Asian Journal of Chemistry; Vol. 38, No. 5 (2026), 1289-1294
ASIAN JOURNAL OF CHEMISTRY
https://doi.org/10.14233/ajchem.2026.35605

Statistical Parameters and Origin of Faecal Contamination in Coastal Waters: Case of Abidjan City (Côte d'Ivoire)

OLIVIER SIMON KOMBO MANANGA[1,*], GANSSO VALENTIN AKILINON[2], AHBEAURIET AHMED OUATTARA[2] and OSSEY BERNARD YAPO[1,3]

[1]Laboratory of Environmental Sciences, Department of Environmental Sciences and Management, Nangui Abrogoua University, Abidjan, Côte d'Ivoire
[2]Department of Physics and Chemistry, Faculty of Science and Technology, Alassane Ouattara University, Bouaké, Côte d'Ivoire
[3]Central Environmental Laboratory of Ivorian Anti-Pollution Center, Ministry of Environment and Sustainable Development, Abidjan, Côte d'Ivoire

*Corresponding author: Tel: +225 070783115; E-mail: komanols@yahoo.fr

Received: 13 January 2026 *Accepted*: 2 April 2026 *Published online*: 4 May 2026 AJC-22354

Bacterial contamination of coastal waters is the cause of various waterborne diseases. In this study, the levels of faecal contamination of coastal waters in the city of Abidjan were assessed. Water samples were collected from six stations located along the coast of the city of Abidjan. Bacterial densities D50 and D90 were determined using the rank method. The healthiness of beach waters was assessed according to WHO/UNEP criteria developed under Mediterranean (MED) POL.VII programme. *Clostridium perfringens* D50 concentrations exceeded the threshold of 100 CFU/100 mL in half of the stations. The D90 concentrations of faecal coliforms and faecal streptococci were all greater than 1,000 CFU/100 mL. The results obtained suggested that the pollution was mainly of human origin, with bacterial concentrations exceeding the recommended quality thresholds for bathing. According to the quality limits for bathing water, all beaches studied were of poor quality for bathing.

Keywords: Faecal contamination, Degree of contamination, Bacterial density, Coastal water, Pollution.

INTRODUCTION

Demographic pressure and the growth of human activities contribute significantly to the degradation of water resources. This situation results in health and environmental risks. Futhermore, the lack of wastewater treatment, poor household waste management and landfilling practices are the main factors of water degradation [1]. Côte d'Ivoire, a West African nation bordering the Gulf of Guinea, possesses an extensive Atlantic coastline of approximately 515 km, with coastal zones accounting for nearly 7% of its total land area. The city of Abidjan, situated within this coastal region, represents a major socio-economic hub where a significant proportion of the population's activities are concentrated around aquatic environments. These coastal and lagoonal systems support diverse economic sectors including fisheries, agriculture, coastal tourism, industrial operations and various informal activities, all of which contribute substantially to the regional development while exerting pressure on the local water resources [2]. Faecal contamination of water bodies poses significant public health risks to local populations. Exposure pathways include the consumption of contaminated water and aquatic products, which may lead to gastrointestinal infections and diarrhoeal diseases as well as direct contact during recreational activities, potentially resulting in the dermatological conditions and other infections [3]. The main indicator agents of faecal bacteria are identified as fecal coliforms, faecal *streptococci* and *Clostridium perfringens* [4].

The microbiological contamination of the coastal environment is linked to inputs from various sources including urban and agricultural anthropogenic discharges. The presence of contaminants in water and in particular microorganisms that are pathogenic to humans, can pose a health risk when swimming or consuming aquatic species [5,6]. Indeed, swimming in natural waters can lead to more or less intense contact with pathogenic germs that may be present in the water in small or

This is an open access journal, and articles are distributed under the terms of the Attribution 4.0 International (CC BY 4.0) License. This license lets others distribute, remix, tweak, and build upon your work, even commercially, as long as they credit the author for the original creation. You must give appropriate credit, provide a link to the license, and indicate if changes were made.

large quantities. The pathologies associated with these germs concern the ENT sphere, the digestive system, eyes and skin [6]. The pathogenic microorganisms present in natural waters are responsible for a range of waterborne diseases, most commonly diarrhoea, tonsillitis, conjunctivitis and respiratory infections [6,7]. Based on the available literature, this study represents the first percentile-based assessment specifically focused on the beaches of Abidjan [3,8]. The objective of this work is to evaluate the level of faecal contamination in the coastal waters of Abidjan. To achieve this, the study aims to quantify bacterial densities using statistical approaches, assess the extent of faecal pollution in accordance with WHO guidelines and identify the sources of contamination through the analysis of microbial indicator ratios.

EXPERIMENTAL

Six sampling stations were selected from the national monitoring network for lagoon and coastal water quality managed by the Ivorian Anti-Pollution Centre [9]. Water samples were collected at a depth of approximately 20 cm using sterile bottles, which were rinsed twice with the sample water prior to collection. The bottles were filled completely and capped underwater to prevent air entrapment and preserve sample integrity. All samples were transported in the insulated coolers containing dry ice, maintained in the dark at ~4 ºC, and processed promptly upon arrival at the laboratory.

Enumeration of indicator bacteria was performed using standard culture-based microbiological techniques on selective media. Faecal coliforms were cultured on violet red bile lactose (VRBL) agar and incubated at 44 ºC for 24 h to select thermotolerant strains. Faecal streptococci were enumerated on Slanetz and Bartley agar following incubation at 37 ºC for 48 h, with confirmation of characteristic colonies where required. *Clostridium perfringens* spores were determined using tryptose sulfite cycloserine (TSC) agar under anaerobic conditions, with incubation at 44 ºC for 24 h. Quality assurance measures included the use of sterile blanks, duplicate sample analyses and routine verification of incubation conditions.

Statistical analyses were conducted using R software (version 4.5.3). Given the non-normal distribution typically associated with bacterial data, non-parametric methods were employed [10]. Spatial variations in bacterial concentrations across the six stations were assessed using the Kruskal-Wallis test, followed by pairwise Mann-Whitney tests to identify significant differences between sampling sites. In addition, Pearson correlation analysis was used to examine relationships among the three bacterial indicators measured in the coastal waters.

Fig. 1 shows the different sampling stations for the analysed water. The water samples were taken from six stations located on the coast of the city of Abidjan. These are the West beach (P1), East beach (P2) and Cocobeach (P3), all located in Vridi. Station P4 is located in Port-Bouët, station P5 is near the airport and station P6 is located in Gonzagueville. The water samples were packaged in transparent glass bottles previously sterilised. They were stored according to the standard protocols [11,12] for bacteriological analyses. Fifteen samplings were carried out every 2 months from 2024 to 2025.

Determination of bacterial densities D50 and D90: Bacterial densities D50 and D90 represent the concentrations of bacteria corresponding to 50% and 90%, respectively, of the counts obtained for surface waters at the sampled stations

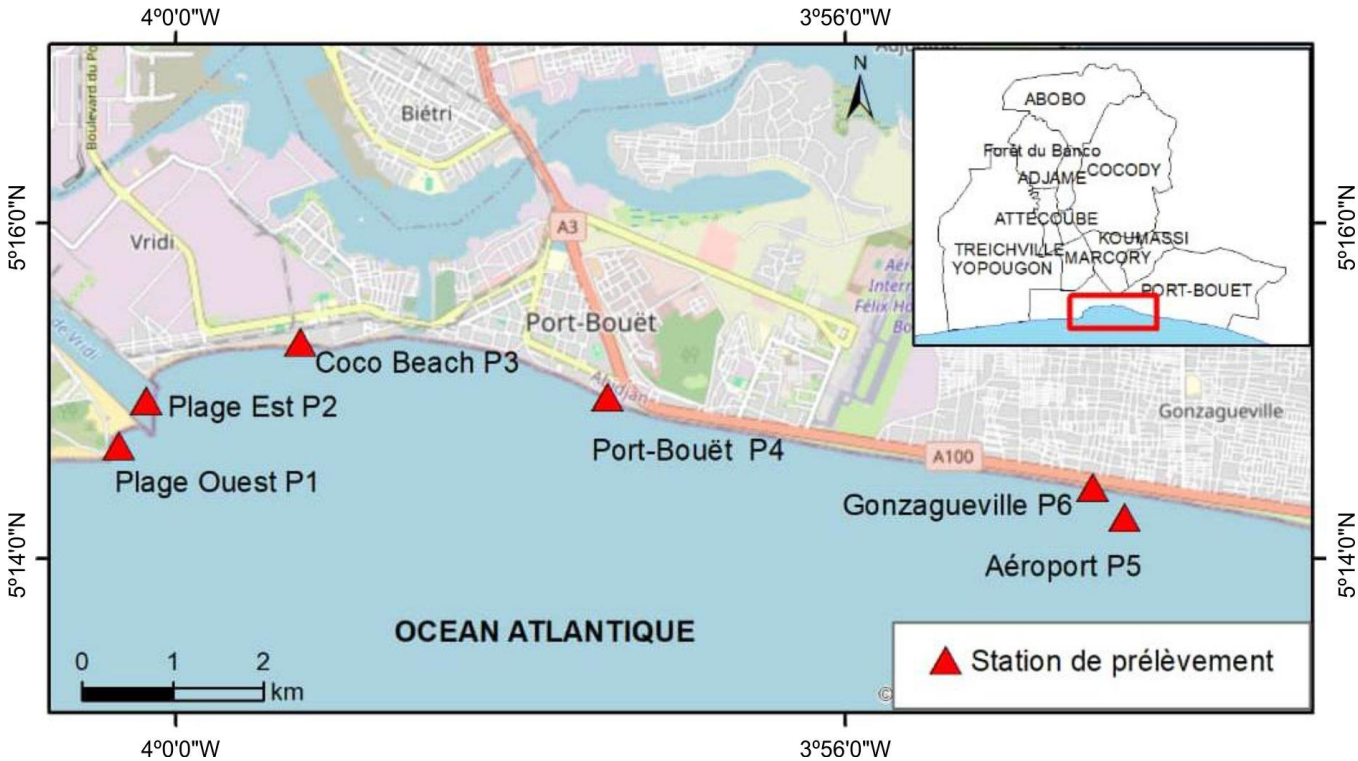

Fig. 1. Abidjan coastal water sampling stations

[3,13-15]. Bacterial densities (D50 and D90) were determined using the rank method in accordance with WHO/UNEP standards [2,14,15]. These criteria indicate that if the density D50 < 100 faecal coliforms or faecal streptococci per 100 mL of water and the density D90 < 1,000 faecal coliforms or faecal streptococci per 100 mL of water, then the bathing water is considered bacteriologically satisfactory.

Determination of degree of faecal pollution of water: Based on the WHO/UNEP criteria outlined above, the degree of contamination or faecal pollution (DP) is defined as the number of times a bacterial concentration exceeds the limit recommended by WHO/UNEP [12]. Thus, the degree of faecal pollution is obtained by dividing D90 by the threshold concentration of 1000 bacteria per 100 mL [16]. In this study, the DP value was determined for faecal coliforms, faecal streptococci and *Clostridium perfringens* at each of the stations studied.

Determination of origin of faecal contamination of water: The origin of faecal contamination was assessed using the ratio of faecal coliforms to faecal streptococci (R = CF/SF). According to the criteria proposed by Borrego & Romero [18], values of R < 0.7 indicate a predominantly animal origin, whereas 0.7 < R < 1 suggests mixed contamination with animal predominance. Ratios in the range of 1 < R < 2 are considered inconclusive. The values between 2 < R < 4 reflect mixed contamination with a predominance of human origin, while R > 4 indicates contamination which is primarily or entirely of human origin. The CF/SF ratio was calculated using all measurements obtained throughout the study period.

RESULTS AND DISCUSSION

The assessment of faecal indicator bacteria across the six coastal stations revealed pronounced spatial and temporal variability in the microbial contamination, reflecting the dynamic nature of coastal environments influenced by both anthropogenic activities and environmental processes. The coefficients of variation (CV) for all three indicators, faecal coliforms, faecal streptococci and *Clostridium perfringens*, were generally high, often exceeding 100%, which indicates substantial fluctuations in bacterial concentrations over time (Table-1). Such high variability suggests that contamination events are not constant but occur intermittently, likely driven by episodic inputs such as stormwater runoff, wastewater discharges, and tidal influences. Stations such as P1, P5 and P6 exhibited particularly elevated variability for specific indicators, highlighting the role of localised factors in shaping contamination patterns.

TABLE-1
COEFFICIENT OF VARIATION IN WATER SAMPLES FROM DIFFERENT BEACHES

Beach	Coefficient of variation (%)		
	Faecal coliforms	Faecal streptococci	*Clostridium perfringens*
P1	79	170	193
P2	132	129	64
P3	133	179	161
P4	116	134	91
P5	108	194	76
P6	164	156	67

The boxplot analysis further supports these observations by illustrating considerable dispersion and the presence of extreme values at several sites (Fig. 2). For instance, faecal coliform concentrations were notably higher at station P1, which also exhibited a wide interquartile range and multiple outliers, indicating both persistent contamination and episodic spikes. In contrast, stations P3 and P6 generally displayed lower median values, although occasional peaks were still observed, suggesting intermittent pollution inputs. A similar pattern was evident for faecal streptococci, where stations P3, P4, P5 and P6 showed substantial variability, with extreme values approaching 8000 CFU/100 mL at certain times. These peaks likely correspond to short-term contamination events, possibly associated with rainfall-induced runoff or localised discharge sources. For *C. perfringens*, higher median concentrations at stations P5 and P6 indicate more persistent contamination, as this organism is known for its resistance to environmental degradation and its ability to survive longer in aquatic systems.

Despite the evident variability in bacterial concentrations, the Kruskal-Wallis test did not reveal statistically significant differences among the six sampling stations ($p > 0.05$) (Table-2). This suggests that at a broader scale, contamination levels across the beaches are relatively comparable. However, this lack of statistical significance should be interpreted cautiously, as high within-site variability can obscure spatial differences. Indeed, pairwise Mann-Whitney comparisons identified significant differences between certain stations,

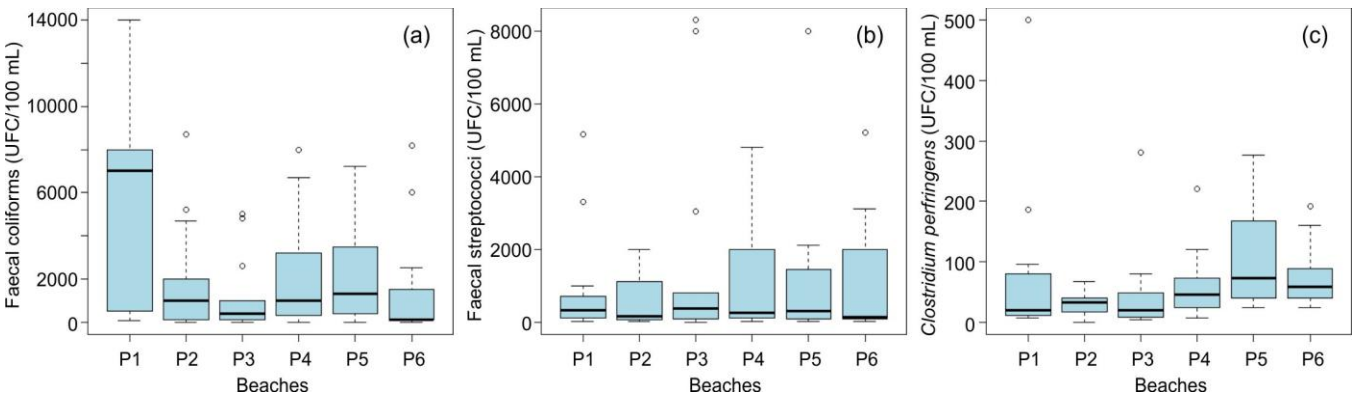

Fig. 2. Spatial and temporal distribution of faecal coliforms (a), faecal streptococci (b) and *C. perfringens* (c) in the studied beaches

TABLE-2
GLOBAL COMPARISON BETWEEN BEACHES (KRUSKAL-WALLIS TEST)

	Faecal coliforms	Faecal streptococci	*Clostridium perfringens*
H statistic	9.84	0.77	6.1
p-value	0.0798	0.979	0.30

Pairwise Mann-Whitney tests has given no significant *p*-value (> 0.05) for faecal coliforms, faecal streptococci and *Clostridium perfringens*. Except beaches P1 *vs*. P3 and P1 *vs*. P6 which have respectively *p*-value 0.0196 and 0.0166 for faecal coliforms.

particularly between P1 and P3; and P1 and P6 for faecal coliforms. These findings indicate that while overall contamination may appear homogeneous, localised hotspots exist, with P1 emerging as a site of relatively higher contamination. Such discrepancies highlight the importance of combining statistical analysis with descriptive data interpretation to fully understand spatial patterns in environmental studies.

Correlation analyses between the different bacterial indicators: The Pearson correlation matrix (Table-3) indicates weak relationships among the three bacterial indicators, highlighting the complex and heterogeneous nature of faecal contamination across the studied beaches. A moderate negative correlation was observed between faecal coliforms and faecal streptococci (r = -0.33), suggesting that these indicators do not exhibit synchronous variation across sampling sites. However, this relationship was not statistically significant ($p > 0.05$), indicating that the observed trend is not robust and may be influenced by site-specific or temporal variability. Similarly, weak positive correlations were found between faecal coliforms and *C. perfringens* (r = 0.189); and between faecal streptococci and *C. perfringens* (r = 0.07). The low correlation coefficients, together with non-significant *p*-values, suggest that these bacterial indicators behave largely independently, likely reflecting differences in their environmental persistence, transport mechanisms, and source contributions.

Further insight into contamination patterns is provided by the analysis of bacterial density metrics (D50 and D90), as illustrated in Fig. 3. The consistently higher D90 values relative to D50 across all stations indicate the occurrence of peak contamination events, supporting the presence of episodic

TABLE-3
PEARSON CORRELATION MATRIX BETWEEN THE DIFFERENT BACTERIAL INDICATORS

	Faecal coliformes	Faecal streptococci	*Clostridium perfringens*
Faecal coliformes	1		
Faecal streptococci	-0.331283256	1	
C. perfringens	0.189195164	0.071287906	1

pollution inputs rather than continuous discharge. Notably, D90 concentrations of faecal coliforms and faecal streptococci exceed the WHO/UNEP guideline threshold of 1000 CFU/100 mL at all sites, confirming that the coastal waters are unsuitable for recreational use. In contrast, *C. perfringens* concentrations remain below this threshold at the D90 level, although elevated D50 values at several stations indicate persistent background contamination.

These findings suggest that contamination is not isolated but rather widespread throughout the study area. The observed pollution patterns are likely influenced by continuous inputs of wastewater from surrounding urban areas, combined with environmental factors such as water circulation and confinement [19]. As observed by Akilinon [17], the extent of contamination is strongly governed by both the magnitude of pollutant discharge and the hydrodynamic characteristics of the receiving water body, which control dilution and dispersion processes [20].

Degree of faecal contamination of lagoon waters: The degree of faecal contamination (DP) in the coastal waters was evaluated by comparing the D90 concentrations of faecal indicator bacteria with the WHO/UNEP threshold value of 1000 CFU/100 mL. The spatial distribution of contamination levels is illustrated in Fig. 4, where variations in colour intensity reflect differences in pollution magnitude across the studied beaches.

As shown in Fig. 4, faecal coliform contamination is the highest at beach P1, indicated by the most intense colour (DP = 10), confirming it as the most impacted site. In contrast, beach P5 exhibits comparatively lower contamination (DP = 4), represented by lighter colour intensity. Intermediate levels are observed at P4 and P6, followed by P2 and P3, which is consistent with the ranking: P1 > P4 > P6 > P2 > P3 > P5. For

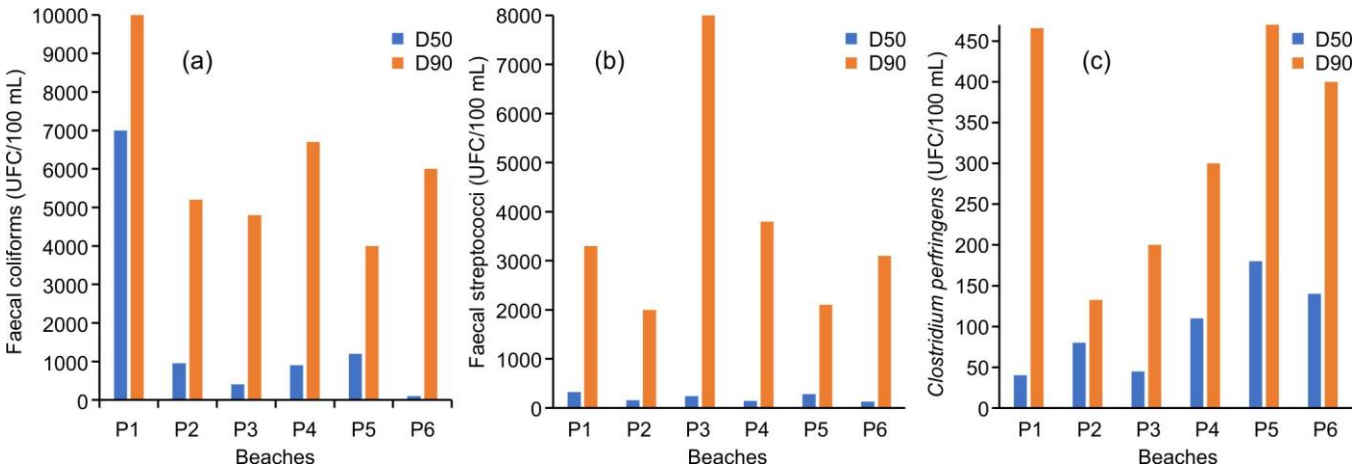

Fig. 3. D50 and D90 concentrations of faecal coliforms (a), faecal streptococci (b) and *C. perfringens* (c) in the coastal waters of Abidjan

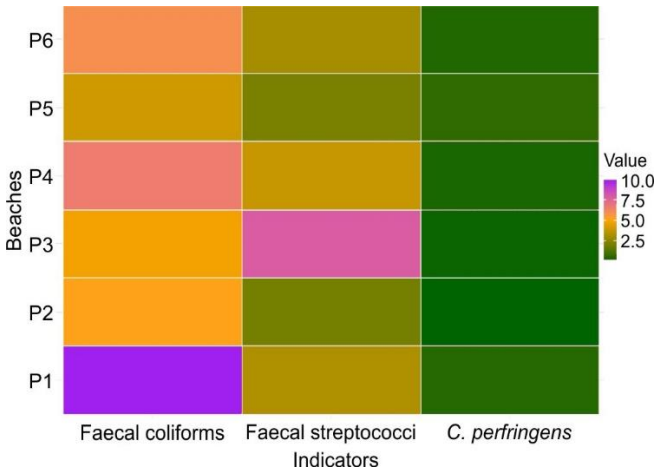

Fig. 4. Heat map of faecal pollution by studied beaches

faecal streptococci, Fig. 4 highlights beach P3 as the most contaminated site (DP = 8), clearly distinguished by a stronger colour gradient. Beaches P4 and P1 follow with moderate contamination levels, whereas P2 shows the lowest contamination (DP = 2), represented by the least intense colour. This distribution aligns with the ranking: P3 > P4 > P1 > P6 > P5 > P2. In case of *C. perfringens*, the heat map indicates generally lower contamination levels across all beaches, with relatively uniform and less intense colour patterns. Although beach P5 shows slightly higher values compared to other stations, all measured concentrations remain below the WHO/UNEP threshold, confirming lower relative contamination. The observed ranking (P5 > P1 > P6 > P4 > P3 > P2) is consistent with the subtle variations. Fig. 4 effectively visualises the spatial heterogeneity of faecal pollution, clearly distinguishing highly impacted sites such as P1 and P3 from relatively less contaminated locations like P2 and P5.

Origin of faecal contamination of coastal waters: The distribution of CF/SF ratios (Table-4) provides insight into the origin of faecal contamination across the studied beaches. The results indicate that contamination is predominantly of human origin at most stations (P1, P2, P3 and P6), where the highest proportions correspond to human-derived inputs, reaching up to 66.67% at P1. The contributions from animal sources are present but comparatively lower, while mixed and indeterminate origins occur less frequently.

At stations P4 and P5, a more complex pattern is observed. Although human-origin contamination remains dominant (53.85% at P4 and 38.46% at P5), significant proportions of uncertain and mixed sources are also recorded. In particular, P5 exhibits contributions from all categories including animal and mixed human-dominated contamination indicating multiple and interacting pollution sources. These findings confirm that faecal pollution in the study area is largely anthropogenic. This is consistent with the known distribution of indicator bacteria, where faecal coliforms are typically associated with human waste, whereas faecal streptococci are more prevalent in animal sources. The dominance of human-derived contamination can be attributed to wastewater discharges, inadequate sanitation infrastructure and recreational activities. Bathers represent a direct source of microbial inputs through the release of biological materials, while indirect inputs arise from sewer overflows, poorly connected drainage systems, and urban runoff. Rainfall events are particularly influential, as they facilitate the transport of contaminants from terrestrial environments into coastal waters, leading to episodic increases in the microbial loads [5].

However, the CF/SF ratio approach has limitations, as environmental factors such as temperature, salinity and solar radiation can differentially affect bacterial survival and persistence [15]. Consequently, the inferred sources should be considered indicative rather than definitive. The results highlight a predominance of human-origin faecal contamination, with spatial variability reflecting the combined influence of anthropogenic activities and environmental processes. These findings underscore the need for improved wastewater management and monitoring strategies to mitigate contamination in coastal recreational waters.

Conclusion

This study evaluated the level and origin of faecal contamination in the coastal waters of Abidjan, Côte d'Ivoire, revealing significant deterioration in microbial water quality. Elevated concentrations of faecal coliforms and faecal streptococci were observed, with D90 values exceeding WHO/UNEP guideline limits at all sampling stations, indicating that the beaches are unsuitable for recreational use. Although *Clostridium perfringens* generally remained below threshold limits, its presence at significant levels suggests persistent background contamination. The CF/SF ratio analysis indicates that faecal pollution is predominantly of human origin, reflecting the impact of wastewater discharges, inadequate sanitation systems, and intensive human activities. Contributions from animal sources were also identified, highlighting the complexity of contamination pathways. Based on the results, it is concluded that all studied beaches were classified as poor in terms of bathing water quality, posing potential health risks to users. These findings emphasise the need for

TABLE-4
DISTRIBUTION OF CF/SF RATIO VALUES IN WATER CALCULATED FOR EACH STATION

Beaches	Mainly or entirely animal (%)	Mixed with animal predominance (%)	Uncertain or indeterminate (%)	Mixed with human predominance (%)	Mainly human (%)
P1	16.67	0	8.33	8.33	66.67
P2	23.08	0	15.38	15.38	46.15
P3	30.77	0	15.38	15.38	38.46
P4	15.38	0	30.77	0	53.85
P5	23.08	0	15.38	23.08	38.46
P6	27.27	18.18	8.09	8.09	36.36

improved wastewater management, effective control of urban runoff, and continuous monitoring of coastal water quality.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Ivorian Anti-Pollution Center (CIAPOL) for providing access to data and support which made this study possible.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

DECLARATION OF AI-ASSISTED TECHNOLOGIES

During the preparation of this manuscript, the authors used an AI-assisted tool(s) to improve the language. The authors reviewed and edited the content and take full responsibility for the published work.

REFERENCES

1. L. Lin, H. Yang and X. Xu, *Front. Environ. Sci*., **10**, 880246 (2022); https://doi.org/10.3389/fenvs.2022.880246
2. P.A.G.M. Scheren, C. Kroeze, F J.J.G. Janssen, L. Hordijk and K.J. Ptasinski, *J. Mar. Syst*., **44**, 1 (2004); https://doi.org/10.1016/j.jmarsys.2003.08.002
3. S.K. Akpo, P.J.M. Ouattara, M.G. Eba, S. Ouffouet and L. Coulibaly, *J. Mater. Environ. Sci.*, **7**, 621 (2016).
4. R.S. Fujioka, C.J. Hurst, G.R. Knudsen, M.J. McInerney, L.D. Stezenbach and M.V. Walter, Manual of Environmental Microbiology, ASM Press, Washington, D.C., pp. 176-183 (1997).
5. J.P.S. Cabral, *Int. J. Environ. Res. Public Health*, **7**, 3657 (2010); https://doi.org/10.3390/ijerph7103657
6. A. Prüss, *Int. J. Epidemiol*., **27**, 1 (1998); https://doi.org/10.1093/ije/27.1.1
7. D.F.R. Meless, Ph.D. Thesis in Pharmacy, Characterization of Bathing Waters in the Atlantic Ocean: Case of Vridi Beach and Port-Bouët Centre, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire, no. 1947/18, p. 129 (2018), (In French)
8. A. Giardino, R. Schrijvershof, C.M. Nederhoff, H. de Vroeg, C. Brière, P.-K. Tonnon, S. Caires, D.J. Walstra, J. Sosa, W. van Verseveld, J. Schellekens and C.J. Sloff, *Ocean Coast. Manag*., **156**, 249 (2018); https://doi.org/10.1016/j.ocecoaman.2017.09.019
9. O.S.K. Mananga, G.V. Akilinon, K.L. Kouamé and O.S. Yapo, *Res. J. Chem. Environ.*, **28**, 927 (2024).
10. M.E. Eissa, *Universal J. Pharmaceut. Res.*, **10**, 96 (2025).
11. AFNOR, Water Quality, Major Elements, Other Elements and Mineral Compounds, Aubenas, Ardèche, edn 6, p. 635 (2021) (In French).
12. WHO/UNEP, Guidelines for Sanitary Surveillance of Coastal Water Quality, Regional Office for Europe, Copenhagen, Denmark, p. 177 (1977).
13. A. Lanusse, Ph.D. thesis in Science, Microbial Contamination of a Tropical Lagoon (Ébrié Lagoon, Côte d'Ivoire). Influence of hydroclimate, Université de Provence (Aix-Marseille I), p. 147 (1987). (In French).
14. P. Dufour, *Hydrobiologia*, **94**, 105 (1982); https://doi.org/10.1007/BF00010889
15. A. Gansso Valentin, K. Mananga Olivier Simon, Y. Coulibaly and Y. Ossey Bernard, *Am. J. Environ. Prot.*, **12**, 15 (2024); https://doi.org/10.12691/env-12-2-1
16. A.M. Kouassi, D. Guiral and M. Dosso, *Rev. Hydrobiol. Trop.*, **23**, 181 (1990).
17. G.V. Akilinon, Ph.D. Dissertation in Environmental Science and Management and Risk of Eutrophication, Dynamics of Nutrient Inputs and Fecal Bacteria in the Estuarine Zone of Ébrié Lagoon (Côte d'Ivoire), Université Nangui Abrogoua, Abidjan, Côte d'Ivoire, No. 707, pp. 189 (2021).
18. A.F. Borrego and P. Romero, Study of the Microbiological Pollution of a Malaga Coastal Area II. Relationship between Faecal Coliforms and Faecal Streptococci, 6th Study Day on Pollution, Cannes, France, pp. 561-569 (1982).
19. A. Freddi, F. Ricci, M. Coci, S. Guicciardi, S. Casabianca, P. Penna, L. Bolognini, M. Marini, A. Penna and E. Manini, *Marine Pollut. Bull.*, **224**, 119156 (2026); https://doi.org/10.1016/j.marpolbul.2025.119156
20. Y. Pan and S. Lou, *Front. Marine Sci*., **10**, 1199807 (2023); https://doi.org/10.3389/fmars.2023.1199807