

Microbiological Quality, Physicochemical Characteristics, and Antimicrobial Susceptibility of Recreational Swimming Pool Water in Selected Hotels in South-South Nigeria

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Abstract

Background: Hotel swimming pools are widely used for leisure, yet inadequate disinfection and maintenance can turn them into vehicles for recreational water illness. Data from Edo State, Nigeria, are scarce. **Objective:** To assess microbiological quality, selected physicochemical characteristics and maintenance practices of hotel swimming pools in Ekpoma, and the antimicrobial susceptibility of the isolates recovered. **Methods:** In this cross-sectional study (June–August 2024), one water sample was collected aseptically from each of 15 hotel swimming pools. pH, temperature, colour, transparency and total dissolved solids (TDS) were measured, and maintenance practices were recorded. Heterotrophic bacteria and fungi were enumerated, coliforms were estimated by multiple-tube fermentation (most probable number, MPN), isolates were identified by cultural, microscopic and biochemical methods, and susceptibility was tested by disc diffusion. **Results:** pH (6.9–8.2) was within 6.5–8.5 in all pools, whereas temperature (24.0–28.5 °C) exceeded 26 °C in three. TDS ranged from 22 to 441 mg/L. Heterotrophic bacterial counts ($1.2\text{--}8.0 \times 10^4$ CFU/mL) exceeded the 100 CFU/mL benchmark in all 15 pools; fungi were counted in five pools ($1.5\text{--}2.5 \times 10^4$ CFU/mL); and presumptive coliforms (1–5 MPN/100 mL) were detected in every pool. Thirty-three isolates representing seven taxa were recovered. *Staphylococcus aureus* was the most frequent (12 isolates, 36.4%; present in 80% of pools), followed by *Escherichia coli* (6 pools, 40%), *Bacillus* spp. (33.3%), *Klebsiella* spp. (26.7%), *Rhizopus* spp. (20.0%), *Salmonella* spp. (13.3%) and *Providencia* spp. (6.7%); the distribution was non-uniform ($\chi^2 = 16.85$, $df = 6$, $p \approx 0.01$). Gram-negative isolates were uniformly susceptible to amoxicillin, amoxicillin–clavulanate, imipenem, cefuroxime, ceftriaxone and cefixime but uniformly non-susceptible to ofloxacin; Gram-positive isolates were non-susceptible to azithromycin. **Conclusions:** None of the pools met the microbiological benchmarks, despite largely acceptable pH and appearance. Routine microbiological surveillance, operator training and enforceable pool-management standards are needed to protect bathers.

Keywords: Swimming Pool; Recreational Water; Microbiological Quality; Coliforms; *Staphylococcus Aureus*; Antimicrobial Susceptibility; Nigeria.

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Introduction

Swimming is among the most popular forms of recreation and is widely regarded as a healthy activity for people of all ages. It is often recommended for asthmatic children because inhaling humid air is less likely to trigger exercise-induced asthma (Abdou *et al.*, 2005). Growing interest in swimming for sport, fitness, therapy and relaxation has increased pool use and broadened the range of facilities, including spa, hydrotherapy and wave pools, which are used by people of varying age, health status and standards of hygiene (Abdou *et al.*, 2005; Amala & Aleru, 2016; Hang *et al.*, 2016). Swimming pools are artificially enclosed bodies of water, typically concrete, fibreglass or plastic basins, designed to hold large volumes of treated water (Ajadi *et al.*, 2016). Pool water is expected to be clear and free of contaminants, including pathogenic bacteria, fungi, algae, viruses and protozoa.

Pools are nonetheless shared environments into which bathers continuously introduce microorganisms. Skin alone releases hundreds of millions of bacteria during a swim, and further inputs arise from saliva, mucus, vomit and faecal material (CDC, 2004; Iyevhobu *et al.*, 2025), as well as from air, dust, rainwater, sewage, animals and contaminated source water (Al-Khatib & Salah, 2006). Because swimmers inadvertently ingest pool water (Evans *et al.*, 2001), contamination can cause gastrointestinal, ear, skin and respiratory infections, including diarrhoea, typhoid fever, hepatitis and cholera (Borgmann-Straßen, 2003; WHO, 2003a, 2003b, 2004). Organisms of concern include faecal pathogens such as *Escherichia coli* O157, *Campylobacter jejuni*, *Shigella* spp., *Cryptosporidium parvum* and rotaviruses, and non-faecal agents such as *Legionella pneumophila*, *Pseudomonas aeruginosa*, *Staphylococcus*, *Streptococcus*, *Mycobacterium marinum*, *Klebsiella* and *Yersinia* species (Kaydos-Daniels *et al.*, 2008; Ayandele *et al.*, 2015). Surveillance data from the United States and Europe indicate that recreational water illness is increasing (Yoder *et al.*, 2004). Recirculation systems and disinfectants are essential, but neither prevents colonisation of pool water by hazardous microorganisms on its own (CDC, 2004; Fiorillo & Zucker, 2004; Barben *et al.*, 2005), so compliance with chemical guidelines is not a sufficient indicator of safety and routine microbiological testing is advocated (Kaydos-Daniels *et al.*, 2008).

Disinfection efficacy depends on pH and residual disinfectant. As pH rises, a smaller fraction of free chlorine is present as hypochlorous acid, the more effective species. Poor pH control also causes corrosion, scaling, cloudy water and skin and eye irritation, and chlorine that reacts with nitrogenous material from bathers forms chloramines, which weaken disinfection and irritate the eyes, nose, skin and airways. In developing countries, under- or over-dosing of chemicals by operators with limited training is common and compromises water quality (Cairns & Dickson, 2003; Bello *et al.*, 2012), and disinfection by-products may themselves pose toxicological hazards (Helen *et al.*, 2001). The culture of pool maintenance in Nigeria has been described as poor (Ikpo, 2006; Folu, 2009; Iwarere & Lawal, 2011; Kola, 2011).

Pool water quality has been studied in several Nigerian cities (Indabawa *et al.*, 2015; Esinulo & Ogbuagu, 2016; Verla *et al.*, 2021) and in Ghana (Courage & Saviour, 2015), China (Wei *et al.*, 2018; Zhou *et al.*, 2019; Lau *et al.*, 2021), Ethiopia (Yademe *et al.*, 2017), Portugal (Gabriel *et al.*, 2019; Felgueiras *et al.*, 2020) and France (Tsamba *et al.*, 2020). However, few studies have characterised the microbial and physicochemical quality of pools in Edo State. This study therefore aimed to (i) assess the microbiological quality, selected physicochemical characteristics and maintenance practices of 15 hotel swimming pools in Ekpoma, and (ii) determine the antimicrobial susceptibility of the bacterial and fungal isolates recovered.

Materials and methods

Study area and design

The study was conducted in Ekpoma (6°45'N, 6°08'E), the administrative headquarters of Esan West Local Government Area, Edo State, Nigeria (Osarenmwinda & Idachor, 2019). Ekpoma had a population of about 125,842 at the 2006 national census (NPC, 2006), has a tropical climate with a mean annual temperature of about 30.5 °C (Siloko & Siloko, 2023), and hosts Ambrose Alli University. A cross-sectional, laboratory-based design was used between June and August 2024. Fifteen swimming pools located in Ekpoma hotels were sampled by purposive sampling technique to select hotels with operational recreational swimming pools. Laboratory analyses were performed in the Research Diagnostic Laboratory of the Department of Medical Laboratory Science, Ambrose Alli University, Ekpoma.

Ethical considerations

Ethical approval was obtained from the Ethics and Research Committee of Ambrose Alli University, Ekpoma (approval no. AAU/HREC/2024/0184). Written and verbal consent was obtained from the managers or owners of the hotels before sampling.

Sample collection

One water sample was collected aseptically from each of the 15 pools at a depth of about 200 mm below the surface, using sterile 250 mL wide-mouthed bottles that were labelled with unique identification numbers. Sodium thiosulphate was used to neutralise residual disinfectants; samples were collected between August to September 2025 at about 7:30am every time sample collection was scheduled; and transported in a cool box, at -0°C; and processing was carried out within a maximum time of 39mins after sample collection.

On-site measurements and maintenance survey

Temperature and pH were measured in situ with a portable Jenway 370 meter (Jenway, UK). Colour and transparency were recorded by visual inspection. TDS (mg/L, reported as ppm) and electrical conductivity (µS/cm) were measured with Hanna Instruments DiST® 5 HI98311. Information on cleaning frequency and method, chemicals used, water replacement interval and whether the pool was open-air or enclosed was obtained from hotel managers via a structured questionnaire and interview. Free residual chlorine and bather numbers were not measured.

Media preparation and sterilisation

MacConkey agar, MacConkey broth, nutrient agar and Sabouraud dextrose agar (SDA) were prepared from dehydrated commercial products according to the manufacturers' instructions and sterilised by autoclaving at 121 °C for 15 min (15 psi). SDA (65 g/L) was supplemented after sterilisation with chloramphenicol (0.25 mg/mL; Odds, 1992) dissolved in ethanol, added when the medium had cooled to about 48 °C. Work benches were disinfected with [concentration] 0.1% hypochlorite solution, glassware was washed and sterilised, and wire loops were flame-sterilised before use.

Heterotrophic bacterial count

Ten-fold serial dilutions of each sample were prepared in 9 mL sterile peptone water. One millilitre of the 10² and 10⁴ dilutions was transferred to sterile Petri dishes and mixed with molten nutrient agar (pour-plate method; APHA, 2005). Plates were incubated at 37 °C for 48 h, and visible colonies were counted. Counts were expressed as colony-forming units per millilitre (CFU/mL) = number of colonies × reciprocal of the dilution factor ÷ volume plated.

Coliform estimation

Presumptive coliform counts were determined by the multiple-tube fermentation technique using MacConkey broth with inverted Durham tubes. Five 10 mL portions were inoculated into double-strength broth, and five 1 mL and five 0.1 mL portions into single-strength broth (five-tube, three-dilution design). Tubes were incubated at 37 °C and read at 24 and 48 h. Tubes showing acid (colour change from purple to yellow) and gas in the Durham tube were scored positive, and the MPN of coliforms per 100 mL was read from standard MPN tables (Collee *et al.*, 1998).

Isolation and identification of bacteria

Growth from the nutrient agar plates and positive MacConkey broth tubes was subcultured onto MacConkey agar and Salmonella–Shigella agar at 37 °C for 24 h. Discrete colonies were purified by streaking and characterised by colonial morphology (shape, elevation, surface, edge and consistency), Gram staining, and catalase, coagulase, oxidase, citrate utilisation, indole production, methyl red, triple sugar iron and sugar fermentation tests, following standard procedures (Olutiola *et al.*, 2000; Monica, 2025; Iyevhobu *et al.*, 2025).

Enumeration, isolation and identification of fungi

Serial dilutions of the samples were plated on SDA supplemented with chloramphenicol and incubated at 37 ± 2 °C for 3 days (Monica, 2025). Colonies were counted and expressed as CFU/mL. Distinct colonies were subcultured onto fresh SDA to obtain pure cultures. Isolates were identified from colony characteristics (including pigmentation) and microscopic morphology of lactophenol cotton blue wet mounts examined at ×10 and ×40 objectives (Collee *et al.*, 1998; James & Natalie, 2001; Monica, 2025). Yeasts were tested for germ-tube formation to identify *Candida albicans*.

Antibiotic susceptibility testing

Susceptibility was determined by the modified Kirby–Bauer disc diffusion method on Mueller–Hinton agar inoculated with a suspension adjusted to the 0.5 McFarland standard. Zones of inhibition were measured and interpreted according to CLSI (2021). Gram-positive isolates were tested against amoxicillin–clavulanate, erythromycin, gentamicin, imipenem, ceftriaxone, cefixime, levofloxacin, ciprofloxacin, azithromycin, cefuroxime, ofloxacin and cefotaxime. Gram-negative isolates were tested against amoxicillin–clavulanate, amoxicillin, imipenem, neomycin, cefuroxime, ceftriaxone, cefotaxime, cefixime, ofloxacin, gentamicin, levofloxacin and nalidixic acid.

Antifungal susceptibility testing

Fungal isolates were tested against nystatin, fluconazole and ketoconazole by disc diffusion on SDA incubated at 37°C for 48 h; inhibition zones were measured in millimetres.

Statistical analysis

Data were entered and charted in Microsoft Excel and summarised as ranges, means ± standard deviation and frequencies. The distribution of isolates among taxa was compared with a uniform expectation using the chi-square goodness-of-fit test. Associations between temperature or TDS and bacterial count were explored with Spearman's rank correlation. Statistical significance was set at $p < 0.05$ (95% confidence level).

Results

Physicochemical characteristics

The physicochemical results are shown in Table 1. pH ranged from 6.9 to 8.2 (mean 7.3 ± 0.4) and was within the 6.5–8.5 range adopted as the benchmark in all 15 pools. Seven pools (1, 3, 4, 8, 9, 10 and 13) fell outside the narrower 7.2–7.8 range commonly recommended for chlorine-disinfected pools: six were below 7.2 and one (pool 9, pH 8.2) was above 7.8. Temperature ranged from 24.0 to 28.5 °C (mean 25.7 ± 1.3 °C); three pools (5, 9 and 14) exceeded the 26 °C upper benchmark. Nine pools were colourless, four were blue (3, 9, 10 and 11) and two were green (6 and 12). Water was very clear in

three pools, clear in nine, slightly cloudy in one (pool 9) and cloudy in two (pools 6 and 12, both green). TDS ranged from 22 to 441 mg/L (mean 200 ± 173 mg/L): the highest values (424–441 mg/L) occurred in pools 1, 6 and 14, and five pools (4, 5, 8, 11 and 15) had values of 35 mg/L or less.

Table 1. Physicochemical characteristics of the 15 hotel swimming pools sampled in Ekpoma.

Pool	pH	Temperature (°C)	Colour	Transparency	TDS (mg/L)	Conductivity (µS/cm)
1	7.1	25.0	Colourless	Clear	424	780
2	7.6	24.5	Colourless	Clear	341	686
3	7.0	25.0	Blue	Very clear	187	374
4	6.9	26.0	Colourless	Clear	32	64
5	7.4	27.5	Colourless	Clear	22	44
6	7.2	25.5	Green	Cloudy	431	768
7	7.5	26.0	Colourless	Clear	372	698
8	7.0	26.0	Colourless	Clear	23	48
9	8.2	28.5	Blue	Slightly cloudy	87	169
10	7.1	24.0	Blue	Very clear	144	282
11	7.3	25.0	Blue	Very clear	32†	251†
12	7.6	24.5	Green	Cloudy	62	151
13	7.0	25.0	Colourless	Clear	361†	201†
14	7.8	27.5	Colourless	Clear	441†	221†
15	7.2	26.0	Colourless	Clear	35†	181†
Range	6.9–8.2	24.0–28.5	–	–	22–441	44–780
Benchmark	6.5–8.5	22–26	–	–	–	–

TDS, total dissolved solids (reported as ppm). Benchmarks as adopted by the authors (attributed to WHO). †TDS and conductivity values for these pools are not mutually consistent and are under verification.

Maintenance and hygiene practices

All 15 pools were open-air (Table 2). Cleaning was daily in one pool (12), every two days in three (3, 8 and 13), weekly in five (2, 4, 9, 10 and 14), fortnightly in three (1, 5 and 11) and only before or during use in three (6, 7 and 15). Vacuuming was practiced in every pool, with additional washing in five (1, 8, 9, 11 and 13) and draining in two (1 and 13). Water was replaced weekly in nine pools, fortnightly in three and monthly in three (5, 11 and 14). Eleven pools reported using chlorine and eleven used alum; powder lime and “blue seal” were each used in three pools. Four pools (9, 10, 12 and 13) reported no use of chlorine.

Table 2. Maintenance and hygiene practices reported for the 15 swimming pools (all open-air).

Pool	Cleaning frequency	Cleaning method	Chemicals used	Water replacement
1	Every 2 weeks	Draining, washing, vacuuming	Chlorine	Weekly
2	Weekly	Vacuuming	Chlorine	Weekly
3	Every 2 days	Vacuuming	Chlorine, powder lime, alum	Weekly
4	Weekly	Vacuuming	Chlorine	Every 2 weeks
5	Every 2 weeks	Vacuuming	Chlorine	Monthly
6	Whenever in use	Vacuuming	Alum, chlorine	Every 2 weeks
7	Before each use	Vacuuming	Chlorine, powder lime, alum	Every 2 weeks

8	Every 2 days	Washing, vacuuming	Chlorine, alum, blue seal	Weekly
9	Weekly	Washing, vacuuming	Alum	Weekly
10	Weekly	Vacuuming	Alum, blue seal	Weekly
11	Every 2 weeks	Washing, vacuuming	Chlorine, alum	Monthly
12	Daily	Vacuuming	Alum	Weekly
13	Every 2 days	Draining, washing, vacuuming	Powder lime, blue seal, alum	Weekly
14	Weekly	Vacuuming	Chlorine, alum	Monthly
15	Whenever in use	Vacuuming	Chlorine, alum	Weekly

Information as reported by pool attendants/managers; free residual chlorine was not measured.

Microbial counts and presumptive coliforms

Heterotrophic bacterial counts ranged from 1.2×10^4 CFU/mL (pool 3) to 8.0×10^4 CFU/mL (pool 2), with a mean of $4.3 \pm 2.0 \times 10^4$ CFU/mL (Table 3). All 15 pools (100%) exceeded the 100 CFU/mL benchmark, by approximately 120- to 800-fold. Fungal growth occurred in five pools (5, 10, 11, 12 and 15; 33.3%), with counts of 1.5 – 2.5×10^4 CFU/mL. Presumptive coliforms were detected in all 15 pools (MPN 1–5 per 100 mL, against a benchmark of 0): the MPN was 5/100 mL in eight pools (1, 5, 6, 9, 10, 11, 14 and 15), 3 in two pools, 2 in two pools and 1 in three pools. Neither temperature (Spearman $\rho = -0.16$, $p = 0.57$) nor TDS ($\rho = 0.28$, $p = 0.32$) was significantly correlated with bacterial count.

Table 3. Heterotrophic bacterial and fungal counts and presumptive coliform most probable number (MPN) in the swimming pool water samples.

Pool	Heterotrophic bacterial count ($\times 10^4$ CFU/mL)	Fungal count ($\times 10^4$ CFU/mL)	Presumptive coliforms (MPN/100 mL)
1	6.4	ND	5
2	8.0	ND	3
3	1.2	ND	1
4	5.6	ND	2
5	3.2	2.5	5
6	5.2	ND	5
7	1.3	ND	1
8	2.1	ND	1
9	6.4	ND	5
10	3.6	2.0	5
11	3.2	2.2	5
12	6.2	1.5	2
13	3.6	ND	3
14	4.4	ND	5
15	3.5	1.8	5
Benchmark	< 0.01 (100 CFU/mL)	–	0

ND, no growth detected.

3.4 Microorganisms isolated

Thirty-three isolates representing six bacterial genera and one fungal genus were recovered (Tables 4 and 5). Every pool yielded at least one isolate (one to four taxa per pool), and members of the Enterobacterales (*E. coli*, *Klebsiella*, *Salmonella* or *Providencia*) were found in 12 of the 15 pools. *Staphylococcus aureus* was the most frequent taxon (12 isolates, 36.4% of isolates; 80.0% of pools), followed by *E. coli* (6 isolates, 18.2%; 40.0% of pools), *Bacillus* spp. (15.2%), *Klebsiella* spp. (12.1%), *Rhizopus* spp. (9.1%), *Salmonella* spp. (6.1%) and *Providencia* spp. (3.0%). The distribution of isolates among taxa differed significantly from a uniform distribution ($\chi^2 = 16.85$, $df = 6$, $p \approx 0.01$).

Table 4. Occurrence of bacterial and fungal isolates in each swimming pool.

Pool	<i>E. coli</i>	<i>S. aureus</i>	<i>Klebsiella</i> spp.	<i>Salmonella</i> spp.	<i>Bacillus</i> spp.	<i>Providencia</i> spp.	<i>Rhizopus</i> spp.
1	—	+	—	—	—	—	—
2	+	+	—	—	—	—	—
3	+	—	—	—	—	—	—
4	—	+	—	+	+	—	—
5	+	+	+	—	—	—	+
6	—	+	+	—	—	—	—
7	—	—	—	—	+	—	—
8	—	—	—	—	—	+	—
9	—	+	+	—	+	—	—
10	+	+	—	—	+	—	—
11	—	+	—	—	—	—	—
12	—	+	—	+	—	—	+
13	+	+	—	—	—	—	—
14	—	+	+	—	—	—	+
15	+	+	—	—	+	—	—
Pools positive, n (%)	6 (40.0)	12 (80.0)	4 (26.7)	2 (13.3)	5 (33.3)	1 (6.7)	3 (20.0)

+, present; —, absent. *Rhizopus* spp. is the only fungus identified.**Table 5. Frequency distribution of the microbial isolates (total = 33).**

Organism	Isolates, n (%)	Pools positive, n (%) of 15
<i>Staphylococcus aureus</i>	12 (36.4)	12 (80.0)
<i>Escherichia coli</i>	6 (18.2)	6 (40.0)
<i>Bacillus</i> spp.	5 (15.2)	5 (33.3)
<i>Klebsiella</i> spp.	4 (12.1)	4 (26.7)
<i>Rhizopus</i> spp.	3 (9.1)	3 (20.0)
<i>Salmonella</i> spp.	2 (6.1)	2 (13.3)
<i>Providencia</i> spp.	1 (3.0)	1 (6.7)
Total	33 (100)	—

Goodness-of-fit test against equal distribution among the seven taxa: $\chi^2 = 16.85$, $df = 6$, $p \approx 0.01$. One isolate of each taxon was recorded per positive pool.

Antimicrobial susceptibility

Gram-positive isolates (*S. aureus*, $n = 6$; *Bacillus* spp., $n = 5$) were uniformly susceptible to amoxicillin–clavulanate, gentamicin and cefuroxime, and 90.9% were susceptible to imipenem, ceftriaxone, cefixime and cefotaxime (Table 6). Susceptibility to levofloxacin and ciprofloxacin was 63.6% and to ofloxacin 54.5%. Only 27.3% of isolates were susceptible to erythromycin, and none was susceptible to azithromycin. *S. aureus* was non-susceptible only to erythromycin and azithromycin, whereas *Bacillus* spp. showed low susceptibility to levofloxacin and ciprofloxacin (20% each) and none to ofloxacin or azithromycin.

Among Gram-negative isolates ($n = 19$), 100% were susceptible to amoxicillin–clavulanate, amoxicillin, imipenem, cefuroxime, ceftriaxone and cefixime, and 89.5% to cefotaxime (Table 7). In contrast, susceptibility was 36.8% for the agent labelled NEF, 31.6% for gentamicin, 26.3% for nalidixic acid, 15.8% for levofloxacin and 0% for ofloxacin. *E. coli* ($n = 12$) was susceptible to all β -lactams tested but non-susceptible to NEF, ofloxacin, gentamicin, levofloxacin and nalidixic acid.

All three *Rhizopus* isolates were susceptible to fluconazole and ketoconazole, and one (33.3%) to nystatin (Table 8).

Table 6. Antibiotic susceptibility of Gram-positive isolates, n (%) susceptible.

Isolate	N	AUG	ERY	GEN	IMP	CRO	ZEM	LBC	CIP	AZN	CXM	OFX	CTX
<i>S. aureus</i>	6	6 (100)	0 (0)	6 (100)	6 (100)	6 (100)	6 (100)	6 (100)	6 (100)	0 (0)	6 (100)	6 (100)	6 (100)
<i>Bacillus</i> spp.	5	5 (100)	3 (60)	5 (100)	4 (80)	4 (80)	4 (80)	1 (20)	1 (20)	0 (0)	5 (100)	0 (0)	4 (80)
Total	11	11 (100)	3 (27.3)	11 (100)	10 (90.9)	10 (90.9)	10 (90.9)	7 (63.6)	7 (63.6)	0 (0)	11 (100)	6 (54.5)	10 (90.9)

AUG, amoxicillin–clavulanate; ERY, erythromycin; GEN, gentamicin; IMP, imipenem; CRO, ceftriaxone; ZEM, cefixime; LBC, levofloxacin; CIP, ciprofloxacin; AZN, azithromycin; CXM, cefuroxime; OFX, ofloxacin; CTX, cefotaxime.

Table 7. Antibiotic susceptibility of Gram-negative isolates, n (%) susceptible.

Isolate	N	AUG	AOX	IMP	NEF	CXM	CRO	CTX	ZEM	OFX	GEN	LBC	NXA
<i>Klebsiella</i> spp.	4	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	4 (100)	2 (50)	4 (100)	0 (0)	4 (100)	2 (50)	2 (50)
<i>E. coli</i>	12	12 (100)	12 (100)	12 (100)	0 (0)	12 (100)	12 (100)	12 (100)	12 (100)	0 (0)	0 (0)	0 (0)	0 (0)
<i>Salmonella</i> spp.	2	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	0 (0)	2 (100)	0 (0)	2 (100)
<i>Providencia</i> spp.	1	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)	0 (0)	0 (0)	1 (100)	1 (100)
Total	19	19 (100)	19 (100)	19 (100)	7 (36.8)	19 (100)	19 (100)	17 (89.5)	19 (100)	0 (0)	6 (31.6)	3 (15.8)	5 (26.3)

AUG, amoxicillin–clavulanate; AOX, amoxicillin; IMP, imipenem; NEF,; CXM, cefuroxime; CRO, ceftriaxone; CTX, cefotaxime; ZEM, cefixime; OFX, ofloxacin; GEN, gentamicin; LBC, levofloxacin; NXA, nalidixic acid.

Table 8. Antifungal susceptibility of the fungal isolates, n (%) susceptible.

Isolate	N	Nystatin	Fluconazole	Ketoconazole
<i>Rhizopus</i> spp.	3	1 (33.3)	3 (100)	3 (100)

Discussion

Main findings

Although the routine physical measurements of the 15 hotel pools were largely acceptable, none met the microbiological benchmarks applied. Every pool exceeded the heterotrophic plate count benchmark by two to three orders of magnitude, every pool was presumptively coliform-positive, and every pool yielded at least one potentially pathogenic or opportunistic organism. These findings support the view that the appearance and basic chemistry of pool water are poor proxies for microbiological safety (Kaydos-Daniels *et al.*, 2008), and they are consistent with reports that pool contamination is common in Nigeria where maintenance is inadequate (Ikpo, 2006; Iwarere & Lawal, 2011).

Physicochemical quality and operating conditions

All pH values lay within the 6.5–8.5 range used as the benchmark here, but that range is wide. Guidelines for pools disinfected with chlorine recommend 7.2–7.8 (7.2–8.0 for bromine-based and other non-chlorine processes) (Health Protection NSW, 2013; South Australia Health Commission, 2013), and seven of our pools fell outside 7.2–7.8. Low pH accelerates chlorine loss and chloramine formation and is associated with itching, skin spots and sore eyes (Saberianpour *et al.*, 2015), whereas high pH, as in pool 9 (pH 8.2), reduces chlorine efficacy and promotes scaling and cloudy water (South Australia Health Commission, 2013). Pool 9 was indeed slightly cloudy. Values in this study are comparable with the 6.72 reported for pools in Port Harcourt (Agbagwa & Young-Harry, 2012) and with the pH 7.1–7.7

range reported elsewhere in Nigeria (Eze *et al.*, 2015; Esinulo & Ogbuagu, 2016), whereas markedly acidic values have been recorded in some Ghanaian pools (Addo *et al.*, 2018).

Three pools (5, 9 and 14) exceeded 26 °C. Warmer water favours microbial growth and has been associated with higher contamination (Leoni *et al.*, 2001; Attah *et al.*, 2007), although it also shortens the chlorine contact time needed for inactivation (APHA, 2005). In the present data, however, temperature was not significantly correlated with bacterial count, so temperature alone did not explain differences between pools. Cloudiness in pools 6, 9 and 12, two of which were also green, indicates inadequate clarification or disinfection and possibly algal growth, although algae were not examined. Notably, pools 9 and 12 reported using alum without chlorine.

Total dissolved solids (TDS) (22–441 mg/L) was below the 500 mg/L value commonly applied to drinking water and was comparable with values reported in Nigerian pools (Aremu *et al.*, 2011; Eze *et al.*, 2015; Onajobi *et al.*, 2013). TDS in pools reflects source-water mineral content, salts from chlorination and other treatment chemicals (John & Petri, 2006), and the twenty-fold range seen here suggests heterogeneous source waters and dosing practices. Pool operators in Ekpoma reportedly depend on tanker-delivered river water because of recurrent water scarcity. Surface-derived water may carry sewage, runoff and other contaminants (Itah & Ekpombok, 2004; Abd El-Salam, 2012). TDS was not significantly correlated with bacterial count in this dataset, so it should be regarded as an indicator of source and treatment rather than of microbial load.

Maintenance practices were heterogeneous and often inadequate. Water was replaced only monthly in three pools and fortnightly in three, cleaning was weekly or less frequent in eight pools, and four pools (9, 10, 12 and 13) reported no chlorine use, relying instead on alum, lime or “blue seal”. Because free residual chlorine was not measured, the actual disinfectant residual in any pool is unknown, which limits inference about the cause of the high counts. The pools were also reportedly managed by attendants with little training in hygiene, consistent with earlier reports that operators lack knowledge of correct dosing (Cairns & Dickson, 2003; Bello *et al.*, 2012).

Bacteriological and coliform quality

Heterotrophic counts of $1.2\text{--}8.0 \times 10^4$ CFU/mL were lower than the $7.3\text{--}8.3 \log_{10}$ CFU/mL reported for a public pool in Makurdi (Omoni *et al.*, 2019) but higher than the $1.11\text{--}1.61 \log_{10}$ CFU/mL found by Ndunuisi & Igwe (2019). Pool use at the time of sampling and bather load, which were not recorded here, strongly influence counts, because each bather adds skin flora, oils and secretions and increases sanitiser demand (Al-Khatib *et al.*, 2003; Castor & Beach, 2004). Presumptive coliforms were found in every pool, and *E. coli* was isolated from six (40%). Because *E. coli* is excreted by humans, animals and birds and cannot multiply appreciably in the environment, its presence is a specific indicator of faecal contamination and of failed treatment (Papadopoulou *et al.*, 2008). Probable routes include accidental faecal release or residual faecal material on swimmers, contaminated source water, droppings from birds in open-air pools, and inadequate residual disinfectants (Lempart *et al.*, 2020; Verla *et al.*, 2021).

Isolated organisms and their public-health relevance

Staphylococcus aureus was the most frequent isolate, occurring in 80% of pools. It colonises the nose and skin and is therefore mainly an indicator of shedding by bathers rather than of faecal contamination. This agrees with the report of Itah and Ekpombok (2004), who found *S. aureus* to be the predominant contaminant of pools in south-eastern Nigeria. *S. aureus* causes skin, eye and external-ear infections (John & Petri, 2006) and, with *Bacillus cereus*, produces enterotoxins that can cause gastroenteritis when contaminated water is swallowed (Prescott *et al.*, 2002; Bello *et al.*, 2012). *Bacillus* spp. (33.3% of pools) form spores that resist common disinfectants, and approximately 40% of pool isolates in earlier studies were *Bacillus* (Itah & Ekpombok, 2004; Shittu *et al.*, 2008); species-level identification was not performed here.

Enterobacterales were recovered from 12 pools. *E. coli*, *Klebsiella*, *Salmonella* and *Providencia* indicate faecal input from bathers or animals (Casanovas-Massana & Blanch, 2013), and several are opportunistic pathogens associated with healthcare-related infections (Ducel *et al.*, 2002; Prescott *et al.*, 2002). The identification of *Salmonella* to species level cannot be supported by the biochemical tests listed, and serotyping would be needed before its public-health significance can be stated. The taxa recovered are broadly similar to those reported from pools in Ilorin (Sule *et al.*, 2010), Lagos (Bello *et al.*, 2012), Awka (Onuorah *et al.*, 2017), Ghana (George *et al.*, 2014) and Greece (Chrissanthy *et al.*, 2008). *Pseudomonas aeruginosa*, which is common in those studies, was not recovered; because selective media for this organism and for *Legionella* were not used, its absence should not be interpreted as true absence.

Fungi were counted in five pools, but only *Rhizopus* spp. (three pools) were identified, so the identity of fungi in the remaining pools is unknown. Similar mould genera, including *Rhizopus*, *Aspergillus*, *Fusarium* and *Penicillium*, have been recovered from pools in Palestine and south-western Nigeria (Ali-Shtayeh *et al.*, 2002; Itah & Ekpombok, 2004). Infected bathers can contaminate pool water with fungi in numbers sufficient to cause skin and other infections in other users (Maida *et al.*, 2008), and *Rhizopus* is a recognised opportunistic pathogen of immunocompromised persons.

Antimicrobial susceptibility

Gram-negative isolates remained uniformly susceptible to the β -lactams tested, including imipenem, but none was susceptible to ofloxacin, and *E. coli* was non-susceptible to gentamicin and to the quinolones tested. Gram-positive isolates were largely susceptible except to the macrolides (erythromycin 27.3% and azithromycin 0%). Non-susceptibility to quinolones, aminoglycosides and macrolides in pool isolates is a concern, because bacteria that survive disinfection may also be antibiotic-resistant (Papadopoulou *et al.*, 2008), and resistance undermines treatment and worsens outcomes (Alekshun & Levy, 2007; Walse & Fanning, 2008). Misuse and overuse of antibiotics are widely cited drivers of resistance in Nigeria (Emikpe & Oyero, 2007). These data should nevertheless be interpreted with caution. Every *E. coli* isolate ($n = 12$) showed an identical resistance pattern, and the disc potencies and agents listed differ from those described in the Methods of the original draft; verification against quality-control strains is therefore needed. Multiple antibiotic resistance indices were not calculated.

All *Rhizopus* isolates were reported as susceptible to fluconazole and ketoconazole. Because Mucorales are generally regarded as intrinsically resistant to fluconazole, this finding is unexpected and should be confirmed by a standardised method with appropriate controls and interpretive criteria before any clinical inference is drawn.

Limitations

This study has several limitations. Only 15 pools were sampled, once each, because several hotel managers declined permission, so the results may not represent all pools in Ekpoma and cannot show temporal variation. Free residual chlorine, bather load and sampling time relative to pool use were not recorded. Coliform results were presumptive. Isolates were identified phenotypically, without species-level or molecular confirmation, and selective methods for *Pseudomonas*, *Legionella*, enterococci and protozoa were not used. Maintenance data were self-reported. Despite these limitations, the consistency of the microbiological findings across all pools indicates a real and widespread problem.

Conclusions

The hotel swimming pools in Ekpoma sampled in this study did not meet microbiological benchmarks for recreational water, although most physical parameters were acceptable. All pools exceeded the heterotrophic count benchmark and contained presumptive coliforms, and potentially pathogenic bacteria and fungi, including *S. aureus*, *E. coli*, *Klebsiella*, *Salmonella* and *Rhizopus*, were common. Several isolates showed non-susceptibility to clinically used antibiotics. These findings indicate a

potential risk of recreational water illness, particularly for children, older people and immunocompromised swimmers. We recommend that:

- (1) Pool operators measure and record pH, free residual chlorine and temperature routinely, follow a written maintenance and dosing manual, and receive formal training;
- (2) Health and environmental regulators inspect pools and sample them periodically for heterotrophic bacteria and faecal indicators, including the source of pool water;
- (3) Bathers be required to shower before entering the pool and be discouraged from urinating in it, and that bather numbers be managed;
- (4) Future studies include repeated sampling, free chlorine and bather-load measurements, selective detection of *Pseudomonas aeruginosa* and *Legionella*, and molecular identification and resistance profiling of isolates.

Declarations

Ethics approval

Ambrose Alli University Ethics and Research Committee, approval no. AAU/HREC/2024/0184. Consent was obtained from hotel management or owners.

Author Contributions

- Conceptualisation: Owolabi SO, Okogun GRA, and Iyevhobu KO.
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