Original Research

Evaluating Nahoon Beach and Canal Waters in Eastern Cape, South Africa: A Public Health Concern

Kingsley Ebomah[1]*, Timothy Sibanda[2], Martins Adefisoye[1], Nolonwabo Nontongana[1], Uchechukwu Nwodo[1], Anthony Okoh[1]

[1]SAMRC Microbial Water Quality Monitoring Centre, University of Fort Hare, Alice, South Africa
[2]Department of Environmental Science, UNISA Florida Campus, Roodepoort, South Africa

Abstract

Contamination of water resources by pathogens due to ever increasing anthropogenic activities and the related disease burden remains a major concern of water quality globally. This study evaluated the physicochemical and microbiological quality indices of Nahoon Beach and its canal waters in South Africa over a period of 12 months (September 2014 to August 2015). Water samples were collected bi-weekly from 6 sampling points (3 on the beach and 3 on the canal) and analyzed using standard methods. The physicochemical qualities of the beach and canal waters ranged as follows: turbidity 3.3-99.9 NTU, temperature 15-25ºC, pH 7-10, electrical conductivity 30.0–741.7 µS/cm, and total dissolved solids 19-546 mg/l. As for microbial counts of the water samples, *Escherichia coli* counts ranged in the order of 10^1-10^3 CFU/100 ml while *Enterococcus* counts varied in the order of 10^1-10^2 CFU/100 ml. This study underscores the need for the protection of recreational water resources to safeguard public health.

Keywords: beach, microbiological, physicochemical, pollution, public health

Introduction

Limited and full contact recreational activities are popular in marine beaches in South Africa and elsewhere in the world. There are growing public health concerns that such contact recreational activities are leading to increasing incidents of the outbreak of swimming-related illness associated with exposure to microbial pathogens [1]. Marine recreational beaches get contaminated with microbial pathogens and parasites like viruses, bacteria, fungi, and protozoa through both point-source inputs such as sewage outfalls and nonpoint source inputs such as human bather shedding, sand resuspension, and stormwater runoff [2]. Most Western nations have enacted legislation that requires proactive monitoring of beach and water quality as a way of reducing the incidents of swimming-related illnesses [3], a move that has often resulted in public health advisories and beach closures owing to the detection of high levels of faecal indicator bacteria and/or dangerously high levels of heavy metals.

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*e-mail: kingsleyebomah.ke@gmail.com

The situation is usually different and worrisome in developing countries, where a combination of budgetary constraints and frail institutions result in the absence of surveillance schemes, allowing undetected pollution from stormwater runoff and domestic sewage and industrial effluent discharges to enter beaches. Of particular concern is the possibility of direct discharge of domestic sewage and industrial effluents into beaches, coupled with the absence of early warning systems to warn the public on the safety status of said beaches [3]. The greatest risks posed to swimmers are associated with accidental ingestion of water contaminated with enteric pathogens, the most common source of which is the discharge of wastewater contaminated with human or animal faeces [4]. Enterococci are one important member of the microbial gut communities of many animals whose abundance in human faeces coupled with their ease of growth in culture, greater salt tolerance than faecal coliforms, and correlation with human health outcomes in fresh and marine waters have led to their widespread use not only as tools for assessing recreational water quality but also as surrogates for pathogens and/or health effects in risk assessment and other modeling applications worldwide [5]. In addition to enterococci, *E. coli* is still widely used as a microbial water quality monitoring tool, especially where gastrointestinal pathogens are targeted [6-7].

Given the fundamental socio-economic role that recreational beaches play, it is important that the quality indices of beach waters are periodically determined with respect to their public health connotations. Epidemiological studies have established a relationship between surface water recreational activities such as swimming and boating and gastrointestinal illness, even though the severity of illness tends to vary across demographic characteristics, level of contamination, exposure intensity, and host susceptibility [8]. Because of the popularity of beaches with all population subgroups – including sensitive population groups such as the elderly, minor children, pregnant women, and the immunocompromised, who are more likely to succumb to infection if they come into contact with pathogen-contaminated water – there is need for beach water quality surveillance to include quantitative microbial risk assessment (QMRA) estimations. A study by Deflorio-Barker et al. [8] reported that acute gastrointestinal infections associated with recreating in marine water translated into higher hospital bills and higher numbers of working-age adults missing work than those reported for freshwater recreationists.

South Africa is endowed with recreational beaches on its Indian and Atlantic Ocean interfaces. On the Indian Ocean interface, one of the notable recreational beaches is Nahoon Beach, which is located in East London in the Eastern Cape Province of South Africa. This beach is an important resource for commercial activities such as fishing, recreational tourism, and water sport. A previous study by Igbinosa et al. [9] reported the presence of *Vibrio* species in treated final effluent being discharged by wastewater treatment facilities into the Indian Ocean between Nahoon and Eastern Beach, both in East London. Subsequent studies [10-12] also reported the isolation of *Streptomyces* spp. from the Nahoon Beach waters. In April 2013 there were reports of closure of Nahoon, which according to Schleyer [13]
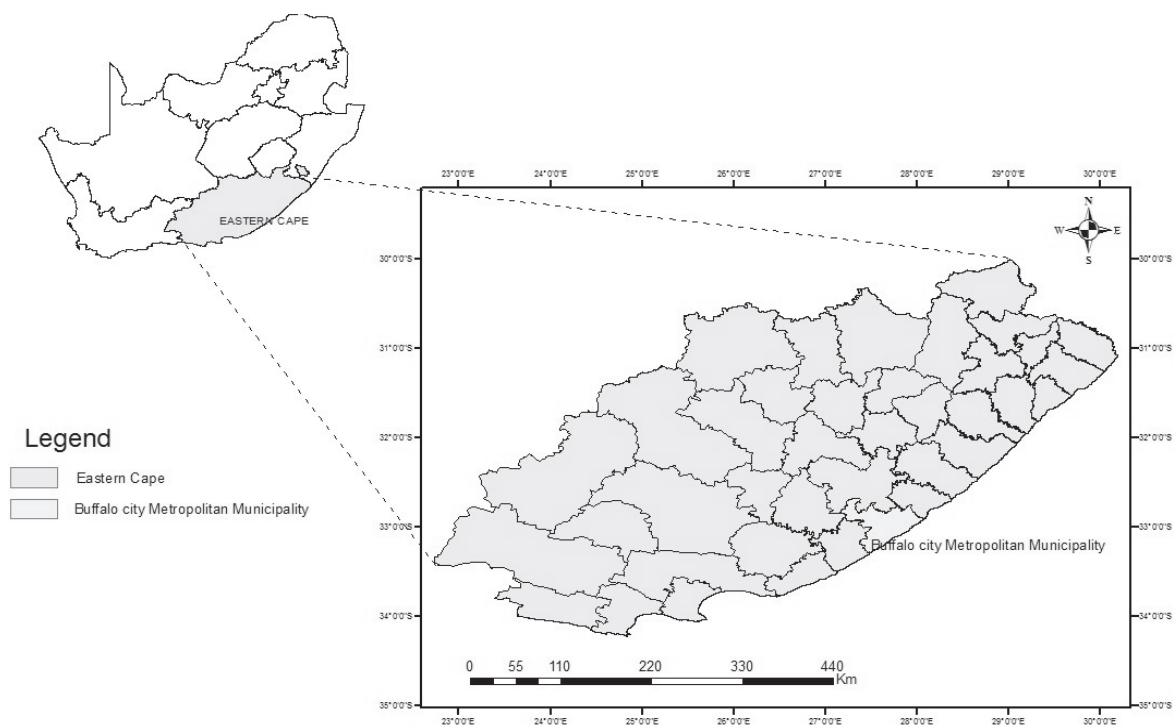

Fig. 1. Location of the study site.

was due to beach water contamination from sewage outfalls. However, there is lack of consistency in the monitoring of beach water quality, leading to inadequate baseline information which may make it difficult to use predictive models in the future. In this paper, we report on the physicochemical and microbiological qualities of Nahoon Beach and its canal because, according to an article by Writer [14], although South Africa was awarded a rating of 58 blue flag status sites, Nahoon beach did not meet the standards (*businesstech.co.za*). Additionally, this paper reports on the estimated risk of infection to contact recreationists in Nahoon Beach and evaluates the perceived public health associated with recreational activity along the beach.

Material and Methods

Description of Study Site

Nahoon beach is situated in East London of Buffalo City Metropolitan Municipality in Eastern Cape, South Africa on the coast of the Indian Ocean (32.99°S and 27.95°E). Nahoon canal is an extension of the Nahoon River, which flows into the beach. Nahoon beach boasts kilometres of mostly uncrowded and unpolluted sand and sea that produces some of the best waves, making it attractive to swimmers and surfers alike. Its reef provides fairly tough surfing conditions and has been preferred as a venue for many of the national surfing competitions. Complementing it is the Nahoon River mouth, a favourite location for fishermen and a safe swimming area for those who want to avoid pounding surf. Fig. 1 is a map showing Buffalo City Metropolitan Municipality in the Eastern Cape, South Africa.

However, final effluents from the East Bank Reclamation Works (sited in East London, South Africa), are released into the Indian Ocean at Bats Cave, which is in the middle of Nahoon and Eastern beach, with potential for these effluents to be spread by wave action onto both beaches.

Sample Collection

Triplicate water samples were collected fortnightly at knee depth using sterile 1 L bottles from 6 sampling points comprising 3 points each from the beach and the canal over a 12-month sampling period. The samples were immediately chilled by placing them in cooler boxes containing ice, transported to the Applied and Environmental Microbiology Research Group (AEMREG) Laboratory at the University of Fort Hare (Alice Campus), and analyzed within 6 h of collection.

Physicochemical Analyses

Five important physicochemical characteristics for beach water as outlined by USEPA [15] were determined on-site. The parameters, including pH, temperature (°C), electrical conductivity (µS/cm), and total dissolved solids (mg/l) were measured using a digital multi-parameter system (Hanna; HI 9828), while turbidity was measured with the help of a digitally operated turbidimeter (HACH; 2100P).

Microbiological Analyses

Microbiological analysis of the beach water samples was done using the membrane filtration technique as previously described by Shash et al. [16]. Briefly, 100 ml aliquots of the water samples were passed through 90 mm diameter, 0.45 µM pore-sized filter membranes using a vacuum system. The filters were then aseptically transferred onto petri-dishes containing appropriated selective media for the isolation and enumeration of *E. coli* (Coliform Chromogenic agar) and *Enterococcus* sp. (Bile aesculin azide agar), respectively. Chromogenic agar plates were incubated at 37°C for 18-20 h while Bile aesculin azide agar were incubated at 37°C for 48 h. Colonies that exhibited a characteristic blue colour in the Coliform Chromogenic agar medium were enumerated as presumptive *E. coli*, while those that exhibited a brown colour in the Bile aesculin azide agar medium were enumerated as presumptive *Enterococcus* sp. Results were reported as colony forming units per 100 ml (CFU/100 ml) of beach water sample analysed. Over the course of 12 months, a sum total of 522 presumptive isolates were collected and analysed. The presumptive isolates were stored in 25% glycerol at -80°C for further analysis.

Molecular Identification

Bacterial DNA was extracted from presumptive *E. coli* and *Enterococcus* isolates using the boiling method [17]. The target gene *uidA* (Forward primer: 5'AAAACGGCAAGAAAAAGCAG-3'; Reverse primer: 5'-ACGCGTGGTTAACAGTCTTGCG-3') was used for the identification of *E. coli* with an amplicon size of 147 bp. The PCR conditions for the molecular identification of the presumptive *E. coli* isolates were as follows: 5 minutes initial denaturation at 94°C followed by 35 cycles of 95°C for 30 seconds, 58°C for 1 minute, 72°C for 1 minute, and final extension at 72°C for 8 minutes. The target gene *SodA* (Forward primer: 5'TACTGACAAACCATTCATGATG3'; Reverse primer: 5'AACTTCGTCACCAACGCGAAC-3') was used for the identification of *Enterococcus* spp. with an amplicon size of 112 bp [18]. The PCR conditions for the molecular identification of the presumptive Enterococcus isolates were as follows: 5 minutes initial denaturation at 94°C followed by 35 cycles of 95°C for 30 seconds, 58°C for 1 minute, 72°C for 1 minute, and final extension at 72°C for 8 minutes. The speciation of *Enterococcus* was carried out using PCR technique with primer sequences and PCR conditions as follows: *E. faecalis* (Forward primer:

5'-TCAATGCAGTTCCGTTATCAGTT3'; Reverse primer: 5'GTAAAGTCCGTTACCCCAACCTG-3'), 30 seconds initial denaturation at 95ºC followed by 28 cycles of 51ºC for 30 second, 68ºC for 9 minutes, 68ºC for 2 minutes, final extension at 72ºC for 1 minute, and *E. faecium* (Forward primer: 5'-GGCGACAGATTATACCGTGC-3'; Reverse primer: 5'-CGGTCTCTATATTCCCTGTT-3'); 2 minutes initial denaturation at 94ºC followed by 35 cycles of 94ºC for 1 minute, 55ºC for 1 minute, 72ºC for 1 minute, and final extension at 72ºC for 5 minutes with amplicon sizes of 360 bp and 215 bp, respectively. The PCR products (5 μL) were stained with 0.5 mg/L ethidium bromide and then resolved on 1.5% agarose gel with the use of electrophoresis in 0.5 × TBE (Tris-borate-EDTA) buffer. The image was then visualized under a BioDoc-It ultraviolet transilluminatore (UVP Upland, CA, USA).

Risk of Infection Analysis

Quantitative Microbial Risk Assessment (QMRA) was used to estimate the probability of infection and assess the health risk it posed to the public by the presence of both *E. coli* and *Enterococcus* in Nahoon Beach and Nahoon Canal waters. For the purposes of risk of infection estimation, data was clustered into wet and dry categories based on hydrological events. Data for April to September was grouped into the "dry" category while data for October to March was grouped into the "wet" category.

Exposure Assessment

In this study, exposure analysis was based on two principles: (1) the average concentration of each of *E. coli* and *Enterococcus* group bacteria in the water samples from each of the six sampling points on the beach and canal, and (2) the average incidental volume of water consumed per individual during recreational activities. Since there was no questionnaire conducted to ascertain the exact volumes of water consumed during recreation, a ten-fold incremental scale ranging from 0.1 ml to 100 ml was used, since 100 ml has been reported by Steyn et al. [19] to represent involuntary volume of water ingested during full-contact recreational activity.

Dose-response

For enterococci, the probability of gastrointestinal (GI) illness from incidental ingestion of enterococci-contaminated water was estimated with an exponential exposure-response model of Haas et al. [20], reported by Stone et al. [21] as follows:

$$p(\text{ill})_{\text{day}} = \{1 - \exp(-D_{\text{oral}}/k)\} \cdot \Psi \qquad (1)$$

$$D_{\text{oral}} = I_{\text{oral}} \cdot (c/100) \qquad (2)$$

…where $p(\text{ill})_{\text{day}}$ is the daily probability of GI illness, D_{oral} is the number of enterococci as CFU ingested per day, k is an *Enterococcus*-specific infectivity parameter (1442), Ψ is the ratio of illness to infection (0.2), I_{oral} is a random variable for water ingestion rates (ml/d), and c is a random variable drawn from the distribution of enterococci density (CFU/100 ml).

For *E. coli*, a beta-Poisson dose-response model was used to calculate the probability of infection (*Pi*) resulting from the incidental ingestion of 0.1 ml, 1 ml, 10 ml, and 100 ml of beach water as described by the World Health Organization [22]. The 1 ml value for incidental ingestion was defined as the volume (droplets resulting from splashing) of water accidentally swallowed through the mouth or inhaled through the nose and subsequently swallowed [23]. Since *E. coli* isolated from environmental samples could include non-pathogenic strains, the *Pi* was calculated based on the assumption that 8% of average *E. coli* counts are pathogenic [24].

The equation used for calculating the *Pi* due to ingestion of 0.1 ml, 1 ml, 10 ml, and 100 ml of beach water based on a single exposure was given as follows:

$$\boldsymbol{P_i = 1 - (1 + d/\beta)^{-\alpha}}$$

…where d = daily exposure and β (2.473) and α (0.395) are organism-specific equation parameters [25].

Statistical Analysis

All statistics were performed using Microsoft Excel 2010 and SPSS Version 20 (Statistical Package for the Social Sciences – IBM Corporation, Armonk, New York, USA). The arithmetic mean of the *E. coli* counts was considered to appropriately describe the summary of the microbial concentration and was thus used for calculating the microbial risk as described elsewhere [20, 26]. A single-factor analysis of variance (ANOVA) was used to compare the mean *E. coli* counts and *Enterococcus* spp. between September 2014 and August 2015, and also to compare their probabilities of infection. All statistics were considered significant at an alpha (α) of 0.05.

Results

Physicochemical Characteristics of Nahoon Beach and Canal Waters

The mean values of physicochemical parameters for the three sampling points on Nahoon Beach are presented in Table 1, while Table 2 shows the mean values for the three sampling sites on the canal. The range of physicochemical parameter readings and the concomitant national and international guideline readings are presented in Table 3. The values of the physicochemical parameters measured in both

Table 1. Physicochemical characteristics of Nahoon Beach waters.

Parameters		September	October	November	December	January	February	March	April	May	June	July	August
Total Dissolved Solids (mg/L)	Mean ±SD	544±2	24±0.6	22.3±2.9	24.7±0.6	437.3±20.8	44±0.4	46.1±0.1	22.1±2	24.6±0.3	23.3±1.2	24.2±0.1	22.9±1.2
	Range	542-546	24-25	19-24	24-25	414-454	44.2-45	46-46.2	20-24	24.3-24.8	22-24	24.1-24.3	22.1-24.2
pH	Mean ±SD	10.5±0.2	7.1±0	7.1±0.1	7.8±0.1	8.7±0.8	7.5±0.4	7.7±0.6	7.0±0	7.1±0.1	7.2±0.2	7.2±0.3	7.4±0.4
	Range	10.4-10.7	7.1-7.1	7-7.1	7.7-7.9	8-9.5	7.2-7.9	7.3-8.3	7-7.1	7-7.2	7-7.4	7-7.5	7.1-7.8
Temperature (°C)	Mean ±SD	19.2±0.6	17.5±1.6	19.2±0.1	19.6±1.0	19.7±0.4	24±0.6	22.3±0.4	19±0.2	19.5±0.3	17±0.3	16.7±0.5	17.8±2.3
	Range	18.5-19.7	17-19	19.1-19.3	18.5-20.4	19.4-20.1	24-25	22-22.7	18.8-19.1	19.2-19.7	16.7-17.2	16.2-17.1	15.5-20
Electrical Conductivity (µS/cm)	Mean ±SD	68.4±0.3	38±1	35.3±4.3	69±0.9	671.9±5.4	69.7±0.6	741.7±0.3	34.3±3.4	38.5±0.2	36.3±1.2	37.6±0.2	35.8±1.8
	Range	68.2-68.7	37-39	30.4-38	68.1-69.8	668.7-678.2	69-70.1	741.5-742.1	30.7-37.4	38.3-38.7	35-37	37.4-37.8	34.6-37.8
Turbidity (NTU)	Mean ±SD	94.2±5.3	24.3±0.6	6.6±2.1	8.9±1.4	57.7±9.8	5.9±1.5	5.5±1.3	5.2±1.4	4.3±1	9.8±0.5	4.5±0.8	7.1±5.4
	Range	88.1-97.3	24-25	4.3-8.3	7.3-10	47.7-67.3	4.3-7.3	4.3-6.9	3.7-6.3	3.3-5.3	9.3-10.3	3.5-5	3.6-13.3

Table 2. Physicochemical characteristics of Nahoon Canal.

Parameters		September	October	November	December	January	February	March	April	May	June	July	August
Total Dissolved Solids (mg/L)	Mean ±SD	520.3±1.2	23.8±0.3	23.6±0.8	23.7±0.6	437±32.5	44±1	46±0.1	21.1±1.2	24±0.4	22.3±2.1	24.1±0.1	22.4±0.5
	Range	519-521	23.4-24	22.7-24.0	23-24	413-474	43-45	45.9-46.1	20.2-22.5	23.6-24.3	20-24	24-24.2	22-22.9
pH	Mean ±SD	10.1±0.1	7.1±0.1	7.2±0.1	7.8±0.1	8.2±0.4	7.3±0.1	8.0±0.6	7.2±0.2	7.3±0.3	7.3±0.3	7.0±0	7.2±0.2
	Range	10.1-10.2	7-7.1	7.1-7.2	7.7-7.9	7.7-8.4	7.3-7.4	7.4-8.4	7.1-7.4	7.1-7.7	7.1-7.7	7.0-7.1	7.1-7.4
Temperature (°C)	Mean ±SD	16.5±0.8	19.7±2.1	20±1.4	19.1±1.1	20.7±0.5	23±0.6	22.2±0.5	19.6±0.6	20.6±1.3	15.9±0.4	18.5±0.6	16.2±0.5
	Range	16.0-17.4	18-22	18.8-21.6	18-20.2	20.2-21.2	23-24	21.6-22.5	19-20.2	19.7-22	15.5-16.3	17.9-19	15.6-16.5
Electrical Conductivity (µS/cm)	Mean ±SD	31.9±2.1	37.3±0.6	36.5±1.1	69.5±0.5	661.7±16.4	69.1±0.2	736.2±31.7	32.9±1.9	37.7±0.6	35±3.4	37.8±0.1	35.1±0.7
	Range	30-34	37-38	35.2-37.4	69-70	647.2-679.4	68.4-70.4	712-772	31.6-35.1	37-38	31.1-37.4	37.7-37.9	34.4-35.8
Turbidity (NTU)	Mean ±SD	91.9±7.2	30.7±4.9	4.3±1	9.0±0.9	68.2±10	4±0.7	6.9±2.7	6.8±0.5	3.8±0.5	8.4±1.9	3.4±0.1	6.1±1.2
	Range	85.9-99.9	25.0-34.0	3.3-5.3	8.1-9.9	58.1-78.1	3.3-4.7	4.5-9.8	6.3-7.3	3.3-4.3	6.3-9.7	3.4-3.5	5.1-7.5

Table 3. Comparison of the range of values of physicochemical parameters recorded in Nahoon Beach and Canal with international guidelines/standards.

Parameter (unit)	Range of values for water quality parameters recorded at the Nahoon beach and canal	South African Water Quality Guidelines: recreational use (target water quality range) [27]	United States Environmental Protection Agency recreational water maximum contaminant level [15]	European Union Guidelines for Surface Waters used as raw water for normal full physical and chemical treatment with disinfection	WHO Recreational water Standard [26]
pH	7.0–10.7	6.5–8.5	6.5–8.5	5.5–9.0	6.5
Temp. (°C)	15.5–25.0	≤25 °C	2.0–30.0	22	5.0–30.0
Turbidity (NTU)	3.3–99.9	1.84–5.07	0–5	5 (USEPA)	6.0
TDS (mg/l)	19.0–546	NA	500 (SMCL)	–	500
EC (µS/cm)	30.0–741.7	700	–	1,000	NA

NA not available, *USEPA* United States Environmental Protection Agency, *DWAF* Department of Water Affairs and Forestry

the beach and canal were mostly consistent with levels established by the health authorities, with the exception of turbidity. Water turbidity for all evaluated samples ranged from 3.3 to 97.3 NTU for the beach and 3.3 to 99.9 NTU for the canal water. pH levels were within acceptable guidelines for most the sampling period, with averages ranging from 7 to 10.7 and from 7 to 10.2 – except for the month of September 2014, which had mean values of 10.5 and 10.1 for the beach and canal waters, respectively.

At all sampling sites (both beach and canal), turbidity ranged between 3.3 and 99.9 NTU, with the highest turbidity of 99.9 NTU and 97.3 NTU for the canal and beach water, respectively, occurring in the month of September. The lowest observed turbidity was 3.3 NTU, which was in the months of February, May, and November. The concentration of total dissolved solids (TDS) ranged between 19 and 546 mg/L for the beach and 20 and 521 mg/L for the canal water.

Microbiological Characteristics of the Nahoon Beach and Canal Waters

A total of 260 presumptive *E. coli* isolates and 172 presumptive *Enterococcus* strains were isolated from both the beach and canal waters. Of the presumptive *E. coli* isolates, 41.2% were confirmed positive for the *uidA* gene, while 59% of the presumptive *Enterococcus* strains were confirmed positive for the *SodA* gene, which positively identifies *Enterococcus* spp. Of the 102 enterococci isolates, 22 strains were identified to species level, being 14 strains for *E. faecalis* and 8 strains for *E. faecium*. The mean month-by-month bacterial counts obtained for both the beach and canal samples are presented in Fig. 2. The highest *E. coli* counts (235 CFU/100 ml) were observed in January 2015, while the lowest counts (4 CFU/100 ml) were in June and July 2015. The highest enterococci counts (50 CFU/100 ml) were obtained in September 2014 while the lowest counts (7 CFU/100 ml) were in June 2015. Further molecular analyses were held and some of the *E. coli* enterococci strains were found to be pathogenic but were not highlighted in this paper.

Probability of Infection (*E. coli*) and Probability of Illness (enterococci) Estimations

Fig. 3a) and b) summarizes the probability of infection (*Pi*) with pathogenic *E. coli* and enterococci respectively due to incidental ingestion of 0.1 ml, 1ml, 10 ml, or 100 ml of recreational beach water from Nahoon Beach and canal waters during water sports such as swimming, surfing, or boating. Based on the accidental ingestion of different volumes of beach water, it was observed that *E. coli* posed a greater risk of infection to swimmers than enterococci. Furthermore, the risk of infection posed by *E. coli* was heightened during the wet season as compared to
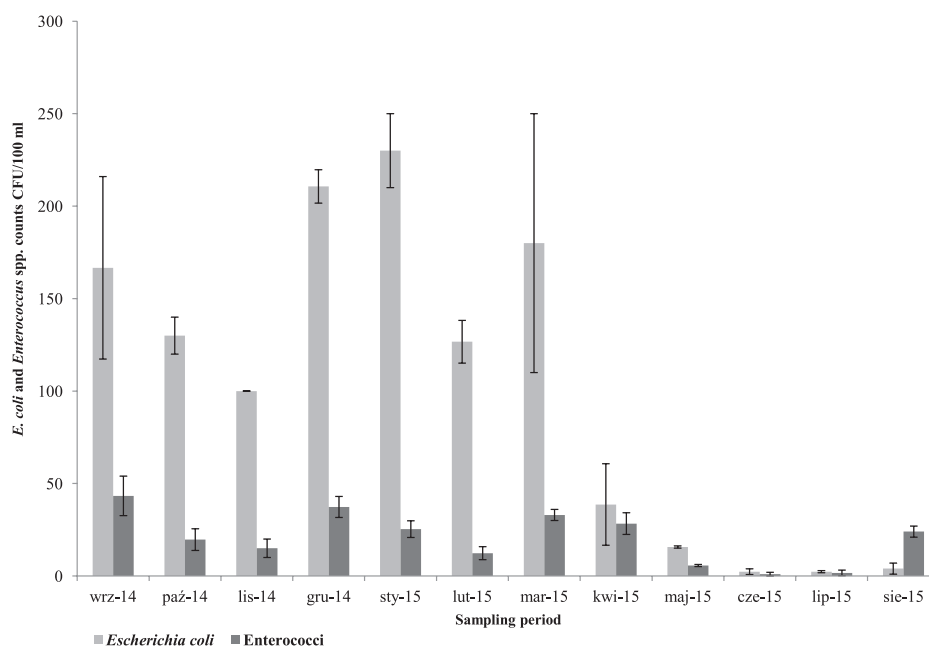
Fig. 2. *E. coli* and enterococci counts (CFU/100 ml) in beach and canal water samples, September 2014 to August 2015.
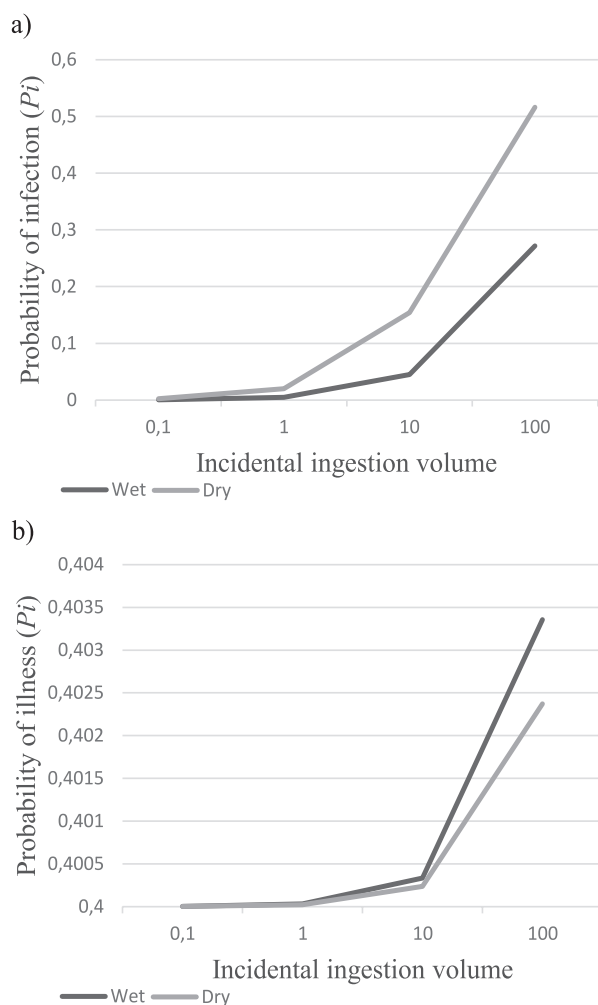

Fig. 3. a) Probability of infection with *E. coli* and b) probability of illness from enterococci exposure after incidental ingestion of 0.1 ml, 1 ml, 10 ml, and 100 ml of recreational beach water.

the dry season. Significant differences of the risk were observed with an increase in the volume of water consumed, starting at 10 ml up to 100 ml, where the risk of infection for the wet category (0.52) became nearly twice as much as the risk for the dry category (0.28).

The probability of illness estimations from *Enterococcus* exposure assumed a similar trend to the risk of infection by *E. coli*, with heightened risk being observed during the wet season compared to the dry season. While the risk posed by enterococci was significantly less than that posed by *E. coli* at lower volumes (0.1 ml, 1 ml, and 10 ml), the risk of infection from *Enterococcus* exposure during the wet season astronomically increased at the consumption of 100 ml of sea water, and became significantly higher than the risk posed by *E. coli* at 100 ml during the dry season. However, contrary to the trend observed for *E. coli*, there were no significant differences in the risk of infection posed by *Enterococcus* in the wet season and in the dry season.

Discussion

The pollution level and anthropogenic pressure on receiving water systems can be measured by the physicochemical quality evaluation of the concerned systems. In this study, five physicochemical characteristics of the Nahoon Beach water samples, including pH, temperature, turbidity (NTU), total dissolved solids (TDS), and electrical conductivity (EC) were assessed over a 12-month sampling period. Changes in water pH can be indicative of either an industrial pollutant or photosynthetic activity, usually as a result of eutrophication. The monitoring of pH is

recommended as an assessment of the health of aquatic ecosystems, safety of recreational waters, and quality of industrial discharges, intakes, and storm water overflows [27].

The pH of uncontaminated water generally shows values ranging from 6.5 to 8.5 [28-29]. In this study, however, the pH values were at an average of 8.7 in the month of January for Nahoon Beach and an average of 10.0 in September for both the beach and canal samples. For recreational water, USEPA [15] recommends a pH range of 6.5-8.5, and contact with water whose pH is higher than this has been linked to primary irritation of the skin (although the mechanism is unclear) [30]. While it may not have been possible to pinpoint the actual cause of the pH surge in September, this increase coincided with stormy weather, which resulted in significant stormwater runoff to the beach. It could be that the stormwater brought with it some inorganic substances which possibly altered the pH balance. In line with this argument, Farrant and Hewson [31] have previously reported that high pH values in receiving water bodies are due to stormwater runoff with contaminants from both vehicular and construction sources.

High turbidity was generally recorded in the months of September and October (which fall into the spring season according to South African seasons). Generally, an increase in turbidity can be a result of an increase in substances that form colloids as compared to dissolved solids; nevertheless, an increase in total dissolved solids can also be linked to high turbidity in the water body [32]. Increased turbidity in water is frequently associated with the prospect of microbiological contamination [33], as high turbidity tends to shield microorganisms from natural sunlight inactivation. Our findings seem to support this view, as the highest counts for both *E. coli* and *Enterococcus* were recorded in September – the month in which the highest turbidity was also recorded. This finding suggests that microbial risk is heightened in the period after stormy weather, when significant inflows are received into the beach. Similar findings and inferences were made by Brady et al. [34], who even suggested that recreational microbial water quality can be predicted using turbidity.

Electrical conductivity (EC) values were compliant with the DWAF [29] guidelines for recreational waters (except in the month of March 2015). Some states, regions, and agencies have regularly set a TDS maximum as an option to conductivity in water quality monitoring, with conductivity largely a derivative of TDS content [35, 36-37]. Concomitantly, a rapid rise in conductivity in any water body can indicate pollution. According to Kemker [38], stormwater runoff, agricultural runoff, or perhaps a sewage outflow will cause EC to rise due to the surplus chloride, phosphate, nitrate ions, and other constituents such as alkaline metals (sodium). EC and salinity both can vary greatly amid various bodies of water. Several freshwater streams as well as lakes and rivers have low salinity and conductivity figures. The

oceans, on the other hand, have high conductivity and salinity owing to their high quantity of dissolved salts. Poma et al. [39] showed strong positive correlations between water conductivity and viruses and parasites, chiefly norovirus, adenovirus, and *Microsporidium* sp. We propose that if conductivity has to be used as a model for viruses and parasites, a baseline conductivity value has to be established by means of sustained assessments over time. Future water quality assessments will then have to take into consideration the established baseline value, and in all instances where this value is exceeded, assessments for viral and parasitological contamination will have to be done.

Generally, the temperature values observed in this current study ranged as follows: Nahoon Beach (15ºC-25ºC) and Nahoon Canal (15ºC-24ºC) fell within the required temperature recommendations of 2ºC-30ºC for recreational waters, where complete contact usage is permitted [15]. Considerably lower temperature (15-19ºC) was constantly recorded during winter season at all sampling points compared to summer water temperatures (18-25ºC).

Microbiological analysis showed that the *E. coli* counts exceeded 130 CFU/100 ml, which is the maximum accepted guideline for recreational water [15, 28-29]. Similarly, *Enterococcus* sp. counts were observed to exceed the recommended limit of 35 CFU/100 ml for marine water [15, 28-29]. However, there was a reduction in the counts during winter, possibly due to a reduction in the number of swimmers and beach goers, which directly reduces real-time faecal bacteria shedding into the beach water and/or sand. During the wet (summer) season, beach water quality was poor judging from analysis made on both physicochemical and bacteriological parameters. This could have been a result of both meteorological and anthropogenic input, since temperatures during this period tend to favor beach activity, resulting in increased numbers of people visiting the beach. Elevated *E. coli* and *Enterococcus* concentrations in water can be indicative of the possible presence of potential pathogens belonging to these genera and others, including viral pathogens. McNinch et al. [40] and Göransson et al. [41] observed that during rainfall, the microbial loads of running water may suddenly increase and reach reservoir bodies very quickly. These observations may explain the increase of bacterial contamination during the month of September (which remained consistently high until April of the following year) in all sampling sites. The bacterial counts decreased drastically during the months of May, June, and July, which is winter (dry) season in South Africa. Similar findings were reported from studies by Shar et al. [42], Aertgeerts et al. [43], and Zia et al. [44]. The increase in microbial loads during the wet season resulted in an increase in the probability of infection/illness posed by both *E. coli* and *Enterococcus* (Fig. 3). Taking into consideration the increase in human beach activities during this period, especially contact with recreational water, the calculated *E. coli* risk of

0.15 (1 in 10 people getting infected) and *Enterococcus* risk of 0.4 (4 in 10 people getting ill) may actually be representing quite a large number of cases, especially if compared to the WHO [26] "acceptable risk" of 1×10^{-4} for recreational water. A 1 in 10 ratio translates to a 10 in 100 cases or 100 in 1000 cases, which can be way too high considering that the calculated risk does not take into consideration bather-to-bather transmission via the water (gastrointestinal illness) and air (respiratory pathogens). Fewtrell and Kay [45] reported that besides the risk of infection caused by organisms naturally present in the water, other causes of infection and illness are a result of direct transmission among bathers – especially in overcrowded beaches.

In addition to microbial pathogens, urine and feces add up to beach contamination while in use by recreationists. Ideally, heterotrophic bacteria respond to organic pollution by decomposing and mineralizing organic matter to inorganic nutrients. Vignesh et al. [46] maintain that as human use of coastal landform increases, the incidence of contaminated water and consumption of shellfish result in subsequent aquatic-borne diseases. On the other hand, it should be noted that the faecal origin of the bacteria is not indicated by the existence of faecal coliforms in the water source [47]. For this reason, enterococci are commonly used as a supplementary faecal indicator due to their ubiquity in human faeces and tenacity in the environment [48, 49]. Enterococci may be better indicators of human faecal pollution in water than *E. coli* [50, 51], and better indicators of threats to swimmers in contact with beach water in comparison to *E. coli* because these microorganisms survive longer in saline environments [47, 52-53].

In studies that focused on domestic and recreational water use in rural communities in developing countries [54-55], there have been issues of poor monitoring of water quality for more than a decade. This study has highlighted some of the challenges faced by public health, the environment, and water resources in South Africa and other developing countries. The possible implications could be outbreaks of water-borne diseases and the spread of pathogen resistance to antimicrobial agents in the presumptive. There is a high risk of infectious diseases such as diarrhea and cholera by bathers, tourists, recreationists, or visitors to recreational facilities. This study also covers identifying the influence of pathogen loading events and the importance of the epidemiology of incidence of infection on surface water quality.

Conclusions

From our findings we can conclude that the microbial quality of Nahoon Beach and its canal waters in the Eastern Cape Province is poor and did not conform to the set physicochemical and microbiological guidelines. There is therefore a need for frequent monitoring of beach water quality with standard methods. This study and other similar research works could assist the environmental protection agencies and health advisory with useful information if there are elevated levels of bacteria until pollution is controlled. More studies should also be encouraged with respect to recreational waters because of the few contributions that have been made, most especially the emergence of multidrug-resistant microorganisms in beach water as well as beach sands.

Acknowledgements

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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