

Review Article

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Microbial Status and Public Health Implications of *Pseudomonas aeruginosa* in Swimming Pool Waters: Disinfection Challenges and Resistance Patterns

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Abstract

Pseudomonas aeruginosa is an opportunistic and widespread bacterium found in diverse environments such as soil, water, hospital systems, and the human body. It is a major pathogen in aquatic environments, particularly in swimming pools, where it can cause skin infections (e.g., folliculitis), external otitis, and, rarely, systemic infections in vulnerable individuals, including burn patients, cystic fibrosis sufferers, and immunocompromised persons. Its intrinsic and acquired resistance to multiple antibiotics and disinfectants—such as chlorine and hydrogen peroxide—as well as its ability to form biofilms, make it a significant public health concern, especially in moist environments. Contamination in swimming pools often stems from user-related pollution, internal piping systems, and inadequate disinfection practices. Epidemiological data show a high prevalence of *P. aeruginosa* in pool waters globally, with some reports exceeding 60%. Moreover, increasing antibiotic resistance among isolates from aquatic environments—including the presence of beta-lactamase genes such as blaTEM, blaCTX-M, and blaVIM—has raised concerns about the role of swimming pools and urban water sources in the spread of multidrug-resistant (MDR) strains and horizontal gene transfer. Therefore, regular microbial monitoring of pool water, strict adherence to disinfection protocols (especially proper chlorine levels and pH control), user education, and effective wastewater and water source management are essential measures to prevent the spread of this bacterium and associated antimicrobial resistance.

Keywords *Pseudomonas aeruginosa*, Swimming pools, Water quality

Introduction

Water is one of the most essential elements for human life, playing a variety of roles including drinking, hygiene, and recreational use. However, microbial contamination of water can pose serious risks to public health. Epidemiological evidence shows that consumption or contact with contaminated water—whether direct (e.g., ingestion) or indirect (e.g., skin or eye contact, inhalation of water droplets)—can lead to various infectious diseases, including skin, respiratory, gastrointestinal, and even systemic infections. Many pathogenic agents found in aquatic environments are microorganisms introduced into water through human or animal excreta. However, some, such as *Pseudomonas aeruginosa*, are opportunistic bacteria capable of thriving in diverse environments—including soil, water, and moist surfaces—and surviving

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under unfavorable conditions (Manaia et al., 2018; Devarajan et al., 2017). Microbial contamination in swimming pools may involve bacterial, viral, fungal, and parasitic pathogens. Therefore, establishing precise hygienic standards and criteria for pool water quality plays a crucial role in preventing waterborne illnesses. In assessing the microbiological quality of swimming pool water, both physical and microbial indicators are highly significant. These include pH, turbidity, residual chlorine levels, total heterotrophic bacteria counts, presence of coliforms, *Escherichia coli*, *Staphylococcus aureus*, and especially *Pseudomonas aeruginosa* (WHO, 2023). Among these, *P. aeruginosa* is recognized as one of the most important pathogenic agents in recreational water environments. This bacterium exhibits high resistance to many disinfectants and can proliferate under favorable environmental conditions, such as elevated temperature and humidity. *P. aeruginosa* is the primary cause of skin infections (e.g., folliculitis), external ear infections (otitis externa), and in rarer cases, systemic infections in immunocompromised individuals, burn patients, and those suffering from cystic fibrosis (Wood et al., 2023; Trautmann et al., 2022). The presence of this bacterium in swimming pools often originates from infected users — particularly those with wounds or skin infections — although environmental factors such as high temperature, humidity, and insufficient chlorine levels also contribute to increased microbial load and spread of the species (Brett & du Vivier, 1985). Exotoxin A is one of the most important virulence factors of this bacterium, playing a key role in triggering severe inflammatory responses. In addition to fecal indicators, non-fecal indicators such as *P. aeruginosa* and *S. aureus* are also significant in evaluating the sanitary quality of swimming pool water. *P. aeruginosa* indicates favorable bacterial growth conditions in the aquatic environment, while *S. aureus* often reflects the introduction of body fluids (such as sweat, saliva, or skin materials) by swimmers into the pool water (Silvestry-Rodríguez et al., 2007). Thus, the development and implementation of comprehensive standards, along with regular monitoring of pool water quality, are fundamental strategies for protecting swimmer health and preventing waterborne diseases. Pool water standards should define acceptable limits for all qualitative indicators — especially microbial ones — and incorporate educational programs for swimmers to prevent transmission of pathogens (WHO, 2023; ASAS, 2021).

Literature Search Strategy

A comprehensive literature search was conducted using PubMed, Scopus, and Web of Science to identify studies on *Pseudomonas aeruginosa* in swimming pools. Key

terms such as “*Pseudomonas aeruginosa*”, “swimming pool”, “disinfection resistance”, and “antibiotic resistance” were combined using standard search operators (AND, OR) to improve accuracy. Peer-reviewed articles in English focusing on microbial contamination, resistance, or public health were included. Studies were selected through screening of titles, abstracts, and full texts. Reference lists were also reviewed to identify additional relevant sources. Findings were synthesized thematically.

Bacteriology and Ecology of *Pseudomonas aeruginosa*

Pseudomonas aeruginosa is an obligate aerobic, Gram-negative, rod-shaped bacterium widely distributed across different environments. It is capable of surviving under a wide range of environmental conditions — from soil and water to human tissues — and utilizes simple organic sources as carbon and energy substrates (Spagnolo et al., 2021). Due to surface components such as flagella, pili, and other adhesion factors, this bacterium can attach to various surfaces — both natural and man-made, including medical equipment — and persist in these environments. *P. aeruginosa* is recognized as one of the most significant pathogenic agents in clinical, hygienic, and public health settings. It is commonly isolated from water sources (drinking water, swimming pools, hot tubs), soil, plants, and even within the human body (Silvestry-Rodríguez et al., 2007). Phylogenetic classification based on 16S ribosomal RNA gene sequences has placed *Pseudomonas* within the Proteobacteria phylum, specifically the Gammaproteobacteria group. This categorization highlights its importance among opportunistic bacteria (Rodríguez & Vogler, 2023).

Virulence Characteristics and Clinical Implications

Pseudomonas aeruginosa is an opportunistic pathogen capable of causing severe, and sometimes life-threatening infections, particularly in immunocompromised individuals such as neutropenic patients, HIV-positive individuals, burn victims, and those undergoing chemotherapy (Moradali et al., 2017). It is recognized globally as one of the leading causes of nosocomial infections and antimicrobial resistance. This bacterium has been associated with a wide range of clinical conditions, including ventilator-associated pneumonia (VAP), intravenous line infections, surgical site infections, urinary tract infections, burn wound infections, keratitis (corneal infection), and both external and middle ear infections (Ito et al., 2021; Tuon et al., 2012). Moreover, *P. aeruginosa* is among the most common causes of hospital-acquired infections in ICU patients and individuals with weakened immune systems. Its ability to resist many antimicrobial agents stems from various resistance mechanisms, including efflux

pumps, modifications in the outer membrane, and antibiotic-degrading enzymes (Moradali et al., 2017).

Pathogenic Mechanisms and Environmental Adaptation

The complex genome of *P. aeruginosa*, containing a large number of regulatory and metabolic genes, enables it to survive under diverse environmental conditions and cause widespread infections (Maurice et al., 2018). Among its most notable virulence features are:

1. Mucoïd Layer (Biofilm Formation)

A thick layer of mucoïd exopolysaccharides—particularly alginate—is formed on the bacterial surface, especially in patients with cystic fibrosis (CF). This layer can exceed the weight of the bacterial cell itself and plays a critical protective role against the host immune system and antimicrobial agents (Maurice et al., 2018).

2. Microcolony Formation

This mucoïd layer facilitates bacterial adhesion and the formation of microcolonies in the lungs and other organs. These bacterial aggregates exhibit high resistance to phagocytosis and components of the human innate immune system.

3. Virulence Factors

Factor	Role in Pathogenesis
Pili and Fimbriae	Mediate attachment to host cells
Exotoxin A	An extracellular toxin present in over 90% of clinical strains, playing a key role in host cell destruction (Bernard et al., 1999)
Type III Secretion System (T3SS)	Direct delivery of toxins into host cells

These virulence factors act synergistically, inducing inflammatory responses, tissue damage, and immune evasion, which contribute significantly to the pathogenicity of this organism.

Ecology and Environmental Survival of *Pseudomonas aeruginosa*

Pseudomonas aeruginosa is a highly resilient and adaptable bacterium commonly found in aquatic sources, soil, moist surfaces, water distribution systems, and medical equipment. Notably, it can persist even under conditions of low chlorine levels or exposure to weak disinfectants (Silvestry-Rodríguez et al., 2007).

1. Resistance to Amoebae

P. aeruginosa exhibits resistance to free-living amoebae

such as *Acanthamoeba*. This survival ability is often associated with biofilm formation, secretion systems, and virulence factors that enable the bacterium to remain viable inside or outside phagocytic cells (Brandes et al., 2022). Such interactions may contribute to its persistence in natural and man-made environments where amoebae are present.

2. Broad Environmental Tolerance

This bacterium demonstrates a wide range of environmental adaptability. It is capable of surviving under varying:

- Temperature conditions, from ambient to up to 42°C,
- Osmotic conditions, including high salt concentrations,
- pH ranges, allowing it to thrive in both acidic and alkaline environments.

This versatility enhances its ability to colonize diverse ecological niches and contributes to its role as an important opportunistic pathogen.

3. Entry into VBNC State (Viable But Non-Culturable)

Under stressful environmental conditions — such as nutrient depletion or exposure to disinfectants — *P. aeruginosa* can enter a viable but non-culturable (VBNC) state. In this physiological state, bacterial cells remain alive and metabolically active at a minimal level but are not detectable using standard culture-based methods. However, these cells retain the potential to regain full metabolic activity and pathogenicity when favorable conditions return (Dey et al., 2019). The VBNC state represents a significant challenge for microbial monitoring in water systems, as conventional detection techniques may fail to identify the organism despite its presence and viability.

Biofilm Formation and Quorum Sensing

Biofilm formation is one of the most critical mechanisms contributing to the survival and persistence of *Pseudomonas aeruginosa* in both clinical and environmental settings. A biofilm is a complex, carbohydrate-protein matrix that forms around bacterial communities, offering protection against antimicrobial agents, host immune responses, and environmental stressors (Bonadonna et al., 2008). *P. aeruginosa* employs a cell-to-cell communication system known as quorum sensing (QS), which enables the bacterium to coordinate collective behaviors such as biofilm development, toxin production, and expression of virulence factors. The QS network in this organism consists of multiple signaling systems — including LasIR, RhlIR, PQS, and IqsIR — that operate in a hierarchical manner (Lee et al., 2015). These systems regulate gene expression in response to population density, allowing the bacteria to adapt effectively to changing conditions and enhancing their pathogenic potential.

Table 1: Prevalence of *P. aeruginosa* Contamination in Swimming Pools Across Different Regions

Country	Contamination Rate (%)	Source	Year
Iran	0% – 63.6%	Firuzi & Hajjartabar	2004–2020
Egypt	3.3% – 21.7%	Abd El-Salam & Aboulfotoh	2012–2017
Italy	19.10%	Dallolio et al.	2013
Northern Ireland	38%	Moore et al.	2002
China	69.20%	Wei et al.	2018

Persistence in Clinical and Public Environments

Pseudomonas aeruginosa has the ability to colonize various surfaces, including medical equipment, hospital water lines, and moist public areas such as sinks, swimming pools, and jacuzzis, where it can lead to disease outbreaks (Trautmann et al., 2022). This bacterium can also be found in the human gastrointestinal tract, on skin surfaces, and in fecal matter, serving as a source of environmental contamination. Its capacity to grow in mild disinfectants, salts, and soaps has made it a significant challenge in public health and hygiene management (Silvestry-Rodríguez et al., 2007). Given its unique characteristics — high antibiotic resistance, biofilm-forming capability, presence of quorum sensing systems, and persistence in challenging environments — *P. aeruginosa* is recognized as an important opportunistic pathogen with major implications for global public health, environmental hygiene, and the spread of antibiotic resistance.

Swimming Pools and the Importance of Water Quality in Preventing Bacterial Infections

The use of safe and clean water in recreational and sports facilities has significant impacts on public health, physical fitness maintenance, and even physiological rehabilitation. Therefore, swimming pools are increasingly recognized as essential components of global health tourism — not only as leisure spaces but also as therapeutic centers for hydrotherapy programs in physiotherapy and healthcare facilities (Darija et al., 2021). However, prolonged exposure to water and associated moist environments increases the risk of microbiological and chemical contamination. This issue becomes particularly relevant when pools are used by large numbers of individuals, including those with weakened immune systems — such as patients with chronic diseases, cancer patients undergoing chemotherapy, elderly individuals, and children.

Pseudomonas aeruginosa: A Major Challenge in Swimming Pools

Pseudomonas aeruginosa is among the most important pathogenic agents in aquatic environments. Due to its high resistance to disinfectants and its ability to form pro-

TECTIVE biofilms, it poses significant management challenges in swimming pools (Trautmann et al., 2022). This bacterium thrives in warm and humid environments, such as hot tubs and heated pools, where it can cause folliculitis, external ear infections (otitis externa), and other skin-related illnesses (Spagnolo et al., 2021).

The presence of *P. aeruginosa* in pool water typically originates from:

- Direct contact with infected users
- Fecal or non-fecal shedding (e.g., sweat, saliva)
- Contamination of internal piping systems
- Inadequate cleaning and maintenance access to remote areas

Therefore, detection of this bacterium in pool water samples may indicate poor facility management and insufficient adherence to hygiene practices by users (WHO, 2006).

Chlorination and the Importance of Proper Concentration

Chlorine is one of the most commonly used disinfectants in swimming pools. However, *Pseudomonas aeruginosa* possesses catalase enzymes that enable it to neutralize low concentrations of chlorine, making it particularly challenging to control (Darija et al., 2021). Studies have shown that in more than 72% of positive water samples from swimming pools, the residual chlorine concentration was below 0.5 mg/L. The minimum recommended levels for effective bacterial control are approximately 1 mg/L for general public pools and up to 3 mg/L for spas or jacuzzis. A significant inverse correlation has been observed between residual chlorine levels and bacterial counts ($r_s = -0.16$), indicating that maintaining chlorine within recommended ranges plays a crucial role in limiting the survival and proliferation of this pathogen (Abd El-Salam et al., 2012). Although hydrogen peroxide is often introduced as an odorless and non-corrosive disinfectant, *P. aeruginosa* can develop resistance to low concentrations due to its catalase activity. Research indicates that in pools using only hydrogen peroxide for disinfection, contamination rates reached 32.4%. In contrast, facilities employing sodium hypochlorite or chlorine re-

ported contamination levels of 3.8% and 4.8%, respectively. Therefore, the use of hydrogen peroxide alone is not recommended. Instead, it should be combined with ultraviolet (UV) light or ozone to enhance disinfection efficiency (Fraise et al., 2019).

These variations may be attributed to multiple factors, including disinfection methods, pool type, water quality monitoring practices, and user hygiene behaviors.

Water Quality Indicators and Pool Management

The World Health Organization (WHO, 2006) guidelines on recreational water environments emphasize the importance of regular water quality monitoring in swimming pools and similar settings. These guidelines include:

- pH control : Recommended range of 7.2–7.8
- Free chlorine concentration : 2–4 ppm for general pools and 4–6 ppm for spas/Jacuzzis
- Bromine concentration : 3–6 ppm

Additionally, the guidelines stress the importance of swimmer education, appropriate pool design, and routine hygiene protocols. Maintaining these standards significantly reduces the need for frequent microbiological testing for microbial indicators such as *P. aeruginosa* (WHO, 2006).

Infections Associated with Swimming Pools and Recreational Water Environments

Recreational water environments such as swimming pools, Jacuzzis, and hydrotherapy tanks can serve as important sources of *P. aeruginosa* transmission. The warm water and high humidity in these environments provide ideal conditions for bacterial growth.

Common Infections:

- Folliculitis: Often occurs in pools with insufficient chlorine levels.
- External otitis (swimmer's ear): Frequently reported among individuals who are constantly exposed to water, such as swimmers and children.
- Skin abscesses and infections: Typically observed in individuals with damaged skin or open wounds.

Studies have shown that pools relying solely on hydrogen peroxide as a disinfectant exhibit higher contamination rates. Therefore, combined use of chlorine with UV or ozone is strongly recommended to improve disinfection efficacy (Fraise et al., 2019).

Antibiotic Resistance of *Pseudomonas aeruginosa* in Aquatic Environments

Pseudomonas aeruginosa is an opportunistic and ubiquitous bacterium capable of thriving in a wide range of environments — from soil and water to hospital settings

(Rahmani-Badi et al., 2021). Due to its complex and adaptable genome, this organism exhibits resistance to a broad spectrum of antibiotics and can persist even under disinfectant pressure (Poole, 2004). This issue becomes particularly significant in aquatic environments such as surface waters, wastewater, drinking water sources, swimming pools, and hospital plumbing systems, where these habitats may act as reservoirs for antibiotic resistance genes (El-Sayed Ahmed et al., 2020). The pathogenic significance of *P. aeruginosa* in clinical and public health contexts is largely attributed to multiple antibiotic resistance mechanisms it possesses, including:

- Efflux pumps , such as MexAB-OprM and MexXY-OprM, which actively expel antibiotics from the cell,
- Impermeable outer membrane , limiting antibiotic penetration,
- Antibiotic-degrading enzymes , like beta-lactamases and aminoglycoside-modifying enzymes,
- Biofilm formation, which enhances bacterial survival and reduces susceptibility to antimicrobial agents (Li, Plésiat & Nikaido, 2015).

Moreover, *P. aeruginosa* demonstrates resistance not only to conventional antibiotics but also to some disinfectants, such as chlorine and hydrogen peroxide (Ocampo-Sosa, Fleitas-Martínez & Martínez-Martínez, 2021). In aquatic environments, this bacterium is capable of:

- Re-establishing viability in contaminated water,
- Surviving exposure to disinfectants,

Transferring resistance genes to other bacteria through horizontal gene transfer mechanisms, including conjugation, transformation, and transduction (Donlan, 2002). Antibiotic resistance in *P. aeruginosa* arises from a combination of intrinsic genetic traits and environmental selective pressures. Its large and versatile genome enables it to develop various resistance strategies, including enzymatic degradation of antibiotics, modification of drug targets (e.g., ribosomes and DNA gyrase), and active efflux of antimicrobial compounds (Breidenstein, de la Fuente-Núñez & Hancock, 2016). However, the primary driver of resistance development in aquatic environments is the presence of residual antibiotics in wastewater and urban or hospital water supplies. These antibiotics exert selective pressure that promotes the proliferation of resistant strains. When combined with genetic exchange processes in water environments, such as gene transfer via conjugation or transformation, they contribute to the rapid global spread of antibiotic resistance (Zhang et al., 2019).

Field Examples of Resistance Spread in Aquatic Settings

Studies from various regions highlight the role of water en-

Table 2: Antibiotic Resistance Rates and Identified Resistance Genes of *Pseudomonas aeruginosa* in Aquatic Environments

Iran (Tehran)	47% resistance to cephalosporins	blaTEM	Atharinia et al. 2023
China	69.2% resistance to common antibiotics	blaCTX-M, blaTEM	Wei et al. 2018
Egypt	21.7% resistance to ceftazidime and imipenem	blaSHV, KPC	Abd El-Salam & Aboufotouh 2017
Italy	19.1% multidrug resistance (MDR)	OXA, VIM	Dallolio et al. 2013
Northern Ireland	38% resistance to co-trimoxazole and cephalosporins	VIM, CTX-M	Moore et al. 2002

vironments in the dissemination of resistant *P. aeruginosa*: In Iran, 47% of isolates from drinking water samples were found to carry the blaTEM gene.

In China, 69.2% of swimming pool water samples contained strains resistant to cephalosporins and carbapenems.

In Egypt, resistance to ceftazidime and imipenem has been reported.

In Italy, 19.1% of tested water samples harbored multidrug-resistant (MDR) strains.

In Northern Ireland, 38% of swimming pools were found to contain isolates resistant to co-trimoxazole and cephalosporins.

These findings suggest that swimming pools, drinking water sources, and hospital water systems can serve as both reservoirs and transmission routes for antibiotic-resistant strains.

Challenges in Controlling Resistance in Aquatic Environments

Several factors contribute to the persistence and spread of antibiotic resistance in aquatic environments:

1. Biofilm Formation

P. aeruginosa readily forms biofilms on moist surfaces, pipes, and water filters. These biofilms act as protective matrices that shield bacteria from antimicrobials and disinfectants, facilitating long-term survival and resistance development.

2. Catalase Activity and Resistance to Hydrogen Peroxide

P. aeruginosa produces catalase, an enzyme that neutralizes hydrogen peroxide by converting it into oxygen and water. Consequently, relying solely on hydrogen peroxide for disinfection in swimming pools is ineffective and not recommended. Combining UV light or ozone with chlo-

rine is considered a more effective strategy for microbial control.

3. Low Chlorine Levels and Improper pH

Studies have shown that in over 72% of positive pool water samples, residual chlorine concentrations were below 0.5 mg/L. The World Health Organization (WHO) recommends maintaining free chlorine levels between 2–4 ppm in general pools and 4–6 ppm in spas. Additionally, the pH should be kept within the range of 7.2–7.8 to ensure optimal chlorine efficacy.

4. Transmission of Resistant Strains to Humans

Resistant strains can enter the human body through contaminated water, direct contact with infected surfaces, or inhalation of water droplets. Immunocompromised individuals — including HIV-positive patients, burn victims, and those undergoing chemotherapy — are at higher risk of severe infections caused by these strains.

5. Dissemination of Resistance Genes in Water Environments

Resistance genes such as blaTEM, blaCTX-M, blaSHV, OXA, and VIM have been detected in water and wastewater samples worldwide. These genes can horizontally transfer among bacterial populations in aquatic environments, leading to the emergence of multidrug-resistant (MDR) and even extensively drug-resistant (XDR) strains.

Epidemiological and Field Data

Numerous studies conducted worldwide have highlighted the critical role of aquatic environments in the dissemination of antibiotic resistance among *Pseudomonas aeruginosa*. The following data summarize key findings from different regions:

Table 3: Resistance Mechanisms to Antibiotics

Mechanism	Role in Antibiotic Resistance
Efflux pumps	Actively expel antibiotics from the bacterial cell, reducing intracellular drug concentration
Outer membrane modifications	Decrease antibiotic penetration by altering porin channels and lipid composition
Antibiotic-hydrolyzing enzymes	Degrade or modify antibiotics, rendering them ineffective (e.g., beta-lactamases)
Biofilm formation	Provides a protective barrier against disinfectants, immune responses, and antimicrobial agents
Quorum Sensing (QS) systems	Regulate toxin secretion, biofilm development, and bacterial proliferation under environmental stress

These findings demonstrate that improper water management and inadequate disinfection practices significantly contribute to the spread of antibiotic resistance genes in aquatic settings. Effective control strategies, including regular monitoring and optimized disinfection protocols, are essential for limiting horizontal gene transfer and preventing the emergence of resistant bacterial strains in public water systems.

Resistance Mechanisms in Aquatic Environments

P. aeruginosa possesses a range of adaptive mechanisms that enable it to persist and thrive in aquatic environments while evading antimicrobial interventions. These mechanisms also play a crucial role in its antibiotic resistance profile:

These adaptive traits allow *P. aeruginosa* to survive under selective pressures imposed by antibiotics and disinfectants, making it a persistent challenge in water quality management. Understanding these mechanisms is essential for developing targeted interventions to reduce bacterial persistence and limit the spread of resistance in recreational and healthcare water systems.

Conclusion

In several studies, it has been reported that the contamination level of swimming pools with *Pseudomonas aeruginosa* often exceeds the permissible limits set by national and international standards (Ahmadi et al., 2018; Abd El-Salam & Moussa, 2012; WHO, 2008). This concerning situation may be attributed to deficiencies in pool water disinfection systems, such as insufficient concentrations of disinfectants like chlorine, inappropriate pH levels, or uncontrollable fluctuations in chemical parameters of the water. Authoritative health organizations, including the UK Health Security Agency (UKHSA) and the U.S. Environmental Protection Agency (EPA), have emphasized the importance of adhering to disinfection protocols and

conducting regular monitoring of pool water quality (UK Health Security Agency, 2023; U.S. EPA, 2014). Moreover, findings regarding antibiotic resistance patterns of *P. aeruginosa* strains isolated from swimming pool waters are highly alarming. This bacterium can readily develop resistance to multiple classes of antibiotics and may cause severe, difficult-to-treat infections if transmitted to susceptible individuals. Therefore, there is a pressing need for updated and more rigorously implemented public health and surveillance programs at public swimming pools. In Iran, ISIRI 9412 a standard specifying microbiological requirements for swimming pool water declares the presence of *Pseudomonas aeruginosa* in any quantity unacceptable (ISIRI 9412, 2012). However, results from several domestic studies indicate that the current performance of water quality control and monitoring systems does not adequately align with this standard. This highlights weaknesses in the management of pool hygiene and underscores the necessity of strengthening oversight and educational initiatives. Although *Pseudomonas aeruginosa* remains a predominant opportunistic pathogen in swimming pools, the presence of other bacterial agents such as *Legionella pneumophila*, *Escherichia coli*, and *Staphylococcus aureus* can also pose significant health risks under certain conditions. Extensive research has demonstrated that *Pseudomonas aeruginosa* is one of the most significant opportunistic pathogens in aquatic environments, particularly in swimming pools. Due to its high intrinsic resistance to many disinfectants, biofilm-forming capacity, and adaptability to changing environmental conditions, this bacterium can persist in pool water and pose a serious threat to swimmer health. Skin infections, external otitis, and, in rare cases, systemic infections are among the clinical consequences of exposure to contaminated water particularly in immunocompromised individuals or those with open wounds. Furthermore, the increasing prevalence of antibiotic resistance in *P.*

aeruginosa within recreational water environments raises significant concerns regarding the control and treatment of infections caused by this organism. The presence and horizontal transfer of resistance genes among bacterial populations play a critical role in the spread of antimicrobial resistance at the community level. This highlights the urgent need for improved water quality management and continuous monitoring of recreational water systems. To mitigate these risks, strict adherence to hygiene standards, regular monitoring of physical and microbial indicators in pool water, and the implementation of effective disinfection methods such as combined chlorine, UV light, or ozone are essential. In addition, user education, promotion of personal hygiene, proper wastewater management, reduced misuse of antibiotics, and strengthened surveillance programs are key strategies to prevent the transmission and outbreak of *P. aeruginosa*, particularly multidrug resistant (MDR) strains. Ultimately, collaboration between environmental health authorities, pool managers, and users supported by increased public awareness about the risks of microbial contamination in water can significantly contribute to the protection of public health and the reduction of waterborne disease burden.

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