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Bacteriological Quality and Occurrence of *Pseudomonas Aeruginosa* in Swimming Pools of Hotel and Recreational Facilities in Port Harcourt, Nigeria

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Abstract: *Swimming pools constitute important recreational infrastructures, but may serve as reservoirs of pathogenic microorganisms when poorly managed. This study evaluated the prevalence of Pseudomonas aeruginosa and assessed the bacteriological and physicochemical quality of swimming pools in hotel facilities and recreational centres in Port Harcourt, Nigeria. A cross-sectional study was conducted on twelve swimming pools (six hotels and six recreational facilities). Physicochemical parameters (temperature and pH) were measured in situ, while bacteriological quality was assessed using total heterotrophic bacterial counts (THBC) via the pour plate technique. Bacterial isolates were identified using standard morphological and biochemical tests, and antimicrobial susceptibility patterns were determined using the Kirby–Bauer disk diffusion method. Water temperatures ranged from 28.5–32.4 °C (mean: 29.9 ± 1.2 °C), while pH ranged from 7.2–8.9 (mean: 7.9 ± 0.6), with no significant difference between hotel and recreational pools ($p > 0.05$). THBC values ranged from 6.0×10^1 to 5.3×10^4 CFU/mL, with recreational pools showing higher mean counts than hotel pools, though the difference was not statistically significant ($p = 0.32$). Only 42 % of pools complied with the WHO-recommended limit (<200 CFU/mL). Seven bacterial species were isolated, including Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae, Enterococcus faecalis, Shigella flexneri, Proteus mirabilis and Bacillus cereus. All isolates exhibited multidrug resistance (MAR index > 0.2), with marked resistance to beta-lactam antibiotics but high susceptibility to fluoroquinolones. Pseudomonas aeruginosa was not detected in any sample (0 % prevalence), possibly reflecting effective chlorination practices. Despite the absence of P. aeruginosa, the presence of other pathogenic and multidrug-resistant bacteria highlights significant public health concerns and underscores the need for improved pool water management and routine microbiological surveillance.*

Keywords: *Swimming pools; Pseudomonas aeruginosa; Heterotrophic bacteria; Antimicrobial resistance; Public health; Nigeria*

1. Introduction

Swimming pools are widely used recreational water bodies that provide social, health, and economic benefits. However, when inadequately maintained, they may serve as vehicles for the transmission of waterborne and water-associated infections (WHO, 2006; Bartram et al., 2015). Pool water contamination arises from bathers, environmental inputs, and ineffective disinfection, resulting in microbial proliferation and disease outbreaks (CDC, 2022).

Pseudomonas aeruginosa is a Gram-negative opportunistic pathogen commonly associated with recreational water environments. It is frequently implicated in otitis externa ("swimmer's ear"), dermatitis, urinary tract infections, and infections among immunocompromised individuals (Mena and Gerba, 2009). Its intrinsic resistance to disinfectants and antibiotics makes it a priority organism in pool water surveillance (WHO, 2006). In addition to *P.* aeruginosa, other bacterial pathogens such as Escherichia coli, Staphylococcus aureus, Shigella spp., and Enterococcus spp. have been isolated from swimming pools globally, serving as indicators of faecal contamination and poor hygienic practices (Papadopoulou et al., 2008; Adefemi et al., 2018).

In Nigeria, rapid urbanisation and increasing recreational activities have led to a proliferation of hotel and recreational swimming pools, often with limited regulatory oversight. Data on the bacteriological quality of these pools, particularly in Port Harcourt, remain scarce. This study, therefore, aimed to determine the prevalence of Pseudomonas aeruginosa, assess bacteriological contamination, and evaluate antimicrobial resistance patterns of bacterial isolates from swimming pools in Port Harcourt.

2. Materials and Methods

2.1. Study Design and Area

A cross-sectional study was conducted in Port Harcourt, Rivers State, Nigeria, a major industrial and commercial hub in the Niger Delta region.

2.2. Sample Collection

A total of twelve swimming pools (six hotel pools and six recreational pools) were sampled. Composite water samples (250 mL) were collected aseptically from four different points of each pool and transported on ice for laboratory analysis.

2.3. Physicochemical Analysis

Temperature and pH were measured using calibrated digital instruments.

2.4. Microbiological Analysis

Total heterotrophic bacterial counts were determined using the pour plate method. Isolation and identification of bacteria were performed using standard biochemical tests. P. aeruginosa detection employed selective plating on Cetrimide agar.

2.5. Antimicrobial Susceptibility Testing

The Kirby–Bauer disk diffusion method was used in accordance with CLSI guidelines.

2.6. Statistical Analysis

Descriptive statistics, independent t-tests, Pearson correlation, and Fisher's exact test were applied using a significance level of $p < 0.05$.

3. Results

3.1. Physicochemical Parameters of Water Samples

The analysis of water temperature revealed values ranging from 28.5°C to32.4°C, yielding an overall mean temperature of 29.9 ± 1.2°C. While this mean value falls close to the upper limit of the World Health Organisation (WHO) optimal range, which typically recommends temperatures between 25.0°C and 30.0°C to mitigate microbial risks. A critical observation was that four individual samples (33.3 % of the total) exceeded the 30.0°C threshold. Elevated water temperatures in this range accelerate the metabolic rates of microorganisms, including potential pathogens, thereby promoting rapid proliferation and colonisation.

The pH values for all samples ranged from 7.2 to 8.9, with an overall mean of 7.9 ± 0.6. This means pH value slightly exceeds the WHO optimal range of 7.2 - 7.8, a range specifically chosen to maximise the concentration of hypochlorous acid (HOCl). At an elevated, alkaline pH (above 7.8), the equilibrium of the disinfection chemistry shifts dramatically, favouring the formation of the significantly less potent hypochlorite ion (OCl-). Five samples (41.7 %) registered a pH above 8.0. The non-significant difference observed in mean temperature (p=0.32) and pH (p=0.21) between hotel and recreational pools.

Table 1: *Physicochemical Parameters of Pool Water Sample*

Parameter	Pool Type	N
Temperature (°C)	Overall	12
pH	Overall	12

3.2. Total Heterotrophic Bacterial Count (Thbc)

The THBC values ranged from 6.0×10^1 CFU/mL to 5.3×10^4 CFU/mL. For public health safety, the World Health Organisation (WHO) mandates a standard maximum limit of less than 2.0×10^2 CFU/mL for recreational water. Analysis showed that only five samples (42 %) adhered to this critical threshold, while seven samples (58 %) were in profound non-compliance. The analysis of the mean counts showed that recreational pools experienced a mean THBC of $1.03 \times 10^4 \pm 2.10 \times 10^4$ CFU/mL, which is substantially higher than the mean recorded for hotel pools ($1.26 \times 10^3 \pm 2.07 \times 10^3$CFU/mL).

Table 2. *Total Heterotrophic Bacterial Count (CFU/mL)*

Sample Code	Number Of Colony	Final Thbc (Cfu/Ml)
HP01	85	8.5×10^2
HP02	60	6.0×10^1
HP03	96	9.6×10^2
HP04	54	5.4×10^3
HP05	110	1.1×10^2
HP06	150	1.5×10^2
RP01	135	1.35×10^2
RP02	159	1.59×10^2
RP03	42	4.2×10^2
RP04	182	1.82×10^3
RP05	65	6.5×10^3
RP06	53	5.3×10^4

3.3. Adherence to World Health Organisation Standards

The level of compliance of both hotel and recreational pools with the World Health Organisation (WHO**)** bacterial standard of $< 2.0 \times 10^2$ CFU/mL for safe recreational water shows that hotel pools demonstrated a 50 % compliance rate, with three out of six samples meeting the required standard. While recreational pools showed a lower compliance rate of 33 %**,** as only two of the six samples fell within acceptable limits. Overall, only 5 out of 12 pools (42 %) complied with the WHO guideline, while **7** samples (58 %) exceeded the permissible bacterial limit.

Table 3. *Adherence to WHO Bacterial Standards*

Facility type	Samples that met the Standard	Samples that Exceeded Standard	Compliance rate (%)
Hotel Pools	3	3	50 %
Recreational pool	2	4	33 %
Overall	5	7	42

3.4. Comparative Analysis of Contamination Levels

The raw data showed that recreational pools harboured an average bacterial count eight times greater than that of hotel pools (1.0339×10^4 CFU/ml vs. 1.255×10^3 CFU/ml). This disparity also manifested in the compliance rates: 50 % of hotel pools met the WHO standard, compared to only 33 % of recreational pools. The statistical comparison showed that this substantial numerical difference was not statistically significant. The t-test yielded a p-value of 0.32 for the total heterotrophic (CFU/ml) comparison and 0.33 for the Log10 transformed data. Since both values are significantly greater than the conventional significance threshold of $p < 0.05$, the null hypothesis (that there is no difference between the means) could not be rejected.

Table 4. *Statistical Comparison of Key Metrics across Pool Categories (Hotel vs. Recreational)*

Pool Type	Hotel Mean	Recreational Mean	t - Statistic	p - Value
THBC (CFU/ml	1255	10339	-1.05	0.32
Log_{10} THBC (CFU/ml)	2.61	3.13	-1.01	0.33

3.5. Correlation Analysis of Environmental Factors and Bacterial Load

A statistically significant positive correlation was identified between water temperature and the THBC (r=0.65, p=0.022). The correlation analysis between pH and Raw THBC yielded a moderate positive coefficient (r=0.47). However, this association was not found to be statistically significant (p=0.12).

Table 5. *Correlation Analysis of Environmental Factors and Bacterial Load*

Parameter Pair	Correlation Coefficient (r)	p-Value	Significance ($p < 0.05$)
Temperature vs.THBC(CFU/ml)	0.65	0.022	Yes

pH vs. THBC (CFU/ml)	0.47	0.12	No
Temperature vs. Log_{10}(CFU)	0.44	0.15	No
pH vs. Log_{10}(CFU)	0.39	0.21	No

3.6. Prevalence Rate of Pseudomonas Aeruginosa

The targeted isolation and identification methods, including selective plating on Cetrimide agar, did not yield any isolates of P. aeruginosa from any of the 12 sampled water bodies.

Table 6. *Prevalence of Pseudomonas aeruginosa*

Pool Type	Number of Samples	Samples Positive for *P. aeruginosa*	Prevalence (%)
Hotel Pools	6	0	0 %
Recreational Pools	6	0	0 %
Overall	12	0	0 %

3.7. Isolation and Identification of Pathogenic Species

These isolates include faecal indicator organisms, direct enteric pathogens, and environmental opportunistic pathogens. The isolation of Escherichia coli (2 isolates) and Enterococcus faecalis (1 isolate) confirms active faecal contamination of the pool water. Such contamination poses an immediate risk of waterborne gastroenteritis and urinary tract infections (UTI).

The isolation of Shigella flexneri (1 isolate from recreational pool RP03). S. flexneri is not merely an indicator but a virulent enteric pathogen that is the causative agent of shigellosis (bacillary dysentery). Other isolates included Staphylococcus aureus (1 isolate), a common member of human skin microbiota. The remaining opportunistic organisms isolated included Klebsiella pneumoniae, Proteus mirabilis, and the spore-forming Bacillus cereus, which are ubiquitous in the environment and are capable of causing infections, including pneumonia, UTIs, and toxin-mediated illness.

Table7. *Bacterial Diversity, Occurrence, and Association Health Hazards*

Bacterial Species	Frequency (No. of Isolates)	Sample Sources	Potential Health Risks
Escherichia coli	2	HP04, RP06	Gastrointestinal illness (diarrhoea, vomiting), urinary tract infections; common faecal indicator in pools.
Staphylococcus aureus	1	HP01	Skin infections (e.g., boils, impetigo), pneumonia, sepsis; thrive in poorly chlorinated water.
Klebsiella pneumoniae	1	HP03	Respiratory infections (pneumonia), urinary tract infections; associated with immunocompromised in divid uals.
Enterococcus faecalis	1	HP04	Urinary tract infections, sepsis, and endocarditis; an indicator of faecal contamination.
Shigella flexneri	1	RP03	Shigellosis (severe diarrhoea, dysentery); highly contagious via water.
Proteus mirabilis	1	RP05	Urinary tract infections, wound infections can form biofilms in pools.
Bacillus cereus	1	RP06	Foodborne-like illness (diarrhoea, vomiting); spore-forming, resistant to chlorine.

3.8. Antibiogram to Isolates

Both gram-negative and gram-positive isolates showed high resistance to multiple agents in this class, including Amoxycillin, Ceftazidime, Cefuroxime, and Ceporex (Cephalexin). The Gram-negative isolates retained high susceptibility to the fluoroquinolones (Ofloxacin and Ciprofloxacin) and were also susceptible to Gentamicin.

Table 8. *Antibiogram to Isolates*

Isolate ID	HP01a	HP03a	HP04a	HP04b	RP03b	RP05b	RP06a	RP06b
Bacterial Species	Staphyloc occusaurs	Klebsiella pneumoniae	Escheri chiacoi	Enterococc us faecalis	Shigela flexneri	Proteus mirabilis	Escheric hiacoli	Bacills cereus
Ofloxacin	S (22)	R (13)	S (24)	I (17)	S(23)	S (21)	S (23)	I (18)
Erythromycin	R (10)	I (16)	R (11)	S (22)	R (9)	I (15)	R (12)	S (21)

Amoxycillin	R (8)	R (9)	R (10)	S (21)	R (8)	R (7)	R (9)	R (10)
Ceftazidime	R (12)	S (21)	S (20)	R (13)	S (22)	I (17)	S (20)	R (14)
Gentamicin	S (20)	S (22)	I (16)	S (23)	S (24)	S (22)	I (15)	S (22)
Ciprofloxacin	S (23)	I (17)	S (25)	I (18)	S (26)	S (24)	S (25)	I (17)
Ceporex (Cephalexin)	R (11)	S (20)	R (12)	R (10)	I (16)	R (11)	R (13)	R (12)
Streptomycin	I (15)	R (10)	R (9)	R (12)	I (14)	R (10)	R (8)	I (15)
Cefuroxime	R (13)	S (21)	I (15)	R (11)	S (20)	I (16)	I (14)	R (13)

4. Discussion

This study provides a comprehensive bacteriological assessment of swimming pools in Port Harcourt and offers valuable insight into the public health implications of recreational water use in an urban Nigerian setting.

4.1. Physicochemical Conditions and Microbial Survival

The mean water temperature (29.9 °C) observed in this study falls within a range known to support bacterial survival and proliferation. Elevated temperatures accelerate microbial metabolism and biofilm formation, particularly in inadequately disinfected pools (LeChevallier et al., 2017). The significant positive correlation between temperature and bacterial load ($r = 0.65$, $p = 0.022$) corroborates previous reports from Nigeria and other tropical regions (Adefemi et al., 2018; Eze et al., 2020). Similarly, the observed pH values exceeded the WHO-recommended upper limit (7.8) in nearly half of the samples. Alkaline pH reduces the proportion of hypochlorous acid, the most effective chlorine disinfectant species, thereby diminishing microbial inactivation efficiency (White, 2010). Although pH did not show a statistically significant correlation with THBC in this study, its role in disinfection chemistry remains critical.

4.2. Bacteriological Quality and Compliance with Standards

The finding that only 42 % of pools complied with WHO bacterial standards is alarming. Comparable studies in Lagos, Ibadan, and Benin City have reported similarly low compliance rates, highlighting systemic challenges in recreational water management in Nigeria (Oladipo et al., 2019; Umeaku et al., 2021). The higher bacterial loads observed in recreational pools compared to hotel pools, though not statistically significant, may reflect higher bather density, reduced supervision, and inconsistent maintenance practices in recreational facilities. These trends align with observations reported in Ghana, Egypt, and South Africa (Papadopoulou et al., 2008; El-Shafai et al., 2015).

4.3. Absence of Pseudomonas Aeruginosa

The absence of P. aeruginosa in all sampled pools is noteworthy. While this organism is frequently reported in swimming pools worldwide, its absence in this study may indicate effective chlorination or rapid turnover of pool water (Mena and Gerba, 2009). Similar findings have been reported in studies where chlorine residuals were adequately maintained (Bartram et al., 2015). Importantly, the absence of P. aeruginosa should not be interpreted as overall microbiological safety, as other pathogenic and indicator organisms were isolated in significant numbers.

4.4. Presence of Faecal and Opportunistic Pathogens

The isolation of E. coli and Enterococcus faecalis confirms faecal contamination, likely introduced by bathers or contaminated source water. The detection of Shigella flexneri is of particular public health concern due to its low infectious dose and ability to cause outbreaks of bacillary dysentery through water transmission (Kotloff et al., 2018). The presence of Staphylococcus aureus reflects contamination from human skin and mucous membranes, commonly associated with poor pre-swim hygiene (WHO, 2006). Environmental opportunists such as Klebsiella pneumoniae, Proteus mirabilis, and Bacillus cereus further underscore the microbial diversity capable of persisting in swimming pools.

4.5. Antimicrobial Resistance Patterns

All isolates exhibited multidrug resistance, particularly to beta-lactam antibiotics. This finding mirrors the global trend of increasing antimicrobial resistance in environmental bacteria and raises concerns about recreational waters as reservoirs of resistance genes (Rizzo et al., 2013). The retained susceptibility to fluoroquinolones and gentamicin aligns with reports from aquatic environments in sub-Saharan Africa (Eze et al., 2020).

The public health implication is significant, as infections acquired from swimming pools may be difficult to treat, especially among vulnerable populations.

5. Conclusion

Although Pseudomonas aeruginosa was absent in all sampled swimming pools, the high heterotrophic bacterial counts, low compliance with WHO standards, presence of faecal pathogens, and widespread multidrug resistance present substantial public health risks. Routine microbiological monitoring, strict enforcement of pool management guidelines, public education on hygiene, and regulatory oversight are strongly recommended to ensure the safety of recreational waters in Port Harcourt.

6. Recommendations

1. Mandatory routine microbiological surveillance of swimming pools.
2. Enforcement of WHO-recommended pH and temperature ranges.
3. Regular training of pool operators on disinfection practices.
4. Public health education on pre-swim hygiene.
5. Integration of antimicrobial resistance monitoring in recreational water quality assessments.

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