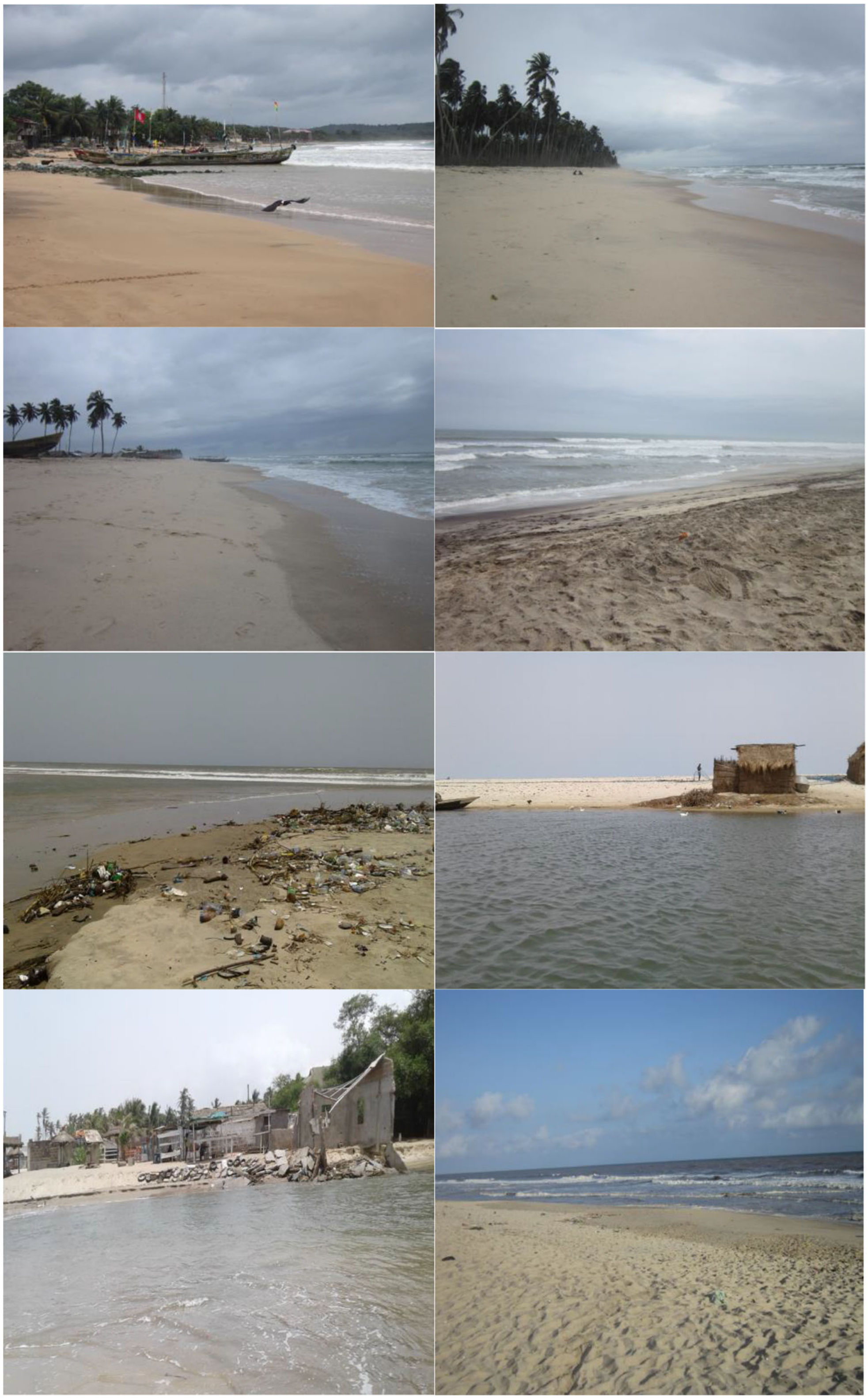

Fig. 1 continued.

discharging of urban, industrial, and domestic wastewaters into the sea, which can be a pollutant, raises concern for disease outbreaks and ecological and public health risks (Bienfang et al. 2011, Prieto et al. 2001, Weiskerger et al. 2019). There are bacteria and pathogenic organisms in beach water and sand (Efstratiou 2018, Ferguson et al. 2005, Sabino et al. 2014, Whitman et al. 2014). Therefore, sensitive indicator organisms are used for quantitative water quality assessment as potential pollution signals (Griffith et al. 2016, Soto-Varela et al. 2021, Thoe et al. 2018). Water quality is a canonical group of a given water's physical, chemical, and biological properties (Gökçe 2016). Environmental factors affecting bacteria dominance and distribution in fresh and marine water are still inadequate (Hirn et al. 1980, Piggot et al. 2012, Whitman et al. 2011). A short survey was conducted to assess Ghana's beach water quality via multiple indicators, specifically physical, chemical, and biological analyses. We hypothesised no variability in physical, chemical, and biological characteristics of nearshore waters along the coast of Ghana during the minor wet season. The second hypothesis assumes no bacteria in the beach water in the Gulf of Guinea, Ghana. The study reveals high bacterial loads in beach water coupled with spatial variation along the coast of Ghana. Environmental parameters of the water body control the spatial variability and abundance of bacterial. Bacterial contamination in coastal waters is a major threat to public health, beach swimmers, and possible transfer in the food chain, resulting in food contamination. The preliminary results serve as useful ecological knowledge for public awareness, prevention of further contamination, policy reforms to safeguard beach swimmers, and future monitoring of nearshore waters in the tropical Atlantic Coast

Sampling and analytical methods

Geological settings

The climate in Ghana is tropical; the eastern coastal belt is dry and warm, while the south-western zone is hot and humid (Nyarko et al. 2015). The climate is drier from southwest to northeast of Accra. The climate variation in the coastal environment of Ghana is characterised by wet and dry seasons (Biney 1993, Biney and Asmah 2010). Two-thirds of the coastal zone falls within the dry coastal savannah strip, where annual rainfall ranged from 625 to 1000 nm and an average of 900 nm (Armah and Amlalo 1998). The coastal belt is characterised by two wet seasons: the major rainy season starts from May and ends in July, while the minor one occurs between August and October. The dry season starts from November to April (Allersma and Tilma 1993). The minimum temperature occurs in July-August and the maximum in February-March. The relatively dry coastal climate of the southeast is caused by the prevailing winds (south-south-westerlies) blowing almost parallel to the coast and to cool current of water originating offshore, local annual upwelling (Armah and Amlalo 1998).

The winds are characterised by persistent southwesterly monsoon modified by land and sea breezes in the coastal area (Armah et al. 2003). Speeds vary between 0.5 m/s at night and 2.0 m/s at day (Armah et al. 2003). The tidal range determines the area of shore that is exposed to the air at any low tide. The tide on the coast of Ghana is regular and semi-diurnal (Armah et al. 2003). The tidal wave has the same phase across the country's coast (Armah et al. 2003). The tidal current has a low and insignificant influence on coastal processes, except within tidal inlets (Armah et al. 2003, Bakun 1993). Off the coast of West Africa, a counter equatorial current, the Guinea Current, flows eastward, and this flow is most prominent near Cape Three Points (Armah et al. 2003, Bakun 1993). The southwest monsoon winds show a maximum from May to July when it frequently exceeds one knot and occasionally reaches two knots (Armah et al. 2003, Bakun 1993). The currents are weaker during the rest of the year, with a minimum occurring between November and January at an average of about 0.5 knots (Armah et al. 2003, Bakun 1993). Throughout the year, particularly due to the northeasterly winds, the current direction may reverse temporarily and may reach a speed of 1.0 knot (Armah et al. 2003, Bakun 1993).

The upwelling is seasonal for Ghanaian coastal waters, dominated by two upwelling peaks per year. During either January, February, or March, weaker upwelling occurs and is strongest off Côte d'Ivoire, whereas intense upwelling fuels the system off Ghana between late June to early October (Quaatey 1996). The two seasons are characterised by decreasing sea surface temperature (SST; typically < 25 °C), increasing salinity, and decreasing dissolved oxygen. The seasonal coastal upwelling periodically modifies the physical and chemical properties of the water masses and controls the biology of the sub-system (Koranteng and McGlade 2002, Minta 2003). Most of the year, coastal waters are stratified thermally with a well-mixed layer of warm (25–36 °C), low salinity water (33.67–34.22) 30–40 m above a sharp thermocline (Mensah and Anang 1998). Salinity is at maximum (35.05–35.38) below the thermocline at 60–80 depth. During upwelling, the thermocline weakens and rises to the surface resulting in a vertically homogeneous salinity profile above the shelf (Mensah and Anang 1998).

Sampling

The sampling randomised selected ten beaches were located in Ghana's eastern, central, and western coasts (Figure 1A, B; Table 1). The Global Position System (Garmin eTrex 10 Model) (Garmin Limited, KS, USA) (www.garmin.com) was used to record the coordinates of the beaches. A short survey was carried out from 8 to 14 October 2016 during a minor wet season at low tide to assess multiple beaches' nearshore water quality status in the tropical Atlantic coast using multiple indicators (e.g. physical, chemical, and biological methods). Horiba digital multiple parameter probe

Table. 1 Description of the coastal beaches of Ghana

Names of the beaches	Alternatives names of the beaches	Coastal zone in Ghana	Latitude	Longitude	Human impact level	Type of human activities	Estimated population
Ghana-Côte d'Ivoire border (Gh-Côte), beach, New Town	New Town/Ghana-Côte d'Ivoire border	Western	5° 5.452′ N	3° 6.106′W	Transboundary/west	Transportation/fishing	Populated
Domunli beach	Jerusalem	Western	5° 1.372′ N	2° 45.853′ W	Moderate	Fishing activities	Moderately populated
Esiama beach	Esiama-Elimna	Western	4° 55.89-5′N	2° 20.957′ W	Moderate	Fishing activities	Populated
Aboadzi beach	Aboadzi Thermal Plant	Western	4° 58.02-9′N	1° 40.158′ W	High industry	Hydrothermal generation	Populated
Amisa beach	Amissano beach Amissano village	Central	5° 12.12-3′N	0° 59.849′ W	Moderate	Fishing activities	Populated
Muni beach	Apam	Central	5° 19.61-1′N	0° 38.842′ W	Moderate	Fishing activities	Populated
Densu beach	Bojo	Central	5° 30.40-3′N	0° 19.718′ W	High industry	Tourism, fishing/-transportation	Highly populated
Kpeshi beach	La/Laboma	Central	5° 33.85-4′N	0° 8.041′W	High industry	Tourism, fishing	Highly populated
Anyanui beach	Fuvenie	Eastern	5° 46.37-2′N	0° 41.785′ E	Moderate	Fishing activities/-transportation	Moderately populated
Ghana-Togo border (Gh-Togo), Afloa	Afloa, Ghana-Togo border	Eastern	6° 6.493′ N	1° 11.319′ E	Transboundary/east	Transportation/fishing	Populated

(Model U-52G 30M) (Horiba Company Limited, Japan) (www.Horiba.com) was used for in situ measurements of sea surface temperature, salinity, specific electrical conductivity, total dissolved solids, pH, redox potential, dissolved oxygen concentration, and saturation in nearshore beach waters. Each parameter was recorded three times, and the average was computed. Three replicates of water samples from each beach were collected from 10 cm depth into 500-mL clean plastic bottles for total solids, phosphate, and nitrate analyses. Three replicates of water samples from each beach were also collected into 500 mL plastic bottles covered with black polyethene bags for chlorophyll-a analyses. Ten surface water samples were collected at nearshore waters at shallow depth (10 cm) into 500-mL sterilised plastic bottles for bacterial examination at Laboratory at Council for Scientific and Industrial Research (CSIR)-Water Research Institute (WRI), Accra, Ghana. The water samples were stored on ice (4 °C) during transport to the laboratory. The analysis was carried out within 12 h of collection.

Analytical methods

Water samples from each beach were prepared using standard methods to examine water and wastewater (APHA 2012, 2017). Phosphates and nutrient concentrations were determined using HACH spectrophotometer (Model DR/2010) (HACH Company, Loveland, CO, USA) (www. hach.com) (HACH 2012). Total suspended solids (TSS) were measured gravimetrically (APHA 2012, 2017). Chlorophyll-a was extracted from 250 mL of water samples in 96% ethanol and determined spectrophotometrically at a specific wavelength method (Lorenzen 1967, Welschmeyer 1994, Wintermans and De Mots 1965). Chlorophyll-a (Chl-a) concentration (μg/L) is an indicator of phytoplankton concentration in the water column (Hinga et al. 1995).

Bacteria in beach water were analysed using standard methods and membrane filtration method (Millipore 1991). Total coliforms (Method APHA 9222A) and *Escherichia coli* (Method APHA 9260F) were determined by placing the filter on solidified Cromocult Agar Medi plates, following 18–24 h incubation at 37 ± 0.5 °C. Similarly, *Enterococcus* spp. (Method APHA 9230C) was enumerated by placing the filters on plates of Slanetz Bartley medium for 18–24 h at 44.5 ± 0.5 °C. Bacteria loads in beach water are expressed in units of organisms per 100 mL of water. Total coliforms were determined by membrane filtration method using M-Endo-Agar Les (Difco) at 37 °C and on membrane faecal coliform agar at 44 °C, respectively (Cabral 2010). The medium contains a fluorogen that reacts with galactosidase in total coliforms, and a chromogen reacts with glucoronidase in *Escherichia coli*. The medium contains a chromagen that reacts with the enzyme glucosidase in *Enterococcus* spp. (Ferretti et al. 2011, Haugland et al. 2005). With the aid of colony counter, purple and blue colonies were counted as total coliforms, only blue colonies counted as *Escherichia coli*, and pinkish to red colonies counted as *Enterococcus* spp. colonies. The number of total coliforms, *Escherichia coli* and *Enterococcus* spp., are expressed by counting the colony-forming units (CFU) per 100 mL of water (Wade et al. 2003). The faecal indicator bacteria (FIB) such as *Escherichia coli* (*E. coli*) and *Enterococcus* spp. (enterococci) are sensitive biomarkers used to detect the faecal presence and potential pathogens in coastal waters and understand associated health risks (Piggot et al. 2012, Wade et al. 2010).

Statistical analysis

Statistical analysis such as mean, maximum, and minimum along with analysis of variance coupled with correlation analysis using Paleontological statistical software, PAST 3 (Hammer et al. 2001), and statistical package for social sciences version 21.0 (SPSS 21.0) (Leech et al. 2011). The environmental parameters were square-root transformed and then classified by clustering of samples based on Euclidean distance. The abundance of bacteria was log-transformed [ln($x \pm 1$)]; then, dendrograms were established based Bray-Curtis similarity (Bellier et al. 2012, Bray and Curtis 1957, Legendre and Gallagher 2001). Principal component analysis (PCA) was used to established sources of variation. Redundancy analysis (RDA) is the canonical form of PCA (Jongman et al. 1995, Rao 1964). Redundancy analysis is simply PCA with on-site restriction scores (Rao 1973, Ripley 1981). The advantage of using PCA and RDA biplots is that they provided more quantitative information than correspondence analysis (CA) (Jongman et al. 1995). Interactive selective forward selection in redundancy analysis (RDA) detected a subset of environmental variables which best explain the bacteria matrix (Šmilauer and Lepš 2014, ter Braak and Verdonschot 1995). The Monte Carlo permutation test ($\alpha = 0.05$; 999 permutations) was adopted and performed using the Canoco software version 5.03 (Šmilauer and Lepš 2014). Correlation coefficients at 0.05 and 0.01 levels were adopted. Pearson correlation coefficient (r) close to 1 was considered a better indicator of a strong association (Kinnear and Gray 1999).

Results

Physical, chemical, and bacteria indicators

There is no significant variation (one-way ANOVA $F_{\text{cal } 9,\ 60} = 0.208$; $p > 0.05$) in the physical parameters (7) measured among the ten beaches. The chemical parameters (5) do not differ significantly (one-way ANOVA $F_{\text{cal } 9,\ 40} = 0.419$; $p > 0.05$) among the ten beaches. However, there is a significant ($F_{\text{cal } 9,\ 40} = 0.4966$; $p < 0.05$) spatial variation in the counts (CFU/100 mL) of total coliform and faecal bacteria (*Escherichia coli* and *Enterococcus* spp.) measured among the beaches (Figure 2B). The Student *t*-test indicated that the count of *E. coli* is significantly (one-tailed, $p = 0.026$, $p = 0.051$) higher than *Enterococcus* spp. among the beaches.

The descriptive statistics of environmental parameters (e.g. ranges, geometric mean, percentiles) are summarised in Table 2. High loads of total coliforms, *Escherichia coli*, and *Enterococcus* spp. were found in beach waters along the coast of Ghana (Table 3; Figure 2A, B). Maximum bacteria loads (CFU/100 ML) occur in central zones (Densu and Kpeshi beaches). However, there is also a high in transboundary border eastern zone (Ghana-Togo beach). However, minimum counts (CFU/100 mL) occur in the eastern zone of Ghana, where freshwater influx is (Anyanui beach).

Multivariate statistical analyses

Cluster analyses

The similarity of environmental parameters formed a cluster (Figure 3A). There is a significant association between temperature and pH (Figure 3A). Similar associations of average group dendrograms of beaches (Euclidean distance) based on environmental characteristics of nearshore waters (Figure 3B). There is a significant association between *Escherichia coli* and *Enterococcus* spp. (Figure 4A). The corresponding hierarchical clusters of beaches are grouped based on bacteria counts (Bray-Curtis similarity) (Figure 4B).

Principal component analyses

The PCA plots display the relation of environmental factors influencing a given site (species-environmental variables) (Figure 5A). There are four major clusters of beach sites based on environmental factors. Sites with similar environmental characteristics cluster together: (i) Anyanui beach (freshwater influence, eastern zone); (ii) Ghana-Côte d'Ivoire and Domonli beaches (increase in oxygenation, western zone); (iii) Aboadzi, Kpeshi, Densu, Ghana-Togo border beach (increase in solute composition-total dissolved solids, western-central-eastern zones); and (iv) Amisa, Esiama and Muni beaches (increased in nutrient content, central zone) (Figure 5A).

Principal component analysis showed spatial grouping of beaches based on environmental data (Figure 5A). The first and second axes contributed to 59.43% of total variation in grouping of four clusters of beaches: (i) Anyanui; (ii) Ghana-Côte d'Ivoire and Domonli; (iii) Aboadzi, Kpeshi, Densu, and Ghana-Togo border; and (iv) Amisa, Esiama, and Muni (Figure 5A).

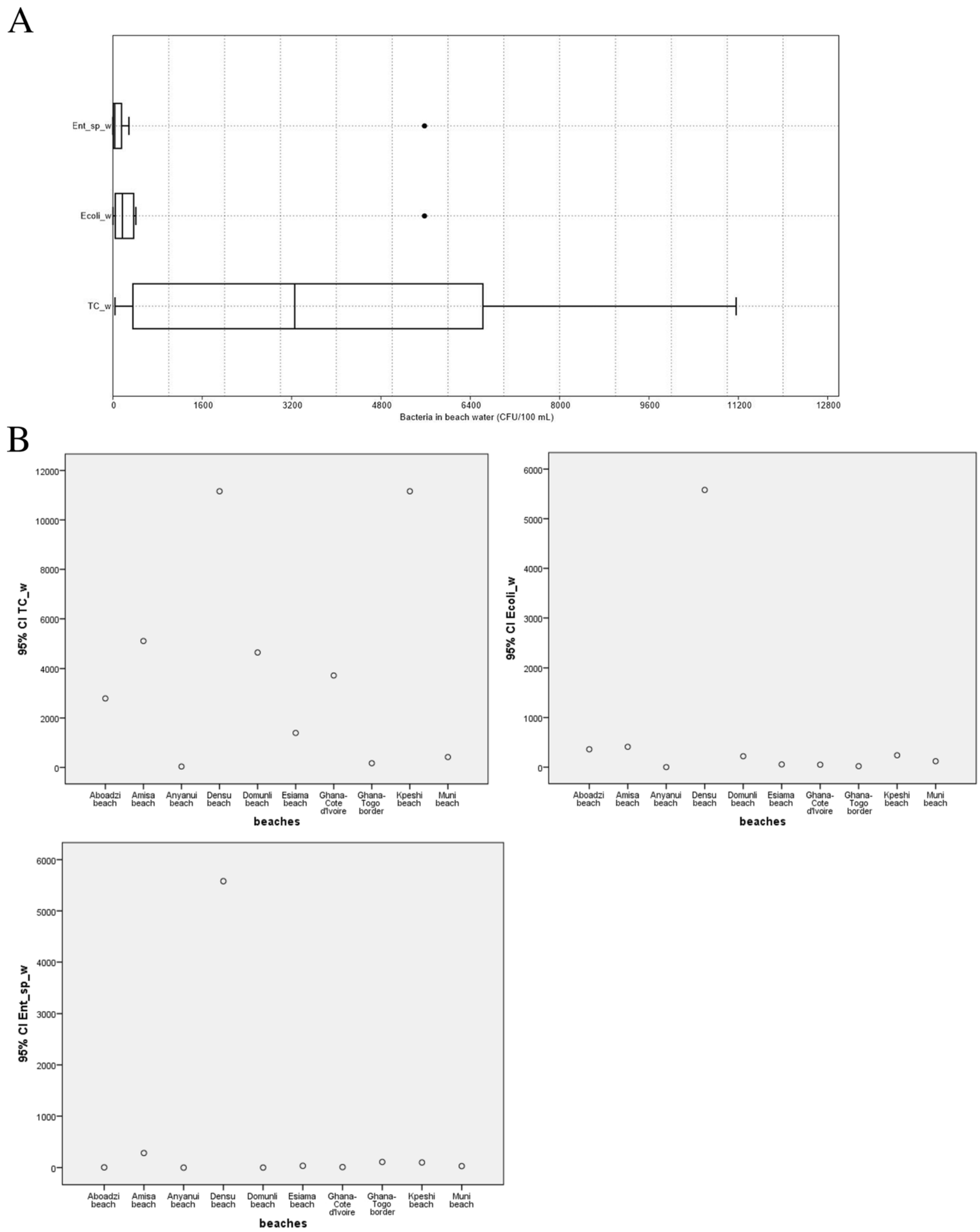

Fig. 2 **A** Boxplot of bacteria in beach water, Gulf of Guinea Coast. The whisker type is the standard error; whisker length is 95% interval, quartile method is an interpolation, and outliers (double asterisks). TC_w, total coliform in water; Ecoli_w, *Escherichia coli* in water; Ent_sp_w, *Enterococcus* spp. in water. **B** Spatial fluctuation (95% CI = confidence interval) of bacteria loads (CFU/100 mL) at study beaches. TC_w, total coliform in water; Ecoli_w, *Escherichia coli* in water; Entsp_w, *Enterococcus* spp. in water

A combination of environmental factors and bacteria data (species-environment) (Figure 5B) showed four groups of beaches with different levels of contamination, mainly (i) cluster 1, Kpeshi (total coliform and *Escherichia coli* most contaminated site); (ii) cluster 2, Ghana-Côte d'Ivoire, Domonli, and Aboadzi (more oxygenated and low contaminated sites); (iii) cluster 3, Esiama, Muni, Anyanui, and Ghana-Togo border; and (iv) cluster 4, Amisa and Densu.

Redundancy analysis

Redundancy analysis (RDA) indicated that two significant environmental factors account for 72.42% variability in the spatial distribution of bacteria (Figure 6) in study sites. Nitrate (55.3%) and total dissolved solids (17.2%) significantly ($p < 0.05$) influenced the spatial distribution of total coliforms, *Escherichia coli*, and *Enterococcus* sp. in the coastal beaches of Ghana (Table 4; Figure 6)

Pearson correlations

Salinity (Table 5) significantly positively correlated with electrical conductivity ($r = 0.995$, $p = 0.000$) and total dissolved solids ($p = 0.956$, $p = 0.000$). There exist significantly positively $r = 0.942$, $p = 0.000$) correlation between dissolved oxygen concentration and dissolved oxygen saturation. Total suspended solids significantly positively correlated with phosphate ($r = 0.818$, $p = 0.004$) and nitrates ($r = 0.694$, $p = 0.026$).

Table. 2 Descriptive statistics of environmental parameters of coastal beaches in Ghana

Names of the beach	Temp. (°C)	EC (mS/cm)	Sal (PSU)	pH	O_2 (mg/L)	O_2 Sat (%)	TDS (mg/L)	TSS (g/L)	Eh (mV)	Phos (mg/L)	Nit (mg/L)	Chl a (μg/L)
Gh-Côte	29.24	43.04	27.52	8.33	6.40	85.10	21.52	4.00	83.50	0.06	1.97	2.61
Domunli	27.53	49.39	30.57	9.05	5.06	75.00	23.57	7.00	61.83	0.04	2.10	2.26
Esiama	27.47	43.50	27.95	8.03	3.80	55.80	21.74	23.00	194.40	0.25	2.77	2.88
Aboadzi	26.94	48.76	31.75	8.66	4.01	59.61	24.36	7.00	163.00	0.12	2.30	2.64
Amisa	28.20	33.13	21.00	8.70	3.68	52.00	16.57	76.33	109.57	0.54	3.57	2.61
Muni	30.82	41.85	76.67	9.20	4.33	65.80	20.94	10.33	217.20	0.37	2.17	0.43
Densu	30.74	52.60	34.70	8.30	6.44	109.60	31.60	10.67	194.70	0.16	3.27	1.23
Kpeshi	28.27	50.23	32.81	8.75	3.69	55.90	25.09	18.67	265.00	0.16	2.73	1.69
Anyanui	29.36	23.41	14.01	8.56	6.17	86.90	11.71	13.00	134.90	0.07	1.63	2.44
Gh-Togo	29.51	49.21	33.01	8.80	4.85	74.50	24.61	12.00	158.20	0.08	2.53	6.13
Mean ± SD	28.81 ± 1.4	43.51 ± 9.1	33.00 ± 16.6	8.64 ± 0.4	4.84 ± 1.1	72.02 ± 18.1	22.17 ± 5.3	18.20 ± 21.2	158.23 ± 62.7	0.18 ± 0.2	2.50 ± 0.6	2.49 ± 1.5
Minimum	26.94	23.41	14.01	8.03	3.68	52.00	11.71	4.00	61.83	0.04	1.63	0.43
Maximum	30.82	52.60	76.67	9.20	6.44	109.60	31.60	76.33	265.00	0.54	3.57	6.13
Geom. mean	28.65	43.13	27.67	8.63	4.83	71.74	21.86	12.71	136.94	0.14	2.44	2.08
75 percentile	27.51	40.56	25.89	8.5	3.77	55.88	103.08	20.28	7	0.07	2.07	1.57
25 percentile	29.4	49.6	32.86	8.77	6.23	85.55	194.48	24.73	19.75	0.28	2.9	2.7
Median	28.76	48.89	31.16	8.72	4.96	74.75	146.55	23.97	11.34	0.14	2.42	2.52
Std. error	0.38	2.9	2.03	0.09	0.36	5.75	19.01	1.69	6.7	0.05	0.19	0.47
Natural background ranged	27–33	20–52.60	34–36	8–9	6–7	-	-	-	-	-	-	-

Temp temperature, *EC* electrical conductivity, *Sal* salinity, *DO* dissolved oxygen concentration, *DO Sat* dissolved oxygen saturation, *Eh* redox potential, *TDS* total dissolved solids, *TSS* total suspended solids, *Phos* phosphate, *Nit* nitrates, *Chl a* chlorophyll-a, *SD* standard deviation, *Std. error* standard error, *Geom. mean* geometric mean

There is a significant positive correlation (r = 0.633, p = 0.049) between *Escherichia coli* and total coliforms. There is positive significant (r = 0.997, p = 0.000) correlation between *Escherichia coli* and *Enterococcus* spp. *Escherichia coli* (r = 0.662, p = 0.037) and *Enterococcus* spp. (r = 0.678, p = 0.031) positively and significantly correlated with dissolved oxygen saturation (Table 5).

Discussion

Physical and chemical characteristics of nearshore beach water

The lowest temperature (26.94 °C) was recorded at Aboadzi beach on the western coast and the highest (30.82 °C) at Kpeshi beach in the central zone. Sea surface water temperature along the coast of Ghana ranged from 25.0 to 28.7 °C with mean ± SD 26.9 ± 1.28 °C, and Chorkor beach ranges from 24.5 to 28.7 °C with mean ±SD 27.2 ± 1.32 °C (Akita et al. 2014). Ghana is situated in the tropical equatorial climate belt with an annual mean temperature between 25 and 36°C (Allersma and Tilma 1993). In this region, the sea surface water temperature varies marginally throughout the year (Biney 1982, 1993). The coastal waters are thermally stratified with a well-mixed layer of warm (25–36 °C), low salinity water of 33.67–34.22 PSU in 30–40 m above a sharp thermocline (Mensah and Anang 1998). The salinity of 35.05–35.38 PSU is below the thermocline at 60–80 depth. During upwelling, the thermocline weakens and rises to the surface resulting in vertically homogeneous salinity profile above the shelf (Mensah and Anang 1998). The lowest salinity (14.01 PSU scale) was recorded at Anyanui beach on the eastern coast due to freshwater intrusion from Volta River at Lower Volta Lake, which also connects to Anyanui Lagoon, whereas the highest (34.70 PSU scale) in Densu beach in the central coast. Marine waters have a much higher conductivity than fresh to estuarine, ranged from 20.0 to 40.0 mS/cm). Salinity of seawater is normally 36 PSU scale. The salinity of coastal beach waters in Ghana ranged from 33.5 to 37.9 (PSU scale) with mean ± SD value 36.6 ± 1.53 (e.g. for La beach) and from 34.5 to 38.0 (PSU scale) with mean ± SD value 36.7 ± 1.21 (e.g. for La beach) (Akita et al. 2014). The lowest (8.30) pH was measured at Esiama beach and the highest (9.05) at Domunli

Table. 3 Bacterial loads (CFU/100 mL) in beach waters, Gulf of Guinea, Ghana

Beaches	**Bacteria types**		
	TC_w (CFU/100 mL)	***E. coli*_w (CFU/100 mL)**	***Ent.*_sp_w (CFU/100 mL)**
Gh-Côte	3.72×10^3	5.0×10^1	1.0×10^1
Domunli	4.65×10^3	2.20×10^2	1×10^0
Esiama	1.40×10^3	5.5×10^1	3.5×10^1
Aboadzi	2.79×10^3	3.60×10^2	5×10^0
Amisa	5.12×10^3	4.10×10^2	2.85×10^2
Muni	4.20×10^2	1.20×10^2	30 × 101
Densu	11.16×10^3	5.58×10^3	5.58×10^3
Kpeshi	11.16×10^3	2.40×10^2	1.0×10^2
Anyanui	3.6×10^1	1×10^0	0×10^0
Gh-Togo	1.70×10^2	2.0×10^1	1.10×10^2
Mean ± SD	$4.06 \times 10^3 \pm 4.16 \times 10^3$	$7.06 \times 10^2 \pm 1.72 \times 10^3$	$6.15 \times 10^2 \pm 1.75 \times 10^3$
Minimum	3.6×10^1	1×10^0	0×10^0
Maximum	11.16×10^3	5.580×10^3	5.58×10^3
Geom. mean	1.6×10^3	1.11×10^2	0×10^0
75 percentile	6.63×10^3	3.72×10^2	1.53×10^2
25 percentile	3.57×10^2	4.20×10^1	4×10^0
Median	3.26×10^3	1.70×10^2	3.20×10^1
Std. error	1.32×10^3	5.43×10^2	5.52×10^2
Confidence level 95%	2.98×10^3	1.23×10^3	1.25×10^3
Ghana Standard Water Quality (GS 175-1)	0×10^0	0×10^0	0×10^0
WHO guidelines	0×10^0	0×10^0	0×10^0

WHO guidelines (< 1 CFU/100 mL) for potable water (WHO 2011). The drinking water quality guideline (0 CFU/100 mL) of Ghana, Ghana Water Company Limited

TC total coliforms, *E. coli_w Escherichia coli* in water, *Ent._sp_w Enterococcus* sp. in water, *SD* standard deviation, *Std. error* standard error, *Geom. mean* geometric mean

beach. The EU has set protection limits of pH ranged from 6 to 9 as harmless for fisheries and aquatic life (Chapman 1996). The pH values fall within the pH ranged between 6 and 9 for natural waters and pH of 8.30 for seawater (Stumn and Morgan 1981). The lowest (3.68 mg/L) dissolved oxygen concentration (DO) was recorded in Amisa beach and the highest (6.44 mg/L) at Densu beach. The nature of beach morphodynamics type may influence circulation in this system. Dissolved oxygen concentration is 7.0 mg/L for tropical surface waters (Biney 1993, Clark 2000) and unpolluted waterbodies of 8.0 to 10.0 mg/L at 25 °C (DFID 1999). Dissolved oxygen concentration is another important environmental variable used for water quality controls. Adequate oxygen is needed to maintain the biological life of ecosystems. A dissolved oxygen concentration of 4–5 (mg/L) can sustain aquatic life. However, below 5.0 (mg/L) may indicate high microbial activity and adversely affect aquatic life (DFID 1999, Stumn and Morgan 1981). In extreme situations, decrease dissolved oxygen levels can lead to anoxic conditions, fish kills, and odours resulting from anaerobic conditions (DFID 1999, Stumn and Morgan 1981). The lowest (61.80 mV) redox potential was measured at Domunli beach and the highest (265.00 mV) at Kpeshi beach. A low redox potential corresponds to high pH, as observed in Domunli beach. Higher redox potential means anoxic conditions as observed in Kpeshi. The redox potential for natural waters ranged from 500 to 600 mV (Stumn and Morgan 1981, Wetzel 2001). With depletion of oxygen, the redox potential decreased to 0 to 200 mV (Stumn and Morgan 1981, Wetzel 2001). The lowest total dissolved solids (11.71 mg/L) concentration was recorded at Anyanui beach and the highest (31.60 mg/L) at Densu beach. The lowest total suspended solids (4.00 g/L) concentration was recorded at the Ghana-Côte d'Ivoire, border beach and the highest (76.33 g/L) at Amisa beach which is connected to the Amisa Estuary, has tidal mixing and a large fishing industry. These activities may results in resuspension of minerals and salt particles through tidal influx and bottom trawling. High total dissolved solids in water originate from

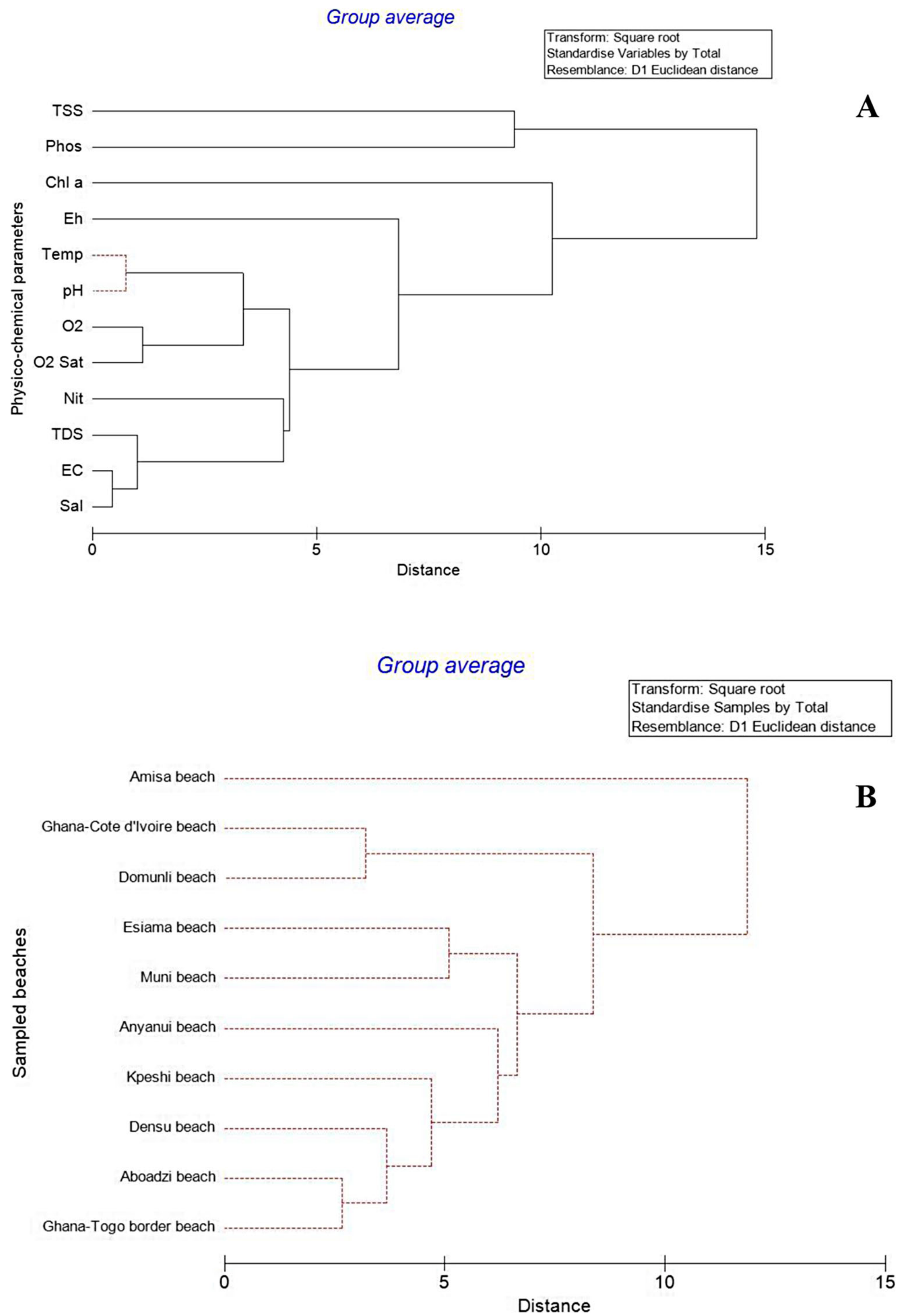

Fig. 3 **A**Group average hierarchical dendrogram of environmental parameters. There are three major clusters. The only significant cluster exists between temperature and pH. The thin red dotted lines indicate a significant structure of similarity (SIMPROF Test, $p < 0.05$). The thick black lines indicate no significant structure. TSS, total suspended solids; Phos, phosphate; Chla, chlorophyll-a; Eh, redox potential; Temp, temperature; pH; O2, dissolved oxygen concentration; O2 Stat, dissolved oxygen saturation; Nit, nitrates; TDS, total dissolved solids; EC, electrical conductivity; Sal, salinity. **B** Hierarchical cluster (group average) of beaches based Euclidean distances of environmental data. The cluster displays the similarity of beaches based on environmental data

natural sources, urban and agricultural runoff, sewage discharges, and industrial wastewater. The lowest phosphate (0.04 mg/L) concentration was measured at Domunli beach and the highest (0.54 mg/L) at Amisa beach. The mean phosphate concentration of (0.18 ± 0.16 mg/L) is higher concentration in unpolluted, natural waters (ranged from 0.005 to 0.020 mg/L) (Biney 1993, Clark 2000) (Chapman 1996). Phosphate concentration is as low as 0.001 mg/L in some pristine waters (Chapman 1996). Phosphate is the limiting nutrient for algal growth and controls a surface water body (Crouzet et al. 1999, Paerl et al. 2011). High phosphate concentrations may indicate pollution and are largely responsible for eutrophic conditions (Omoike and Vanloon 1999, Saad and Younes 2006). The lowest nitrate (1.63 mg/L) concentration was measured at Anyanui beach and the highest (3.57 mg/L) at Amisa beach. Nitrates in the coastal beach waters

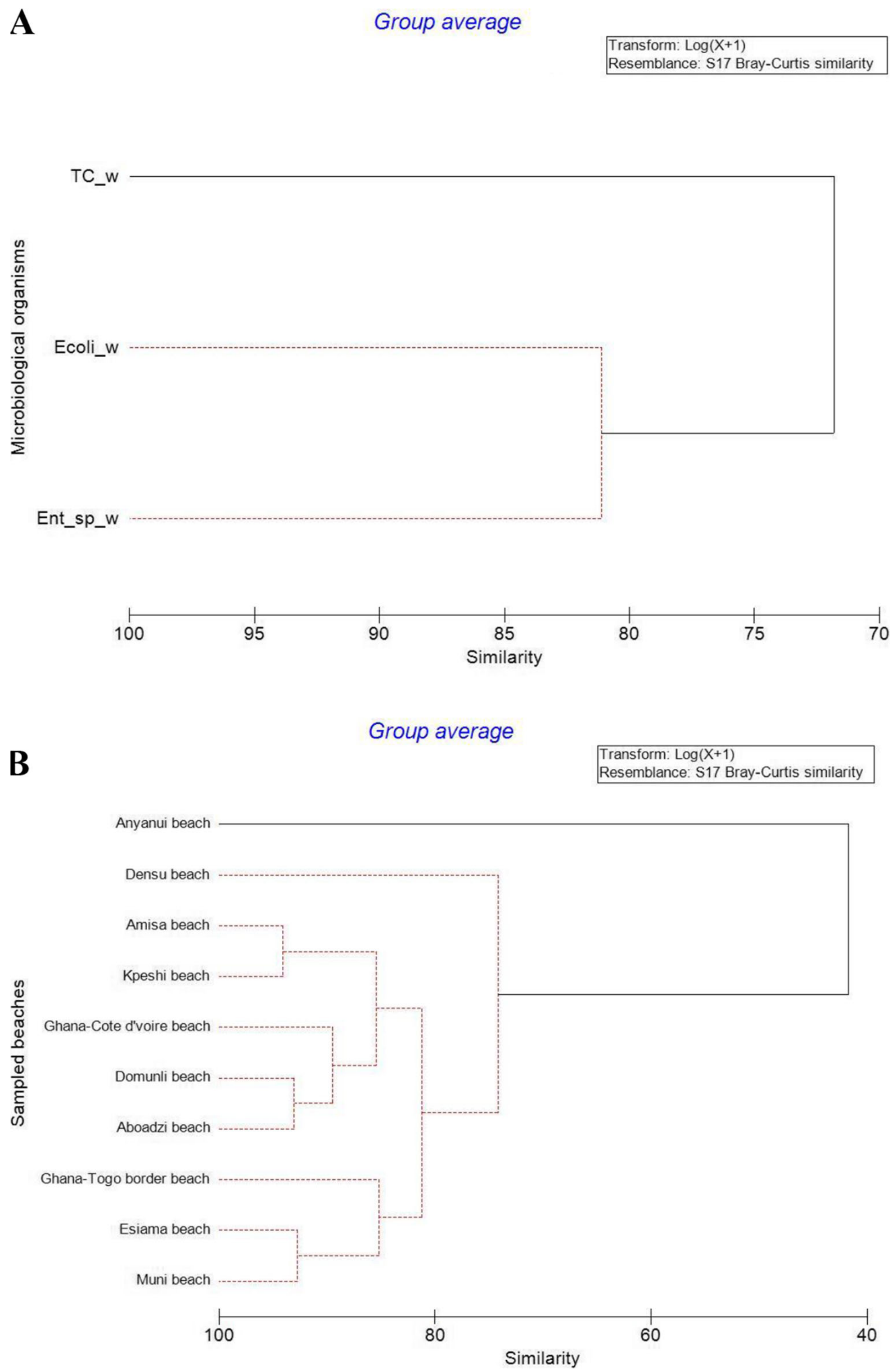

Fig. 4 **A** Group average hierarchical dendrogram of bacterial loads. There is a significant association between *Escherichia coli* and *Enterococcus* spp. Thin red dotted lines showed significant clusters (SIMPROF Test, $p < 0.05$). TC_w, total coliform in water; *E. coli*_w, *Escherichia coli* in water; *Ent*. sp_w, *Enterococcus* spp. in water. The thick black lines indicate no significant structure. **B** Group average hierarchical clusters of beaches based on only bacteria. There exist three significant clusters of beaches except for Anyanui beach (evidence of structure)

of Ghana ranged from 0.5 to 0.25 to 1.8 mg/L in coastal waters of Ghana (Akita et al. 2014, Biney and Asmah 2010). Low nitrates occur in unpolluted waters (Jaji et al. 2007). Nitrates is the most highly oxidised form of nitrogen compounds present in surface waters (Igobinosa and Okoh 2009). Nitrogen-fixing bacteria and algae convert free nitrogen gas (N_2) into nitrates (NO_3^-) (Igobinosa and Okoh 2009). Nitrogen waste products such as urea and uric acid are converted to ammonia. Nitrate bacteria then utilise ammonia to form nitrites (NO_2^-), which are converted into nitrate. Phosphates and nitrates are essential nutrients necessary for primary production and naturally replenished by river runoff (Correl 1998, Sharpley et al.

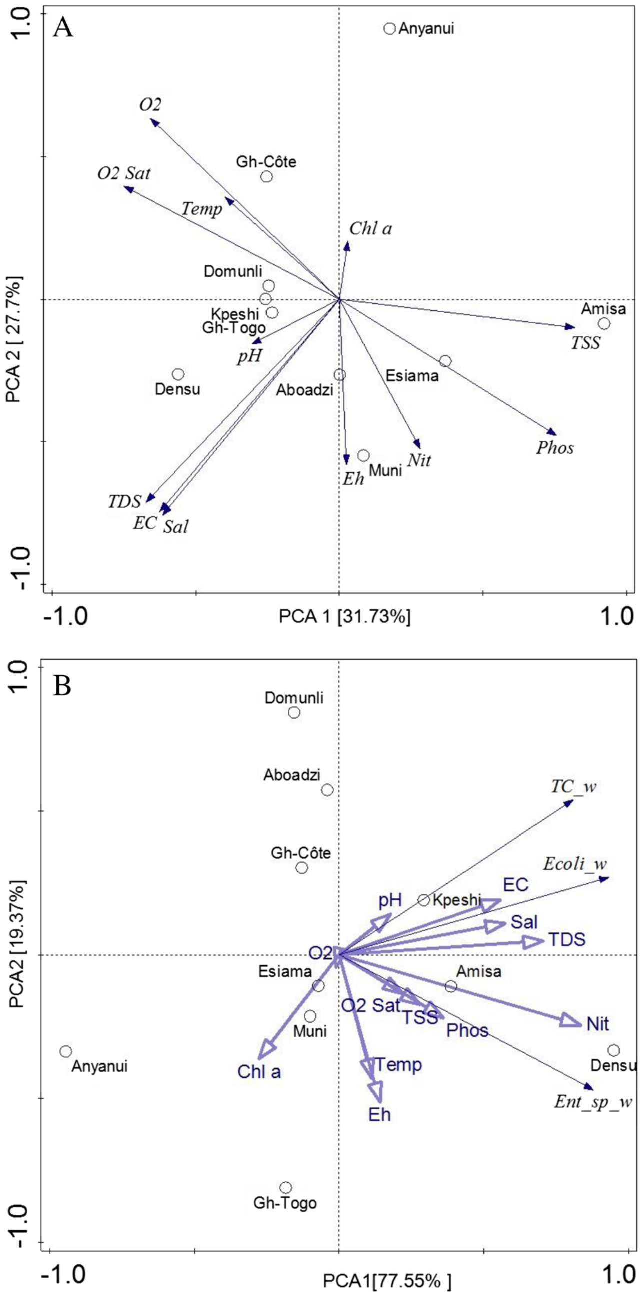

Fig. 5 **A** Principal component analysis (PCA) of a grouping of beaches (circles) based on environmental parameters (blue arrows). The long arrows show the most influential environmental parameters for the group of beaches. The horizontal first axis contributes 31.73% in the PCA plots, and the vertical second axis contributed 27.7%. The orientations of these arrows indicate the correlation of these parameters in PCA ordination axes. Thus, the PCA shows the influencing environmental factors at a given beach. **B** Principal component analysis (PCA) ordination of integrated environmental parameters (thick violet arrows) and bacteria data (thin blue arrows) (triangles). The long arrow indicates the most influential parameters. The first and second axes of PCA contribute 96.9% to explain the variation. The *Escherichia coli* and total coliform are prevalent in beaches with increased nitrate concentration, while *Enterococcus* spp. are predominant in beaches with higher total dissolved solids

2013). Phosphates and nitrates are limiting nutrients for plant growth (Paerl and Huisman 2008). However, excess nutrients lead to the phytoplankton blooms process, often termed eutrophication (Kennish 2001, Nixon 1995, Smith and Schindler 2009). The major proportion of phosphate are transported to the aquatic environment from cultivated land usually in particulate form through erosion and leaching transports relatively little soluble P, as P is strongly adsorbed on clay particles (Carpenter et al. 1998, Elser et al. 2007, Sharpley et al. 2013).

The trophic state of beach water in Ghana based on chlorophyll-a concentration (0.43 to 6.13 μg/L) indicated ultra-oligotrophic (<0.95 - 2.5 μg/L) to mesotrophic condition (2.5–7.3 μg/L) (Gökçe 2016, Vollenweider and Kerekes 1982). Chlorophyll-a concentration at the Densu estuary ranged between 0.96 and 4.38 μg/L (Akita et al. 2020). Chlorophyll-a concentration ranged from 0.10 to 3.80 mg/L (average 1.39 ± 0.84) in coastal waters of the Caspian Sea (Boyer et al. 2009, Bucci et al. 2012, Möller and Scharf 1986). Very low and high levels of chlorophyll-a concentration can be harmful to marine biota (Acheampong et al. 2021, Jamshidi and Abu Bakar 2011). Chlorophyll-a concentration act as an indicator of phytoplankton abundance and biomass in coastal ecosystems (Addico et al. 2018, Hinga et al. 1995, Monbet 1992). The chlorophyll-a concentration provides estimates of phytoplankton biomass and thus productivity of a water body (Boyer et al. 2009, Jamshidi et al. 2010, Tripathy et al. 2005, UNESCO 1994). Eutrophication is associated with increased phytoplankton blooms and increased primary production (Gökçe 2016, Wellman et al. 2002).

Bacterial loads in beach water

The presence of bacteria (total coliforms, *Escherichia coli*, and *Enterococcus*) in beach water (Figure 2A) is an indicator of pollution along the coast of Ghana. High bacteria indicator organisms were measured at central zone beaches (e.g. Densu, Kpeshi) (Table 3; Figure 2A), characterised by massive human activities such as populated coastal fishing communities, industries, beach resorts, coastal tourism, and frequent tourism beach swimmers, among others. A maximum and equal amount of *Escherichia coli* (5.58×10^3 CFU/100 mL) and *Enterococcus* (5.58×10^3 CFU/100 mL) were detected at Densu beach (Table 3; Figure 2A). In urban cities such as Greater Accra, the Metropolitan has to deal with insufficient waste treatment facilities. There are inadequate sewage treatment plants; hence, sometimes, there is dumping of effluent without treatment directly at the coast. The bacteria pollution can be either a single point source or diffuse sources from different sources such as industries, factories, beach resorts, domestic activities, and Ghana's coastal belt. A minimum (Figure 2B) *E. coli* (1.0×10^0 CFU/100 mL) without

Table. 4 Summary of redundancy analyses (RDA) on selecting the best environmental variables influencing spatial variation of bacteria loads in beach waters in Ghana

Analysis "constrained"					
Method: RDA					
Total variation is 129.38; explanatory variables account for 72.4%					
(Adjusted explained variation is 64.5%)					
Summary table:					
Statistics	Axis 1	Axis 2	Axis 3	Axis 4	
Eigenvalues	0.7099	0.0142	0.202	0.0479	
Explained variation (cumulative)	70.99	72.42	92.62	97.41	
Pseudo-canonical correlation	0.9591	0.303	0	0	
Explained fitted variation (cumulative)	98.03	100			
Analysis "constrained"					
Forward selection results:					
Name of environmental parameter	Explains %	Contribution %	Pseudo-F	P	P(adj)
Nit (nitrates—mg/L)	55.3	55.3	9.9	0.002	0.024
TDS (total dissolved solids—mg/L)	17.2	17.2	4.4	0.017	0.102

Enterococcus was recorded at Anyanui beach, characterised by freshwater flow into the nearshore waters and less populated communities.

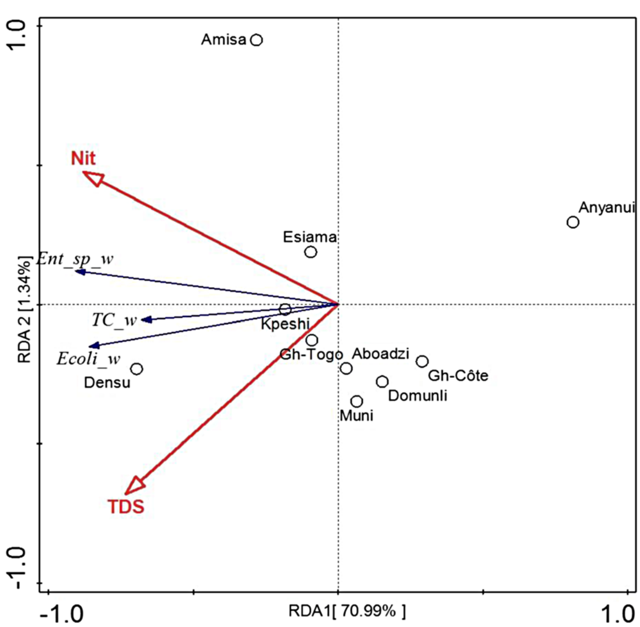

Fig. 6 Redundancy analysis (RDA) diagram of the best environmental variables (red arrows) selected by the forward selection procedure influencing the bacteria (blue arrows) counts in the studied beaches. The ordination diagram with the first axis (horizontal) and the third (vertical) axis of distance-based constrained RDA. The first and second axis of RDA contributes 72.24% to species response to environmental variables. The RDA analysis showed beaches with high nitrate group together while beaches with high total dissolved solids also form another cluster group. The RDA indicates nitrates to control the abundance of *Escherichia coli* and total coliform, while total dissolved solids promote an increase in *Enterococcus* spp.

Sources of spatial variation in bacteria load

Cluster (Figure 3A) and principal component analyses (Figure 4A) established four clusters of beaches based on only environmental factors at a given site: (i) cluster 1, Anyanui beach located in the eastern coast is influence by freshwater flow from Volta River leading to low saline condition and controlled by chlorophyll-a concentration; (ii) cluster 2, Ghana-Côte d'Ivoire and Domonli beaches are situated in the western coast and mostly influenced by high oxygenated seawaters; (iii) cluster 3, Aboadzi, Kpeshi, Densu, and Ghana-Togo border beaches are located in western-central-eastern coast and characterised by increased electrical conductivity, salinity, total dissolved solids, and pH; and (iv) cluster 4, Amisa, Esiama, and Muni beaches are situated in the central zone and characterised by high total suspended solids, phosphate, and nitrates and redox potential (Figure 3A). The grouping of the beaches suggests similar characteristics for a group of beaches due to the major influential physical and chemical composition of water quality.

Cluster analysis of only bacteria data (Figure 3B) also established four major groups of beaches, mainly (i) cluster 1: Kpeshi beach is a major contaminated beach with high loads of total coliform and *Escherichia coli*. The Kpeshi beach is situated on the central coast in the Greater-Accra region, Ghana. The beach is a tourism centre with two major hotels, La Beach Hotel and La Palm Hotel, and the location is densely populated communities along the coast. Discharges of sewage without adequate treatment can lead to high bacterial loads, i.e. (ii) cluster 2: Ghana-Côte d'Ivoire, Domonli, and Aboadzi less contaminated beaches characterised by oxygenation. These beaches are located in western region where the

Table. 5 Pearson correlation (*r*) between environmental parameters and bacteria in beach waters of Ghana

Environmental parameters	Temp	EC	Sal	pH	O_2	O_2 Sat	Eh	TDS	TSS	Phos	Nit	Chl a	TC_w	*E. coli*_w	*Ent*_sp_w
Temp	1														
EC	−.049	1													
Sal	−.011	**.995****	1												
pH	.114	.298	.278	1											
O_2	.619	−.102	−.108	.058	1										
O_2 Sat	.625	.099	.101	.186	**.942****	1									
Eh	−.129	.274	.323	−.180	−.376	−.193	1								
TDS	.046	**.948****	**.956****	.271	.057	.302	.354	1							
TSS	−.083	−.440	−.421	−.040	−.454	−.451	−.138	−.406	1						
Phos	−.205	−.162	−.138	−.087	**−.667***	−.600	.355	−.138	**.818****	1					
Nit	.042	.190	.224	.033	−.281	−.078	.120	.322	**.694***	.632	1				
Chl a	.050	−.080	−.041	−.061	−.041	−.098	−.260	−.158	.039	−.292	−.008	1			
TC_w	.441	.360	.350	.267	.379	.537	−.227	.496	.107	.014	.551	−.401	1		
*E.coli*_w	.176	.329	.346	.185	.429	**.662***	.253	.604	−.080	−.022	.492	−.317	**.633***	1	
*Ent*_sp_w	.212	.310	.330	.161	.449	**.678***	.265	.590	−.079	−.025	.489	−.287	.612	**.997****	1

The bold shows significant corrections between two variables

Temp temperature (°C), *EC* electrical conductivity (mS/cm), *Sal* salinity (PSU), *DO* dissolved oxygen concentration (mg/L), DO *Sat* saturation of dissolved oxygen (%), *Eh* redox potential (mV), *TDS* total dissolved solids, *TSS* total suspended solids (g/L), *Phos* phosphate (mg/L), *Nit* nitrates (mg/L), *Chl a* chlorophyll-a (μg/L), *Tcol_w* total coliforms in seawater (CFU/100 mL), *E. coli_w Escherichia coli* in seawater (CFU/100 mL), *Ent.spp_w Enterococcus* spp. in seawater (CFU/100 mL)

*Correlation is significant at the 0.05 level (2-tailed); **correlation is significant at the 0.01 level (2-tailed)

population may be low and less frequent beach users and hotels, i.e. (iii) cluster 3: Esiama, Muni, Anyanui, and Ghana-Togo border beaches with moderated contaminated beaches characterised by chlorophyll-a concentration may have minimal human impact; (iv) cluster 4: Amisa and Densu beaches with second major contamination are characterised by *Enterococcus* spp. and nitrates. Densu beach is situated in an area with high populated coastal vicinity and adjoining Densu beach Resort and Bojo beach coupled with a connection to Densu estuary and subsequent Densu river. The Amisa Beach is connected with Amisa estuaries and connecting the Amisa River. There are increasing human activities of fish farming, animal husbandry, and water transportation in these coastal systems, which can cause an increase in nutrients and bacteria load.

The principle component analysis (PCA) established spatial variability in sites due to specific environmental factors at a given beach (Figure 5A, B). The best ecological factors are nitrate and total dissolved solids (Table 4; Figure 6). These ecological factors influenced the spatial distribution and abundance of bacteria in the study beaches. *Enterococcus* is mostly abundant in Esiama beach influenced by nitrated enrichment of the seawater (Figure 5A). Increased bacteria loads measured at the nearshore waters of Densu and Kpeshi beaches could be due to the increased concentration of total dissolved solids of seawater, high population of coastal communities, and increased human activities such as industries, agriculture farming, and coastal tourisms, frequent beachgoers. and major hotels situated in this central zone (Figure 5A). Pearson correlation shows strong linearity between salinity, conductivity, and total dissolved solids (Table 5). The combination of cluster and Pearson correlation established a significant linear association among the bacteria (Table 5; Figure 4A). Both correlation and ordination analyses established an association between environmental factors and bacteria in beach water.

Bacterial water quality

Total coliforms, *Escherichia coli*, and *Enterococcus* were low in Anyanui beach but high at Densu and Kpeshi beaches (Table 1). The small communities with limited waste discharges have contributed to the low contamination at Anyanui beach. The major polluted beaches, Densu and Kpeshi, are characterised by densely populated human settlements. Large industries, beach resorts and hotels, coastal fishing communities, beach tourism, animal husbandry, and agricultural farming surround the catchments of these two beaches. The possible contamination sources, including untreated disposal of human and animal waste and runoff from agricultural farmlands, may affect the beach water quality in these localities (Islam et al. 2004, Pandey et al. 2014). Contamination of water bodies is a serious environmental issue since it can affect the ecosystem's health and human health (Parmar et al. 2016, Sabae and Rabeh 2007, Scheren and Ibe 2002). The faecal sources of contamination can be animal or human waste (Domingo and Edge 2010, Dufour et al. 2012, Newton et al. 2013). Most faecal material reaches water bodies either indirectly through discharge after treatment or directly by being washed off the surface by rainfall or through defecation directly into water bodies (Daniel et al. 2000, Devane et al. 2020, Dufour et al. 2012, Karikari and Ansa-Asare 2006). This faecal material can carry pathogenic microbes that may pose a risk to humans exposed to contaminated surface water (Devane et al. 2020, Dufour et al. 2012, Osiemo et al. 2019, Wheater et al. 1979). In south-east Nigeria, maximum bacterial colony count (up to 6×10^4 CFU/100 mL) and the largest variability were found in mesotidal estuaries and adjoining nearshore waters (Anita and Showell 1997). In this study, some limitations are due to the short duration of the research. However, the detection of *Escherichia coli* and *Enterococcus* spp. in the coastal beach waters in Ghana provides enough evidence of faecal pollution, possibly due to animal and human waste sources.

The health of human populations depends on the health of fresh and marine water resources. The coastal communities rely heavily on coastal resources for their economic and social wellbeing. Increasing human activities are pathways for microbes to enter into the freshwater and marine ecosystems. Beach water quality is essential for public health and coastal tourism, linked to the "Sun, Sea and Sand" market and the need to quantify faecal indicator bacteria (Soto-Varela et al. 2021, Zhang et al. 2016). Total coliforms occur in animal intestines, sediment, water, and industrial waste (Osiemo et al. 2019). *Escherichia coli* occurs in the gastrointestinal tract of warm-blooded animals and direct evidence of faecal contamination (Bergholz et al. 2011, Malla et al. 2018b, Niemela et al. 2003, Shields et al. 2015, Zhang et al. 2016). *Enterococcus* spp. are a subset of faecal streptococci and commonly present in the faeces of warm-blooded animals (Cornejova et al. 2015, Moe et al. 1991). *Enterococcus* are more persistent in water than coliforms (Byappanahalli et al. 2012, Xue et al. 2018). They provide a different assessment of the transport of faecal contamination in water than coliforms because of their different shape and survival rate (Ecklu-Mensah et al. 2019, USEPA 2002). These faecal bacteria in marine waters can indicate the possible presence of disease-causing bacteria, virus, and protozoans (Crowther et al. 2001, Korajkic et al. 2018, Price and Wildeboer 2017, Solic and Krstulovic 1992). These pathogens may pose health risks to beach swimmers and seafood consumption (Harwood et al. 2014, Rodrigues and Cunha 2017, Xue et al. 2018). Faecal bacteria can arise from multiple sources such as human and animal waste discharges (Savage 1905, Sayler et al. 1975, Schroeder and Wuertz 2003). *Escherichia coli* is mostly common in fresh and estuarine waters, whereas *Enterococcus* sp. is common in marine water but both are good markers of faecal contamination (Akrong et al. 2019, Leclerc et al. 2001, Malla et al. 2018a, Pachepsky and Shelton 2011). Agriculture runoff and domestic sewage waste water are often associated with high loads of bacteria (Schroeder and Wuertz 2003, Solo-Gabriele et al. 2000). Environmental parameters (thus salinity, temperature, nutrients, and light) can influence the survival and sometimes the proliferation of pathogens and bacteria (Cabral 2010, Edge et al. 2010, Herrig et al. 2019, Pommepuy et al. 2005). Other issues such as climate change such as sea level rise causing coastal flooding and storms runoff may affect beach water quality and cause water borne diseases and illness (Buckerfield et al. 2019, Holcomb and Stewart 2020, Pandey et al. 2014, Weiskerger et al. 2019, Xue et al. 2018). The faecal bacteria organisms such as *E. coli* are often used to detect the presence of perilous faecal pollution and recognised as valuable biomarkers for water quality assessment (Odonkor and Ampofo 2013, Shrestha et al. 2020, Wright et al. 2004, Yeleliere et al. 2018b). Faecal indicator organisms in coastal waters are a growing concern for environmental and human health (Idalia and Franco 2017, Odonkor and Ampofo 2013, Rodrigues et al. 2019, Whitman et al. 2003). Total coliform, *Escherichia coli*, and *Enterococcus* sp. bacteria are used to indicate pathogens of faecal origin in surface and coastal water bodies (Table 2) (Berthe et al. 2013, Guillaud et al. 1997, Ling et al. 2018, Medema et al. 2003, Noble et al. 2003). *Escherichia coli* and *Enterococcus* sp. occurs in intestinal bacteria of warm-blooded animals (Carson et al. 2001, Schönheit et al. 2016, Sinton et al. 1998). Their presence in coastal waters serve as an indicator of potential sewage pollution (Ahmed et al. 2019, Efstratiou 2001, Eichmiller et al. 2013, Oster et al. 2014) Total coliform numbers include non-faecal bacteria, so additional testing is often done to confirm the presence and numbers of faecal indicator bacteria as best markers of faecal pollution (Bettelheim 2003, Leclerc et al. 2001, Maipa et al. 2001, Vantarakis et al. 2006). *Escherichia coli* is the main marker of faecal pollution (Alm et al. 2011, Nowicki et al. 2021, Quilliam et al. 2019, Stewart et al. 2008). But faecal enterococci are also used as complementary microbiological water quality indicator (Byamukama et al. 2000, Katukiza et al. 2013, Maipa et al. 2001, Oster et al. 2014).

Escherichia coli and *Enterococcus* sp. in waters originate from domestic and animals waste discharges (Abdelzaher et al. 2013, Bauer and Alm 2012, Boehm and Sassoubre 2014, Ferguson et al. 2005, Schroeder and Wuertz 2003). Waterborne diseases may impact public health (Beaudeau et al. 2008, Fong and Lipp 2005, Jang et al. 2017, Mwabi et al. 2012). Bacteria in water can transmit diseases such as cholera, typhoid fever, bacillary dysentery, and diarrhoea (Cabral 2010, Drasar 2003, Harwood et al. 2014, Pitkänen 2013). The total coliform abundance in water (mean $4.06 \times 10^3 \pm 4.15 \times 10^3$) exceeded the mandatory levels for the water quality for swimming from most countries (Table 3). The mean total coliforms ranged between 1.14×10^3 and 1.89×10^3 (CFU/100 mL), while the faecal coliforms ranged between 3.36×10^2 and 7.39×10^2 (CFU/100 mL). When comparing with WHO standards (WHO 2008), the results suggest that the sanitary quality of the beach water is unacceptable. In the USEPA, marine recreational water quality criterion for enterococci in water is not more than 1.04×10^2 (CFU/100 mL) (single-sample standard) and 3.5×10^1 (CFU/100 mL) (geometric mean standard) (USEPA 2011). In the EU, bathing water standards for enterococci range from limits of 1.0×10^2–4.0×10^2 (CFU/100 mL), depending on whether the beach is marine or fresh and whether the beach is rated as excellent or sufficient ((EU 2006).

In previous studies, the abundance of bacteria (total coliforms, *Escherichia coli* and *Enterococcus* spp.) in water does not differ from sediments in Densu estuary (Akita et al. 2020). However, high numbers of faecal indicator bacteria (*Escherichia coli* and *Enterococcus* spp.) were found close to landfill sites than seawards suggesting landward contamination sources (Akita et al. 2020). Furthermore, *Escherichia coli* was dominance in water than in sediment while *Enterococcus* spp. were higher in the sediment than water in Densu estuary (Akita et al. 2020). The faecal indicator bacteria in coastal waters arise from multiples sources such as diffuse sources, industrial and domestic sewage discharges, runoff from agricultural and livestock farms (Buckerfield et al. 2019, Kay et al. 1999a, Wyer et al. 1998), migratory shore birds (Jones and Obiri-Danso 1999), and point sources directly at sea.

Bacteriological water quality shows variation according to the magnitude of such inputs, the flux and dispersion of organisms as a result of nearshore hydrodynamics, and the rate of die-off consequences of exposure to UV light (Davies-Colley et al. 1994, Solic and Krstulovic 1992). Microbial concentrations may differ along a particular stretch of the coast and can exhibit marked temporal fluctuations through the bathing season (Crowther et al. 2001, Kay et al. 1999b, Love et al. 2014, Obiri-Danso and Jones 1999). Anthropogenic activities (e.g. land-use activities, sewage discharges) increasingly deteriorate water quality in Ghana (Lawson 2014). Untreated effluents discharges directly at coast can contribute to the microorganisms in the seawater, and the microbes can be transported in the food chain (Fleisher et al. 1996, Haas 2001, Metcalf 1982, Nuzzi and Buhrans 1997, Pommepuy et al. 2005). Bacteria pollution may impose potential health hazards and seafood contamination via transfer in the food chain. The presence of pathogenic microorganisms from sewage discharges leads to human and animal related diseases in the seawater and seafood (Malakoff 2002, Pandey et al. 2014, Poloczanska et al. 2016). Bacteriological and epidemiological studies (Table 6) suggest health risks in swimming contaminated marine coastal waters (Efstratiou 2001, Ferguson et al. 2005, Godfree et al. 1997, Rodrigues and Cunha 2017, WHO 2002, Xue et al. 2017). There are also acceptable bacteria loads such as total coliforms for swim bathing water (Table 6). For instance, human enteric viruses such as norovirus, astrovirus, rotavirus, hepatitis A virus, and pathogenic bacteria including *Salmonella*, *Listeria monocytogenes*, Shiga toxin–producing *Escherichia coli* (Table 6) *Vibrio cholerae*, and *Vibrio parahaemolyticus* causing diseases were associated with faecal contamination in coastal waters (Bosch et al. 2001, Grimes 1991, Kong et al. 2002, Metcalf 1978, Pandey et al. 2014, Rothenheber 2017, Tiwari et al. 2021).

Microorganisms can cause infections such as gastrointestinal and respiratory illnesses, skin diseases, and eye infections (Gerba 2000, Griffin et al. 2003, Payment et al. 1991, Tawiah et al. 2012, Tiwari et al. 2021, VanMensel et al. 2019). High concentration of *E. coli* ($\sim 3.7 \times 10^2$–2.4×10^4 CFU/100 mL) is associated with diseases outbreak. High levels of enterococci were observed after significant rainfall events, in 36 samples (35.6%) that exceeded USEPA's statistical threshold value of 1.3×10^2 (CFU/100 mL) (Dufour et al. 2012, Dufour 1984, Dufour 2001, EPA 1986). The US Public Health Service used epidemiology to detect swimming-associated illness with total coliform levels of 2.3×10^3 (CFU/100 mL) (Dufour et al. 2012, Dufour 1984, Dufour 2001, EPA 1986). An acceptable bacteria load (e.g. total coliforms) for swim bathing waters varies from country to county (Efstratiou 2001, 2018). For example, in the USA, single-sample standards are total coliforms, 10.0×10^3 (CFU/100 mL), and *E. coli*, 1.04×10^2 (CFU/100 mL) (Dufour et al. 2012, Dufour 1984, Dufour 2001, EPA 1986).

In regard to the water quality of beaches in the long department of Atlántico (Caribbean Sea of Colombia), a study observed that *E. coli* counts ranged from 0×10^0 to 2.4×10^2 (CFU/100 mL) with higher values close to urban areas (Soto-Varela et al. 2021). On the other hand, a similar study in the same region but northern part established the highest values of *E. coli* $\geq 5.0 \times 10^2$ (CFU/100 mL) in beaches located at urban areas (e.g. Salgar, Pradomar, Puerto Colombia, and Northern zone of Puerto Velero) but low values between 1.6×10^1 and 5.4×10^1 (CFU/100 mL) in beaches located in rural areas (Sabanilla and the southern zone of Puerto Velero) (Moreno et al. 2019).

The study demonstrated the environmental factors such as nitrates and total dissolved solids significantly controlled the spatial abundance of bacteria in beach seawater. The survival of most bacteria in seawater is also dependent on salinity, temperature, pH, solar radiation, and other factors (Boehm et al. 2018, Hirn et al. 1980, Johnson 2011, Maipa et al. 2001). PH influenced the spatial fluctuations of faecal bacteria at the Densu estuary (Akita et al. 2020). The local environmental factors contribute to the abundance of bacteria in beach water. Faecal indicator bacteria in the water column are

Table. 6 The bacteriological and epidemiological studies in seawater

Indicators examined	Pathogens examined	Indicator/pathogen correlating	Symptoms	Country	Source
TC	Salm	TC/Salm	GI	UK	PHILS (1959)
E. coli	Salm	*E. coil*/Salm		Denmark	Grunnet (1969)
ent, *E. coli*	-	ent	Ear	USA	Cabelli (1982)
TC, *E. coli*, *ent*, TVC	Salm, S. aur, Campobacteria Salm	TC, *E. coli*, ent, TVC/Salm, FC, Cl, perf/Salm	-	Greece	Papadakis (1988)
TC, FC, FS	Salm	TC, FC, FS/Salm	-	Spain	Polo (1996)
TC, ent, *E. coli*	V.vuln	TC, ent/V.vuln	-	Denmark	Hoi (1998)
FC, *E. coli*, ent, staph, coliph	-	-	-	South Africa	Von Schirnding (1993)
E. coli, staph		*E. coli*/staph	S/GI	Hong Kong	Chenug (1990)
ent, *E. coli*	-	Ent/*E. coli*	GI	Egypt	El Sharkawi and Hassan (1982)
Tcol_w, *E. coli*_w, *Ent.* spp_w.	-	Tcol_w/*E. coli*_w, *E. coli*_w/*Ent.* spp_w		**Ghana**	**This study**

The bold illustrate our contribution to knowledge in what has been previously studied in other regions

TC total coliforms, *FC* faecal coliforms, *FS* faecal streptococci, *ent* enterococci, *E. coli Escherichia coli*, *Salm Salmonella* spp., *Cl.perf Clostridium perfringens*, *V.vuln Vibrio vulnificus*, *staph* staphylococci, *coliph* coliphages, *Tcol_w* total coliforms in seawater, *E. coli*_w *Escherichia coli* in seawater, *Ent. spp_w Enterococcus* spp. in seawater, *GI* gastrointestinal, *Ear* ear, *S* skin (modified from Godfree et al. 1997, Efstratiou 2001)

removed by adsorption and deposition through sedimentation (Whitman et al. 2011). The deposition of indicator bacteria is dependent on the association between bacteria and suspended particles (Whitman et al. 2011). Faecal indicator bacteria are also known as chemo-organotrophic bacteria, depending on the decay of organic compounds for food and growth (Maipa et al. 2001). Faecal pollution of water resources is a major concern for public health (Ercumen et al. 2011, Fleisher et al. 1996, Ishii and Sadowsky 2008, Sinigalliano et al. 2010, Wade et al. 2003). There are other pollutant pathogens such as streptococci, staphylococci, and pseudomonas (Johnson 2011). The number of bacterial species in bathing waters depends on other factors such as time of sampling, season, and collection location (Maipa et al. 2001, Obiri-Danso et al. 1999). Tracking sources for contamination, community education, beach hygiene, and local beach regulation plan can help prevent localised accumulation (Abdelzaher et al. 2013). Integrating knowledge from multiple factors (e.g. bacteria, pathogens, ecology, and public health) would increase the understanding of pollution, possible potential causes of pollution and support coastal management planning to improve water quality (Pandey et al. 2014, WHO 2002). Beach monitoring is critical to detect early hazards to warn people to avoid swimming in contaminated waters to safeguard their well-being (Crank et al. 2019, Griffith et al. 2016, Wade et al. 2006). Overall, clean sanitation promotes clean water and protects life below water, leading to good health and well-being. Preventive measures include policy reformations to regulate waste discharges, pollution pay principle, and penalty for pollution. Research on faecal indicator bacteria using genetic markers (Griffith et al. 2016, Korajkic et al. 2018, Xue et al. 2017) and identification of sources of bacteria in the Gulf of Guinea shall expand the understanding of contamination and potential human health risks. The sustainable development goals advocate for good health and well-being (SDG 3) and clean water and sanitation (SDG, 6) (Espey et al. 2015, Persson et al. 2016).

Conclusion

The Gulf of Guinea coast, Ghana, is faced with environmental problems such as water pollution. Beach water quality is examined for bacteria to combat swimming-associated illness. Ten beaches were quantitatively assessed for bacteria detection coupled with measurement of physical and chemical properties of near shore water to understand the status of coastal pollution. Anyanui beach is characterised by freshwater influence from the Volta River Lake system with less saline, whereas Densu beach showed higher saline conditions. The trophic state of beach waters ranged from ultra-oligotrophic to mesotrophic status. Muni beach is characterised by low Chl-a concentration, whereas high concentration occurs at Ghana-Togo border beach. Amisa beach is enriched with high nitrate concentration.

There is no significant variation ($p > 0.05$) in the measured environmental factors for the sampled season. However, multiple indicators (total coliforms, *Escherichia coli*, and *Enterococcus* spp.) showed pollution in the ten beaches. The study integrates physical and chemical characteristics of multiple beaches with an abundance of bacteria to understand ecological conditions favouring spatial fluctuation of the bacteria loads in near shore water. The mean ± standard deviation of total coliforms ($4.06 \times 10^3 \pm 4.16 \times 10^3$) and faecal indicator bacteria (*Escherichia coli*, $7.06 \times 10^2 \pm 1.72 \times 10^3$ and *Enterococcus* spp., $.15 \times 10^2 \pm 1.75 \times 10^3$) suggest faecal contamination in the tropical coastal region of Ghana. There exists significant ($p < 0.05$) spatial variation in bacteria loads (total coliforms, *E. coli*, and *Enterococcus*) in the beach water. The Anyanui beach recorded low bacterial contamination, while Densu and Kpeshi beaches (highly populated central coastal areas) were highly contaminated. Beaches with similar bacteria loads and environmental characteristics of near shore water formed similar clusters. Environmental factors influenced spatial variation of bacteria abundance in the multiple beach study. Redundancy analyses suggest nitrates (55.3%) and total dissolved solids (17.2%) are the best environmental factors controlling the bacteria abundance in beach water. There exist significant ($p < 0.05$) associations between the bacteria (total coliforms, *Escherichia coli*, and *Enterococcus* spp.) and with environmental factors.

The presence of faecal indicator bacteria (FIB) (*Escherichia coli* and *Enterococcus* spp.) suggests that near shore coastal areas are recipients of contaminants and may affect water quality and beach users. Improved water quality is possible through improved sanitation (Bartram et al. 2014, Osiemo et al. 2019, Yang et al. 2012).

The detection of bacteria in the beach water from multiple sites along the coast of Ghana is a concern for beach swimmers, coastal managers, and public health risks associated with contact with contaminated water. Furthermore, policy reforms regulating waste discharges into water resources will help prevent and protect the public from water pollution. The study provides environmental knowledge for improving beach water quality, a basis for safety precaution by beach swimmers, and future biomonitoring of coastal waters in the tropical Atlantic region.

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Availability of data and materials The data is deposited at PANGAEA and can be made available for public use.

Author contribution
- Dr. Lailah Gifty Akita: conceptualization, data curation, statistical analyses, fund acquisition, and writing—original draft.
- Dr. Juergen Laudien: conceptualization, fund acquisition, and writing of review.
- Dr. Charles Biney: conceptualization and writing of the review.
- Mark Akrong: data curation and writing of the review.

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Declarations

Ethical approval This article does not involve any human participants or animals in the authors' study.

Authors consent to participation in the project research

The authors were involved in the research participation and writing, and review.

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