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BACTERIOLOGICAL QUALITY OF SAND AND BATHING WATER AT SIX BEACHES OF ILHA DE LUANDA (ANGOLA): FAECAL CONTAMINATION INDICATORS AND OCCURRENCE OF SALMONELLA

QUALIDADE BACTERIOLÓGICA DAS AREIAS E ÁGUAS BALNEARES DE SEIS PRAIAS DA ILHA DE LUANDA (ANGOLA): INDICADORES DE CONTAMINAÇÃO FECAL E OCORRÊNCIA DE SALMONELLA

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Abstract

Bathing-water surveillance focuses on the water column and underestimates sand contamination, sand being the matrix bathers touch most. This study assessed the bacteriological quality of dry sand, wet sand and water at six beaches of Ilha de Luanda, between August 2008 and April 2009, with 17 sampling events per matrix and per station (n = 306). This is a descriptive and analytical field study with a quantitative approach. Heterotrophic bacteria at 37 °C, total and thermotolerant coliforms, *Escherichia coli*, *Enterococcus spp.* and *Salmonella spp.* were determined following Angolan protocols NA-M-11, NA-M-13 and NA-M-14. Data were $\log_{10}$-transformed and analysed by two-way ANOVA (environment ×

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beach) with replication and by the Kruskal-Wallis test. Heterotrophic bacteria saturated the counting limit at every station (log_{10} CFU between 2.34 and 2.53). Thermotolerant coliforms and *E. coli* reached overall geometric means of 974 and 513 MPN/100 mL, and 83.2 % of dry-sand samples exceeded the 1,000 MPN/100 mL limit of Brazilian CONAMA Resolution 274/2000. *Salmonella spp.* was detected in 41.7 % of the samples (105/252). The beach effect was significant for every indicator ($p < 0.001$) and the environment effect for heterotrophs and coliforms, dry sand being the most contaminated compartment. All six beaches are unfit for bathing, which reflects the absence of sanitation and justifies making sand a mandatory component of national monitoring programmes.

Keywords: Bathing water quality, *Escherichia coli*, Public health, Salmonella, Thermotolerant coliforms.

Resumo

A vigilância da qualidade da água balnear concentra-se na coluna d'água e subestima a contaminação da areia, sendo esta a matriz com a qual os banhistas mais têm contato. Este estudo avaliou a qualidade bacteriológica da areia seca, da areia úmida e da água em seis praias da Ilha de Luanda, entre agosto de 2008 e abril de 2009, com 17 eventos de amostragem por matriz e por estação ($n = 306$). Trata-se de um estudo de campo descritivo e analítico com abordagem quantitativa. As bactérias heterotróficas a 37 °C, os coliformes totais e termotolerantes, *Escherichia coli*, *Enterococcus* spp. e *Salmonella* spp. foram determinados seguindo os protocolos angolanos NA-M-11, NA-M-13 e NA-M-14. Os dados foram transformados em log_{10} e analisados por meio de ANOVA de dois fatores (ambiente × praia) com replicação e pelo teste de Kruskal-Wallis. As bactérias heterotróficas atingiram o limite de contagem em todas as estações (log_{10} UFC entre 2,34 e 2,53). Os coliformes termotolerantes e a *E. coli* apresentaram médias geométricas globais de 974 e 513 NMP/100 mL, e 83,2% das amostras de areia seca ultrapassaram o limite de 1.000 NMP/100 mL estabelecido pela Resolução CONAMA 274/2000 do Brasil. *Salmonella* spp. foi detectada em 41,7% das amostras (105/252). O efeito da praia foi significativo para todos os indicadores ($p < 0,001$), assim como o efeito do ambiente para heterotróficos e coliformes, sendo a areia seca o compartimento mais contaminado. Todas as seis praias são impróprias para banho, o que reflete a ausência de saneamento e justifica a inclusão da areia como componente obrigatório nos programas nacionais de monitoramento.

Palavras-chave: Coliformes termotolerantes, *Escherichia coli*, Qualidade da água balnear, Salmonella, Saúde pública.

INTRODUCTION

Angola lies on the eastern margin of the South Atlantic Ocean and has a coastline of some 1,500 km dominated by long, gently sloping sandy beaches (Azevedo *et al.*, 1972). These beaches structure much of the country's socioeconomic life, serving at once as places of settlement and as hubs of tourism, leisure and recreation. Worldwide, the quality of sand and bathing water has become over recent decades an explicit criterion in the choice of a tourist destination and an integrated indicator of environmental and public health status (World Health Organization, 2021).

Both beach water and beach sand are potential reservoirs of microbial contamination of human origin, linked to poor solid-waste disposal, unplanned occupation of the shoreline, the absence of sewerage networks and the transport of waste by surface runoff and tides (Reinhart, 1980). Scientists and regulators historically concentrated on bathing water; the evidence gathered over the past two decades shows instead that sand is an equally critical compartment and, in many cases, more contaminated than the adjacent water column (Whitman *et al.*, 2014; Solo-Gabriele *et al.*, 2016). Alm, Burke and Spain (2003) showed that faecal indicator bacteria are abundant in wet sand, while earlier work had already pointed to dry sand (the strip bathers use most) as the most contaminated zone of the beach (Fernandes, 2002).

Recent literature has consolidated and deepened this understanding. Comprehensive reviews document that sand acts both as a reservoir and as a vehicle for enteric bacteria, viruses, protozoa and fungi, with faecal indicator concentrations that often exceed those of the adjacent water by one to three orders of magnitude (Whitman *et al.*, 2014; Solo-Gabriele *et al.*, 2016; Weiskerger *et al.*, 2019; King; Leonard, 2025). The explanation is ecological and physical: the sand matrix offers protection from ultraviolet radiation, adsorption surfaces, particulate organic matter and moisture gradients that favour persistence and, under certain conditions, the multiplication of indicators and pathogens (Whitman *et al.*, 2014; Weiskerger *et al.*, 2019). Yamahara *et al.* (2012), studying 53 beaches along the Californian coast, detected *Salmonella* at 15 % of the beaches and enterococci at 94 %, and showed experimentally that pathogens can persist in sand longer than the indicators themselves, being remobilised into the water during wetting and rough-sea episodes. Bolton *et al.* (1999) likewise isolated *Campylobacter* and *Salmonella* from bathing-beach sand, and several authors have argued for the systematic inclusion of microbiological sand screening in surveillance programmes (Sabino *et al.*, 2014; Brandão *et al.*, 2023).

The health relevance of this question is not merely theoretical. In a cohort study of 27,365 bathers at seven beaches, Heaney *et al.* (2009) showed that digging in sand is associated with a higher incidence of gastrointestinal illness, with stronger effects among those who buried themselves in the sand. The finding matters wherever children spend long periods in direct contact with sand, as they do on crowded African urban beaches.

Microbiological indicators fall into established groups, each with its own sanitary meaning. Heterotrophic bacteria at 37 °C express total microbial load and the availability of organic matter; total coliforms carry essentially environmental value; thermotolerant coliforms and, above all, *Escherichia coli* indicate recent faecal contamination; *Enterococcus spp.* complement the assessment in marine environments, being more salt tolerant and better correlated with gastrointestinal illness risk in coastal waters; and *Salmonella spp.*, unlike all the preceding groups, is not an indicator but a frank pathogen, whose detection signals direct risk of disease (Sanchez *et al.*, 1986; Mendes *et al.*, 1997; Mancini *et al.*, 2005; Sato *et al.*, 2005). Building on these indicators, national and international bodies have set bathing standards: Brazilian CONAMA Resolution 274/2000, which classifies waters as fit or unfit on the basis of thermotolerant coliforms, *E. coli* and enterococci (Conselho Nacional do Meio Ambiente, 2000); European Directive 76/160/EEC, with its guide values and mandatory values (Conselho das Comunidades Europeias, 1976), later repealed and replaced by Directive 2006/7/EC, which relies on percentiles of *E. coli* and intestinal enterococci and on bathing-water profiles (Parlamento Europeu; Conselho da União Europeia, 2006); and the World Health Organization guidelines (World Health Organization, 2003, 2021), put into practice through national surveillance programmes such as that of CETESB in São Paulo State (Companhia Ambiental do Estado de São Paulo, 2004). None of these instruments sets legally binding guide values for sand, a gap repeatedly noted in the literature (Solo-Gabriele *et al.*, 2016; Brandão *et al.*, 2023; King; Leonard, 2025).

Pressures on the shore are especially intense in tropical Atlantic regions. Akita *et al.* (2021), studying ten tropical Atlantic beaches in Ghana, recorded high mean total coliform loads (4.06×10^3 CFU/100 mL) and significant differences between beaches ($p = 0.024$), attributed to diffuse pollution sources. On the Cameroonian coast, Nana *et al.* (2023) showed that the spread of enteric parasites at the Kribi beaches is modulated by tides and seasonality, peaking at low tide and in the rainy season. Luanda presents an analogous and, in several respects, harsher picture: over recent decades, demographic expansion of the coastal zone has produced unplanned occupation, an absent sewerage network and direct dumping of waste into the sea and onto the sand (Morais; Torres; Martins, 2006). Pioneer studies at Agostinho Neto University and at the Fisheries Research Institute showed bacterial contamination in Luanda Bay and at some of its beaches (Cruz, 1993; Rocha, 2007), in line with what has been documented in other African coastal cities (David; Stretch, 2004); the microbiological quality of sand in Luanda and, to the best of our knowledge, elsewhere in the country, nonetheless remained uncharacterized.

Against this gap, the general aim of this work was to assess the hygienic and sanitary conditions of dry sand, wet sand and water at six beaches of Ilha de Luanda, using as indicators heterotrophic bacteria at 37 °C, total and thermotolerant coliforms, *E. coli*, *Enterococcus spp.* and *Salmonella spp.* The specific aims were to: (i) determine the frequencies and densities of the micro-organisms in the three matrices; (ii) compare the bacteriological quality of sand and bathing water; (iii) assess the degree of contamination and the sanitary status of each beach against international benchmarks; and (iv) test statistically the effects of environment type, location and their interaction on the degree of contamination. This is the first joint and systematic characterisation of beach sand and bathing water carried out in Angola, which grounds its relevance for the future definition of national guide values.

METHODOLOGY

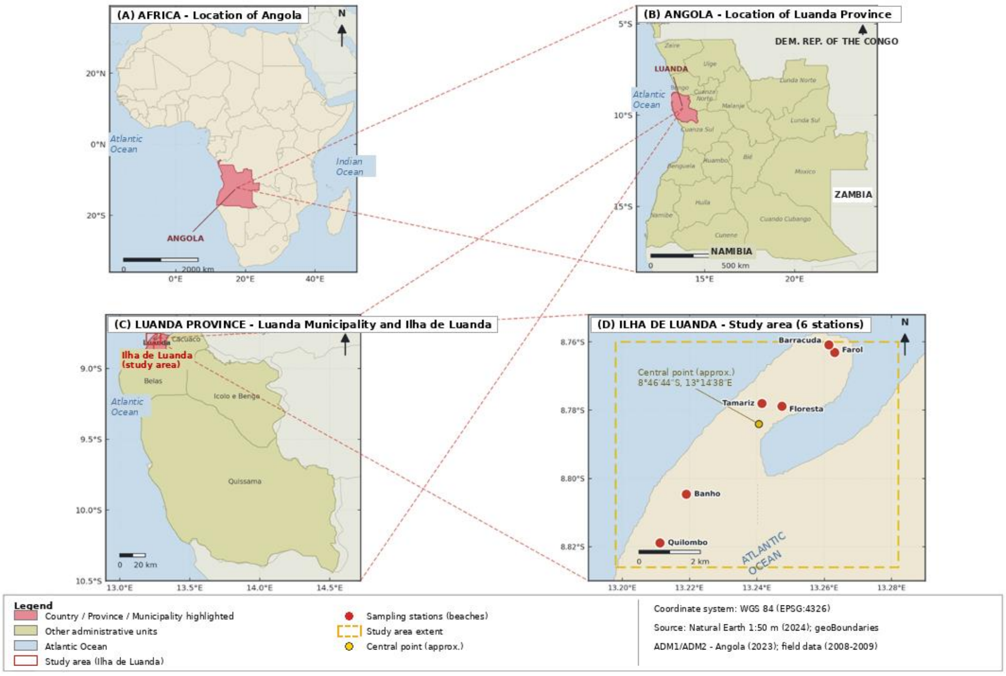
STUDY AREA

Ilha de Luanda, also known as Ilha do Cabo, is a sandy coastal spit with a low, straight shoreline, about 9,500 m long, joined to the mainland by an embankment (Cosme *et al.*, 1995). It lies in the central coastal belt of semi-arid climate, dry steppe climate with summer rains in the Köppen classification, with a mean annual temperature near 25 °C and annual rainfall between 300 and 360 mm, concentrated from January to May (Azevedo *et al.*, 1972; Diniz, 1973). The sea has semidiurnal tides of low amplitude (≈ 1 m) and predominantly swell waves; exceptional rough-sea episodes, locally called calemas, occur periodically and can remobilise sediment and alter the microbiological quality of sand and water. The district is densely occupied and its sanitation network is precarious or absent, with domestic waste deposited along the beaches and effluents discharged directly into the sea.

Six stations were selected, corresponding to six heavily used beaches: Floresta, Farol, Barracuda, Tamariz, Banho and Quilombo, located between Avenida Mortala Mohamed and Rua Massano de Amorim (Ilha de Luanda and Chicala). Each station was georeferenced with a GPS receiver (Garmin GPS 60) in the WGS 84 system (EPSG:4326). Figure 1 shows the spatial distribution of the stations. Field observations documented sharply contrasting sanitary conditions: Quilombo and Banho were very dirty, with faeces visible on the sand, sewage discharge and turbid or oily water, and precarious human occupation nearby; Barracuda was, by direct observation, the cleanest of the set. This visual gradation is an important key to reading the microbiological results.

Figure 1

Location of the study area. (A) African continent, highlighting Angola; (B) Angola and Luanda Province; (C) Luanda Province, Luanda Municipality and Ilha de Luanda (study area); (D) the six sampling stations on Ilha de Luanda, with actual GPS coordinates. Coordinate system WGS 84 (EPSG:4326).



Source: Prepared by the authors (2026).

SAMPLING DESIGN

The study followed a crossed factorial design with two fixed factors: environment, at three levels (dry sand, wet sand and water), and beach, at six levels. In each of the 18 cells of the design (3 environments × 6 beaches), 17 sampling events were carried out between August and November 2008 and between March and April 2009, totalling 306 samples. The scheme covers the dry season (cacimbo) and the start of the rainy season, capturing the temporal variability of the system without having been sized for a formal test of seasonality. For *Salmonella*, expressed as presence/absence, 14 sampling events per cell were considered valid (n = 252).

SAMPLE COLLECTION AND TRANSPORT

Samples were collected in the morning, between 06:00 and 08:00, at low tide, to standardise sampling conditions and to minimise the variability associated with the tidal cycle, which is known to govern the dispersion of faecal indicators on tropical beaches (Nana *et al.*, 2023). Three sample types were taken at each station: dry sand, from the supralittoral zone not reached by the tide; wet sand, from the intermediate strip influenced by the tide; and water.

Sand was collected as a composite sample, in line with good practice described for bathing-sand monitoring (Sabino *et al.*, 2014; Brandão *et al.*, 2023): a transect parallel to the shoreline was defined and subdivided into three equidistant points, from which subsamples of the surface layer down to 5–15 cm depth were taken and then homogenised to make up 250 g in sterile bags. Water was collected against the tidal current, 30 cm below the surface, at a point about 80 cm deep, into sterile 500 mL polyethylene bottles. All samples were labelled, packed in a refrigerated cool box and transported to the Microbiology Laboratory of the Department of Biology, Faculty of Natural Sciences, Agostinho Neto University, where they were processed within 6 h of collection.

MICROBIOLOGICAL ANALYSES

Analyses followed Angolan Protocols NA-M-13 (mesophilic aerobic micro-organisms), NA-M-14 (coliforms) and NA-M-11 (*Salmonella*) (Instituto Angolano de Normalização e Qualidade, [n. d.]) and the corresponding international standards (International Organization for Standardization, 2000, 2013, 2017a, 2017b), complemented by the reference methods for the examination of water (American Public Health Association; American Water Works Association; Water Environment Federation, 2005). From each sand sample, 50 g were washed in 50 mL of sterile distilled water, and decimal dilutions (10^{-1} to 10^{-3}) were then prepared in buffered peptone water; water samples were diluted in the same way from the original volume.

Heterotrophic bacteria at 37 °C were enumerated by the pour plate technique on Plate Count Agar, incubated at 37 °C for 24–48 h, counting only plates with 30 to 300 colony-forming units (CFU). Total and thermotolerant coliforms were determined by the multiple-tube technique, with the most probable number (MPN/100 mL) calculated from the McCrady table (McCrady, 1915). *E. coli* was confirmed by growth in EC broth at 44.5 °C, isolation on eosin-methylene blue (Levine) agar and the IMViC biochemical series (indole, methyl red, Voges-Proskauer and Simmons citrate). *Enterococcus spp.* were screened in azide-dextrose broth as a presumptive test and confirmed on selective Pfizer agar (Boehm; Sassoubre, 2014). *Salmonella spp.* was investigated by non-selective pre-enrichment in buffered peptone water, selective enrichment in Rappaport-Vassiliadis broth, isolation on *Salmonella*-Shigella agar and biochemical identification, the result being expressed as presence or absence in 100 mL of water or 50 g of sand. Negative medium and diluent controls were processed in every analytical series.

DATA TREATMENT AND STATISTICAL ANALYSIS

Data were $\log_{10}$-transformed before analysis, the usual procedure for microbial densities, which are strongly right-skewed. Coliform and *E. coli* densities above the upper limit of the McCrady table (> 2,400 MPN/100 mL) were treated as right-censored and replaced by the limit itself (2,400 MPN/100 mL; $\log_{10} = 3.38$), a conservative choice that underestimates, and never overestimates, the true degree of contamination.

For each indicator, a two-way ANOVA with replication was applied, considering environment (three levels), beach (six levels) and their interaction. Because the data are censored and contain many ties, which partly compromises the assumptions of normality and homoscedasticity, the results were confirmed by the non-parametric Kruskal-Wallis test applied separately to each factor. Central densities were expressed as geometric means, the measure suited to log-normal distributions and adopted by the bathing standards (Conselho Nacional do Meio Ambiente, 2000; Parlamento Europeu; Conselho da União Europeia, 2006). A significance level of 5 % was adopted. All calculations were performed in MS Excel.

Bathing quality was judged against CONAMA Resolution 274/2000 (Conselho Nacional do Meio Ambiente, 2000) and the values of Directive 76/160/EEC (Conselho das Comunidades Europeias, 1976), these being the benchmarks historically used in comparable studies of beach sand and bathing water (Sanchez *et al.*, 1986; Mendes *et al.*, 1997; Companhia Ambiental do Estado de São Paulo, 2004; Sato *et al.*, 2005).

RESULTS AND DISCUSSION

OVERALL PICTURE OF CONTAMINATION

Taken together, the indicators revealed widespread and intense faecal contamination at all six beaches. Overall geometric means were 959 MPN/100 mL for total coliforms, 974 MPN/100 mL for thermotolerant coliforms and 513 MPN/100 mL for *E. coli*; *Salmonella spp.*, a pathogen, not a mere indicator, was present in 41.7 % of the samples. Table 1 summarises densities by beach and environment, and Figure 7 shows the gradient between matrices. These levels are of the same order of magnitude as, or higher than, those reported by Akita *et al.* (2021) for tropical Atlantic beaches and reflect the direct input of domestic sewage, consistent with the absence of sanitation observed in the field.

Table 1

Bacterial densities by beach and environment: mean $\log_{10}$ (CFU) of heterotrophic bacteria at 37 °C and geometric means (MPN/100 mL) of total coliforms, thermotolerant coliforms and E. coli (17 sampling events per cell).

Beach	Environment	Heterotrophs ($\log_{10}$ CFU)	Total coliforms	Thermotolerant coliforms	*E. coli*
Floresta	Dry sand	2.53	1,822	1,822	1,881
	Wet sand	2.43	1,741	1,741	1,465
	Water	2.47	1,741	1,741	1,465
Farol	Dry sand	2.52	1,047	699	399
	Wet sand	2.43	613	497	309
	Water	2.43	616	435	283
Barracuda	Dry sand	2.50	419	456	173
	Wet sand	2.38	403	255	236
	Water	2.35	440	215	132
Tamariz	Dry sand	2.47	1,455	1,330	600
	Wet sand	2.34	774	532	273
	Water	2.35	283	270	142
Banho	Dry sand	2.52	1,500	2,400	291
	Wet sand	2.45	1,508	2,400	268
	Water	2.44	459	2,400	571
Quilombo	Dry sand	2.52	2,400	2,400	2,177
	Wet sand	2.51	2,400	2,400	2,177
	Water	2.53	1,523	2,292	2,286

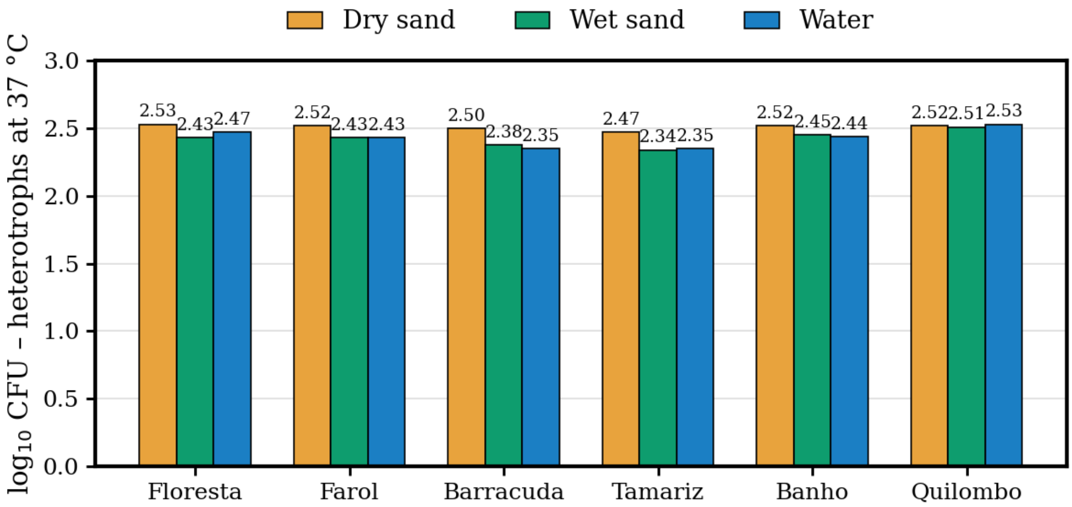
Source: Prepared by the authors (2026). Values equal to 2,400 MPN/100 mL correspond to saturation of the upper limit of the McCrady table and should be read as minimum estimates.

HETEROTROPHIC BACTERIA AT 37 °C

In practically every sample, heterotrophic bacteria reached the upper counting limit considered valid (30–300 CFU per plate), with $\log_{10}$ means between 2.34 and 2.53 (Figure 2). The high and uniform heterotrophic load confirms intense microbial activity across the island and is consistent with a constant input of organic matter. Method saturation limits the power of this indicator to discriminate between stations; even so, the ANOVA detected a significant effect of environment ($F = 25.43$; $p < 0.001$) and of beach ($F = 12.52$; $p < 0.001$), dry sand showing the highest counts, a pattern confirmed by the Kruskal-Wallis test (environment: $p < 0.001$). The result agrees with the characterisation of dry sand as a microbial habitat with conditions favourable to persistence and growth, described in detail by Whitman *et al.* (2014).

Figure 2

Heterotrophic bacteria at 37 °C (log₁₀ CFU) in dry sand, wet sand and water at the six beaches. Bars: mean; segments: standard deviation.



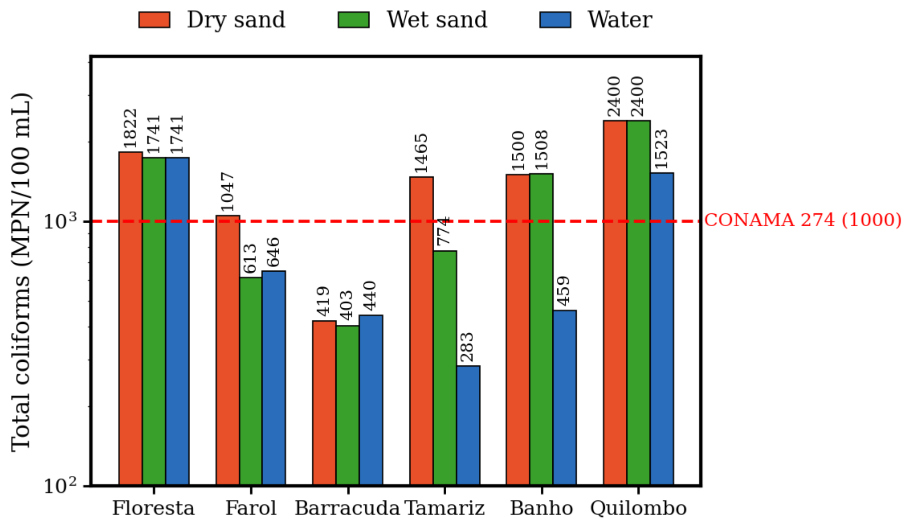
Source: Prepared by the authors (2026).

TOTAL AND THERMOTOLERANT COLIFORMS

Total and thermotolerant coliforms were high at every station (Figures 3 and 4). For thermotolerant coliforms, the indicator of recent faecal contamination, geometric means by beach ranged from 292 MPN/100 mL at Barracuda to 2,400 MPN/100 mL at Banho, followed by Quilombo (2,364 MPN/100 mL) and Floresta (1,767 MPN/100 mL). At Banho and Quilombo, almost every sample saturated the detection limit (> 2,400 MPN/100 mL), so the values reported should be read as minimum estimates of the real contamination. Barracuda, visually the cleanest, consistently recorded the lowest densities. This spatial hierarchy reproduces the sanitary state observed in the field and is consistent with the strong beach effect obtained in the ANOVA ($F = 24.62$; $p < 0.001$; Kruskal-Wallis: $p < 0.001$).

Figure 3

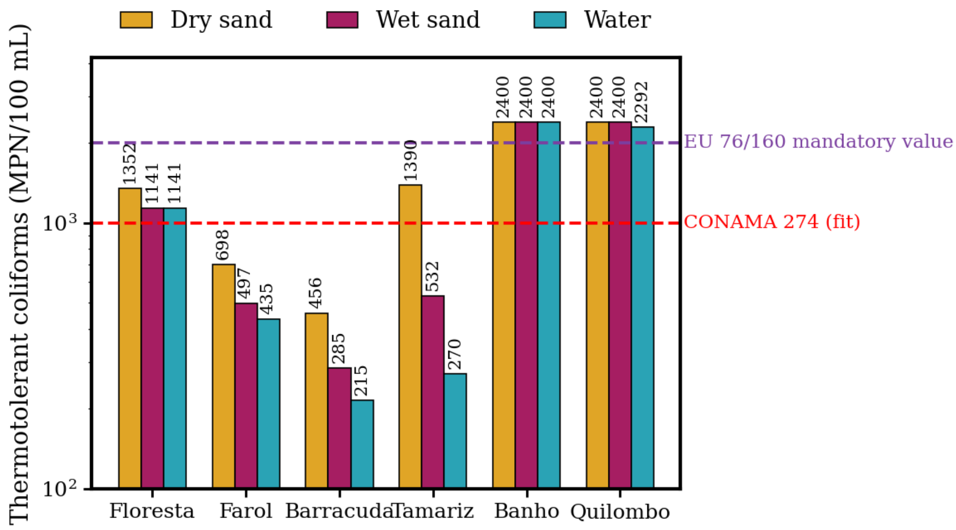
Total coliforms (MPN/100 mL, geometric mean) by beach and environment. Dashed line: limit of 1,000 MPN/100 mL (CONAMA 274/2000). Logarithmic scale.



Source: Prepared by the authors (2026).

Figure 4

Thermotolerant coliforms (MPN/100 mL, geometric mean) by beach and environment, with the limits of CONAMA Resolution 274/2000 (fit ≤ 1,000 MPN/100 mL) and the mandatory value of Directive 76/160/EEC (2,000 MPN/100 mL). Logarithmic scale.



Source: Prepared by the authors (2026).

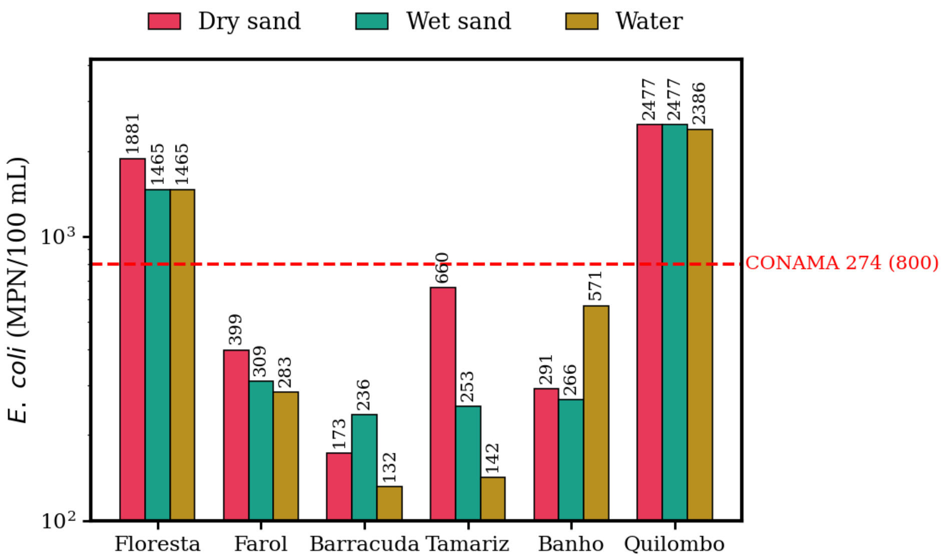
By environment, a decreasing gradient was observed from dry sand through wet sand to water (thermotolerant coliforms: 1,274, 928 and 781 MPN/100 mL, respectively), statistically significant for total coliforms ($p = 0.006$) and for thermotolerant coliforms ($p = 0.024$). The greater contamination of sand, especially dry sand, the most used strip and the one where dermal contact and accidental ingestion are most likely, corroborates the observations of Fernandes (2002) and Alm, Burke and Spain (2003) and the syntheses of Solo-Gabriele *et al.* (2016), Weiskerger *et al.* (2019) and King and Leonard (2025), which describe sand as a reservoir where faecal indicators accumulate and persist, reaching concentrations above those of the water. The environment × beach interaction was not significant ($p = 0.439$), indicating that the gradient between matrices holds broadly across stations.

ESCHERICHIA COLI

E. coli, the most specific faecal indicator, confirmed the pattern of thermotolerant coliforms. Geometric means by beach ranged from 175 MPN/100 mL at Barracuda to 2,213 MPN/100 mL at Quilombo, with Floresta (1,592 MPN/100 mL) also standing out as heavily contaminated (Figure 5). The beach effect was highly significant ($F = 24.37$; $p < 0.001$; Kruskal-Wallis: $p < 0.001$). Unlike the coliforms, the environment effect was not significant for *E. coli* ($p = 0.441$): the bacterium was distributed similarly between sand and water, which fits the inconsistent gradient between beach zones noted by King and Leonard (2025) and supports the hypothesis of diffuse, ubiquitous contamination fed by several local sources at once. Of the presumptive cultures, 95.8 % were confirmed as *E. coli* by biochemical tests, validating the faecal origin of the contamination and reducing the chance of overestimation by coliforms of environmental origin.

Figure 5

Escherichia coli (MPN/100 mL, geometric mean) by beach and environment, with the 800 MPN/100 mL limit of CONAMA Resolution 274/2000. Logarithmic scale.



Source: Prepared by the authors (2026).

OCCURRENCE OF *SALMONELLA SPP*.

The detection of *Salmonella spp.* is the most important sanitary result of this work, since it concerns a pathogen and not an indicator. Across all samples, *Salmonella* was present in 41.7 % (105/252), with frequencies by environment of 41.7 % in dry sand, 38.1 % in wet sand and 45.2 % in water (Table 2; Figure 6). Banho and Quilombo stood out with the highest frequencies (up to 64.3 % in the dry sand at Banho) whereas Floresta recorded the lowest overall values (23.8 %).

Table 2

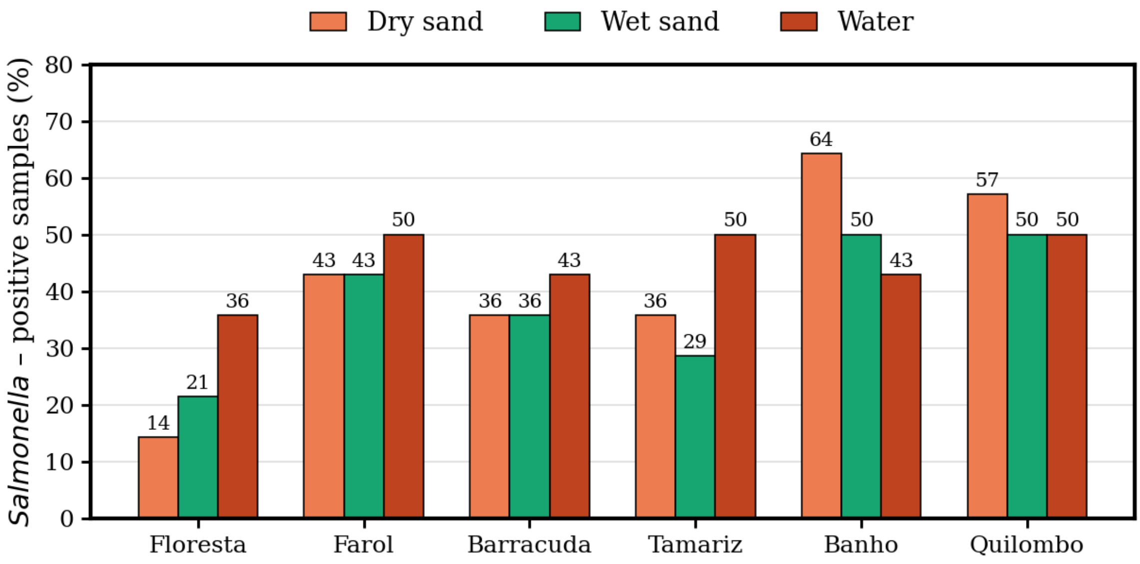
Frequency of samples positive for Salmonella spp. (%), by beach and environment (n = 14 valid sampling events per cell).

Beach	Dry sand	Wet sand	Water	Beach (overall)
Floresta	14.3	21.4	35.7	23.8
Farol	42.9	42.9	50.0	45.2
Barracuda	35.7	35.7	42.9	38.1
Tamariz	35.7	28.6	50.0	38.1
Banho	64.3	50.0	42.9	52.4
Quilombo	57.1	50.0	50.0	52.4
Overall	41.7	38.1	45.2	41.7

Source: Prepared by the authors (2026). Values expressed as a percentage of positive samples; total n = 252.

Figure 6

Percentage of samples positive for Salmonella spp. in dry sand, wet sand and water at the six beaches.



Source: Prepared by the authors (2026).

This prevalence is far above the 15 % of positive beaches reported by Yamahara *et al.* (2012) in California and is consistent in nature, though not in magnitude, with the isolations of *Salmonella* from bathing sand described by Bolton *et al.* (1999) and Sabino *et al.* (2014). The difference in magnitude follows from context: whereas contamination at Californian beaches stems mainly from diffuse sources and treated urban runoff, Ilha de Luanda receives untreated domestic sewage directly. That the detection frequency is slightly higher in water (45.2 %) than in sand, contrary to the quantitative indicators, fits the binary nature of the presence/absence method, which saturates quickly under intense contamination, and the remobilisation of pathogens between sand and the water column described by Yamahara *et al.* (2012) and Weiskerger *et al.* (2019). In any case, the detection of *Salmonella* in about two of every five samples confirms that sand acts as a reservoir of enteric pathogens, with direct implications for bathers' health (Heaney *et al.*, 2009; King; Leonard, 2025).

EFFECTS OF ENVIRONMENT AND BEACH: ANALYSIS OF VARIANCE

The two-way analysis of variance (Table 3) showed, consistently across indicators, that beach, that is, location and the contamination sources specific to it, is the dominant factor explaining the variability of contamination ($p < 0.001$ in every case), while environment exerts a secondary but real effect on heterotrophic bacteria and on total and thermotolerant coliforms. The absence of a significant interaction in every model indicates that the gradient between matrices cuts across beaches, that is, that dry sand tends to be the most contaminated compartment whichever station is considered. The Kruskal-Wallis test yielded the same conclusions, which lends robustness to the inference despite the censored nature of the data. The one notable divergence concerns the effect of environment on thermotolerant coliforms, significant in the ANOVA ($p = 0.024$) but only marginal in the non-parametric test ($p = 0.085$), which follows from the loss of power associated with the many ties among censored values.

Table 3

Two-way ANOVA (environment × beach, with replication) on log-transformed data and p-values of the Kruskal-Wallis test for the environment and beach effects. df = degrees of freedom of the effect.

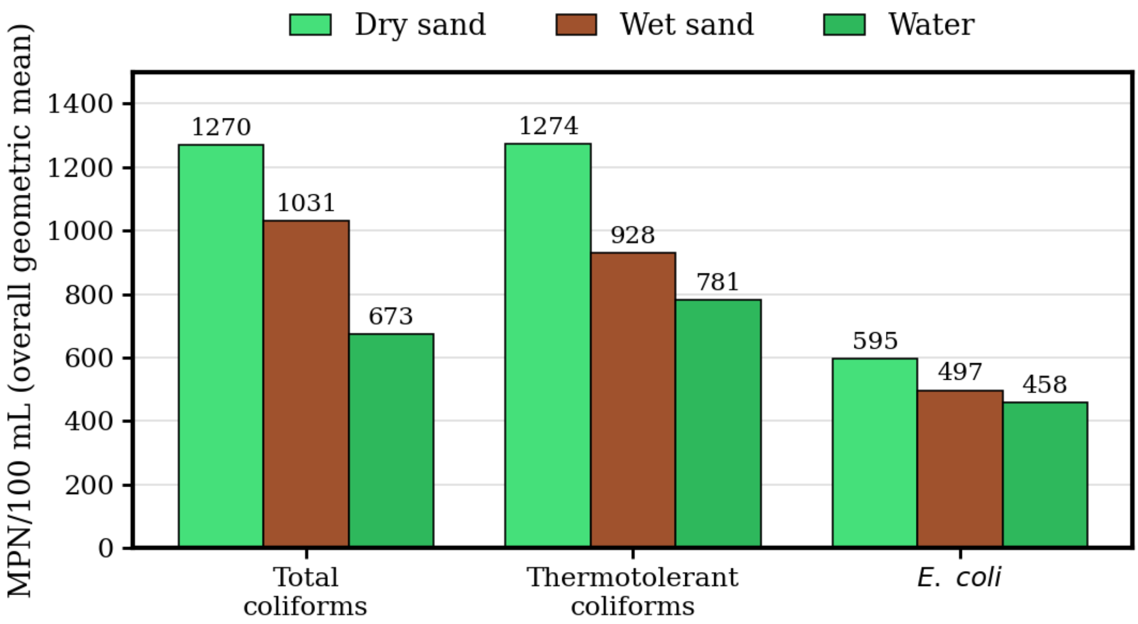
Parameter	Effect	df	F	p (ANOVA)	p (Kruskal-Wallis)
Heterotrophs at 37 °C	Environment	2	25.43	< 0.001	< 0.001
	Beach	5	12.52	< 0.001	< 0.001
	Environment × Beach	10	1.55	0.122	—
Total coliforms	Environment	2	5.29	0.006	0.014
	Beach	5	9.26	< 0.001	< 0.001
	Environment × Beach	10	1.17	0.314	—
Thermotolerant coliforms	Environment	2	3.77	0.024	0.085
	Beach	5	24.62	< 0.001	< 0.001
	Environment × Beach	10	1.01	0.439	—
E. coli	Environment	2	0.82	0.441	0.575
	Beach	5	24.37	< 0.001	< 0.001
	Environment × Beach	10	1.13	0.341	—

Source: Prepared by the authors (2026). The Kruskal-Wallis test was applied separately to each factor and therefore yields no p-value for the interaction.

For management, the result carries two direct operational implications. First, contamination is driven mainly by the local sewage sources of each beach, so corrective action should be directed at station level rather than at the island as a whole. Second, sand, dry sand above all, should be included in routine monitoring, as recommended by Sabino *et al.* (2014), Brandão *et al.* (2023) and King and Leonard (2025), lest the surveillance system systematically underestimate the real exposure of bathers.

Figure 7

Contamination gradient between matrices: overall geometric means (MPN/100 mL) of total coliforms, thermotolerant coliforms and E. coli in dry sand, wet sand and water.



Source: Prepared by the authors (2026).

SANITARY CLASSIFICATION AND PUBLIC HEALTH IMPLICATIONS

Measured against bathing standards, the six beaches fail systematically. For thermotolerant coliforms, 83.2 % of dry-sand samples, 75.2 % of wet-sand samples and 71.3 % of water samples exceeded the 1,000 MPN/100 mL limit of CONAMA Resolution 274/2000 (Conselho Nacional do Meio Ambiente, 2000). For *E. coli*, 61.2 % of dry-sand samples exceeded the 800 MPN/100 mL limit. Taking CONAMA Resolution 274/2000, Directive 76/160/EEC (Conselho das Comunidades Europeias, 1976) and the recurrent presence of *Salmonella spp.* together, all stations must be classified as unfit for bathing (Table 4). This classification, based on 2008–2009 data, aligns with the contamination diagnoses for the

Luanda shoreline produced by Cruz (1993) and Rocha (2007) and with the picture of anthropogenic pressure described by Morais, Torres and Martins (2006).

Table 4

Sanitary summary by beach: geometric means (MPN/100 mL) of thermotolerant coliforms and E. coli, frequency of Salmonella spp. and bathing classification according to CONAMA Resolution 274/2000 and Directive 76/160/EEC.

Beach	Thermotolerant coliforms (MPN/100 mL)	*E. coli* (MPN/100 mL)	*Salmonella spp.* (% positive)	Classification
Floresta	1,767	1,592	23.8	Unfit
Farol	532	327	45.2	Unfit
Barracuda	292	175	38.1	Unfit
Tamariz	576	285	38.1	Unfit
Banho	2,400	356	52.4	Unfit
Quilombo	2,364	2,213	52.4	Unfit

Source: Prepared by the authors (2026). Geometric means across the three matrices, additionally considering the recurrent detection of *Salmonella spp.*

Translating these numbers into health terms is not trivial. The available epidemiological evidence links contact with contaminated sand, digging and burial in particular, both common among children, to a higher risk of gastrointestinal illness (Heaney *et al.*, 2009). Where *Salmonella spp.* was detected in 41.7 % of samples and dry sand concentrates the highest densities of faecal indicators, exposure of the bathing population of Ilha de Luanda must be considered high. Moreover, surveillance based solely on water, as prescribed by the regulatory instruments in force (Conselho Nacional do Meio Ambiente, 2000; Parlamento Europeu; Conselho da União Europeia, 2006), would in this case underestimate contamination of the most used matrix, a situation the literature has flagged as a structural gap in bathing-quality programmes (Solo-Gabriele *et al.*, 2016; Brandão *et al.*, 2023; King; Leonard, 2025).

CONCLUSION

This work is the first joint characterisation of the bacteriological quality of beach sand and bathing water on Ilha de Luanda, Angola, and it answers the four specific aims set out in the introduction. Heterotrophic bacteria, total and thermotolerant coliforms and *E. coli* were high at all six stations, and

Salmonella spp., a pathogen, was detected in 41.7 % of the samples, confirming intense and ubiquitous faecal contamination. The microbiological results showed no enterococci in the samples analysed, within the detection limit of the method.

The statistical analysis showed that location is the main determinant of contamination ($p < 0.001$ for every indicator), with Quilombo, Banho and Floresta presenting the highest pollution levels and Barracuda the lowest, in direct agreement with the sanitary conditions observed in the field. Environment type significantly influenced the densities of heterotrophic bacteria and of total and thermotolerant coliforms, dry sand (the strip bathers use most) proving to be the most contaminated compartment. *E. coli*, by contrast, was distributed evenly between sand and water, with no statistically relevant differences between compartments. The absence of a significant interaction between beach and environment indicates that the contamination pattern across matrices remains consistent over the stations sampled.

Against CONAMA Resolution 274/2000 and Directive 76/160/EEC, the six beaches are unfit for bathing. The following measures are therefore recommended: (i) implementing basic sanitation and intercepting the sewage discharged directly onto the sand and into the sea, the measure of greatest expected impact given the predominance of the beach effect over the environment effect; (ii) establishing a periodic and systematic monitoring programme covering sand, dry sand in particular, alongside water; (iii) adopting national bathing guide values for water and sand, currently absent in Angola; and (iv) environmental education and signposting of unfit beaches, to protect the health of the populations that use them. The main limitation is saturation of the upper limit of the counting techniques, which prevents quantifying the real contamination at the most polluted stations. Replicating this campaign with *Salmonella* serotyping, antimicrobial resistance assessment and molecular source tracking is the natural way to extend this line of research.

Table 5

Nomenclature and abbreviations

Abbreviation	Meaning
ANOVA	Analysis of variance
APHA	American Public Health Association
CETESB	Environmental Company of the State of São Paulo (Brazil)
CONAMA	National Environment Council (Brazil)
EC	EC broth, selective medium for thermotolerant coliforms and *E. coli*
EMB	Eosin-methylene blue agar (Levine)
EPSG	European Petroleum Survey Group (coordinate reference system code)
df	Degrees of freedom
GPS	Global Positioning System
IMViC	Indole, methyl red, Voges-Proskauer and Simmons citrate
ISO	International Organization for Standardization
NA-M	Angolan Microbiology Standard
NMP	Most probable number (multiple-tube technique)
PCA	Plate Count Agar
SS	*Salmonella*-Shigella agar
UAN	Agostinho Neto University (Luanda, Angola)
UFC	Colony-forming units
VMA	Mandatory value (Directive 76/160/EEC)
VMR	Guide value (Directive 76/160/EEC)
WGS 84	World Geodetic System 1984
WHO	World Health Organization

Source: Prepared by the authors (2026).

AUTHOR CONTRIBUTIONS

P. G. Gonçalves: conceptualisation, investigation, data curation and writing of the original draft. H. S. Chipaca Domingos and C. Kiangebeni Zeye: methodology and investigation. K. Luís: validation and formal analysis. M. V. Soqui and M. A. Kiony Nzinga: conceptualisation, formal analysis, supervision, writing, review and editing. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no financial or personal conflict of interest that could have influenced the work reported here.

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