Bacterial Contamination on Beaches by Contaminated Effluents and Its Effect on Public Health: A Case Study in La Libertad, Peru

Luis A. Cabanillas-Chirinos[1,2,*], Karen Diaz del Aguila[2], Yanina Rey-Vilela[2,3], Vicky S. Mariños-Lozada[2,3]

[1]Institutos y Centros de Investigación, Universidad Cesar Vallejo, Trujillo, Peru
[2]Grupo de Investigación en Resistencia Bacteriana y Aplicación Biotecnológica de los Microorganismos, Cesar Vallejo University, Trujillo, Peru
[3]Faculty of Health Sciences, Cesar Vallejo University, Trujillo, Peru
Email: lcabanillas@ucv.edu.pe (L.A.C.H.); kdiazd@ucv.edu.pe (K.D.A.); yrey@ucv.edu.pe (Y.R.V.); vmarinosl@ucvvirtual.edu.pe (V.M.L.)
[*]Corresponding author

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***Abstract*—Beaches have become very popular tourist destinations for both local and international visitors. However, the bacterial contamination they suffer from constitutes an environmental and public health issue that affects numerous coastal communities worldwide. This study aims to investigate and understand the dynamics of bacterial contamination in beaches due to contaminated effluents. A total of twenty samples were collected from four selected sites (P1: contaminated river, P2: mixing zone, P3 and P4: one kilometer to the left and right of the mixing zone) in the district of Víctor Larco, La Libertad, between October and December 2024. Standardized microbiological techniques and procedures, along with the Vitek2 system, were used to identify bacterial groups and species. The results indicated high levels of microbiological contamination, with elevated concentrations of thermotolerant coliforms and *Escherichia coli,* making the area unsuitable for recreational use. *E. coli* was the most prevalent bacterium, alongside *Enterococcus faecalis, Enterobacter cloacae, Enterobacter aerogenes,* and *Proteus mirabilis*. Furthermore, it was found that 3 of the 20 strains of *E. coli* showed higher resistance to Ampicillin (AMP), Ceftriaxone (CRO), Ciprofloxacin (CIP), and Gentamicin (GEN), while all other strains of *E. coli, E. faecalis, E. cloacae, E. aerogenes,* and *P. mirabilis* were sensitive to the 11 antibiotics evaluated. The research concludes that the discharge of wastewater in coastal areas and exposure to contaminated waters can cause infections and diseases in swimmers, especially during the high summer season when the influx of people to beaches is higher.**

***Keywords*—wastewater, antibiotic resistance, coastal contamination, public health**

I. Introduction

Globally, beaches are highly attractive tourist destinations that capture the attention of both local and international tourists, especially during the summer season, when visitors flock in search of relaxation and entertainment [1–3]. Following the COVID-19 pandemic, beaches have become highly frequented coastal and marine meeting points, where people engage in various activities such as swimming, surfing, sunbathing, and enjoying local cuisine. Furthermore, beaches offer an ideal space for disconnection and enjoyment of nature, providing unique experiences for those seeking adventure as well as those longing for tranquility and well-being [3–5]. The growing popularity of these destinations underscores the importance of maintaining environmental quality and health safety in these settings to ensure a pleasant and healthy experience for all visitors [6–8].

Bacterial contamination on beaches is a global environmental and public health issue, affecting numerous coastal communities worldwide. This problem is primarily due to the discharge of contaminated effluents, including untreated wastewater, industrial waste, and agricultural runoff, which introduce pathogenic bacteria into the marine environment [9–11]. These microorganisms can cause diseases in humans, such as gastrointestinal and skin infections [12, 13], and also disrupt aquatic ecosystems, jeopardizing biodiversity and water quality [14–16].

Over time, seas and oceans have been used as dumping grounds for domestic and industrial waste, with devastating consequences for the marine environment. Alongside population growth, this problem is increasing globally as densely populated areas generate a higher volume of domestic and industrial waste that often ends up in seas and oceans through direct or poorly managed discharges into rivers [2, 17]. Between 80% and 90% of wastewater is discharged without adequate treatment into natural water bodies, ultimately reaching marine ecosystems. This practice is more common in developing countries, where waste dumped into rivers reaches the sea and affects marine life and coastal ecosystems [18–20].

Swimming in beaches with contaminated water or sand can cause illnesses, with children, the elderly, and people with weakened immune systems being the most vulnerable [12, 21]. International organizations such as the World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) have indicated that various substances present in beach water can cause serious health problems, especially for swimmers [14]. Gastrointestinal and skin diseases are the most common when coming into contact with or ingesting contaminated seawater. Gastroenteritis is the most frequent illness, presenting symptoms such as nausea, vomiting, stomach pain, diarrhea, headache, or fever. Additionally, contact with contaminated water on the skin, eyes, or open wounds can cause mild infections, which, if not treated properly, can become severe [8, 9, 13].

Studying bacterial contamination on beaches is of paramount importance and crucial for public health due to the significant negative effects this contamination can have on both aquatic ecosystems and human health. Contaminated effluents that discharge onto beaches can contain pathogenic bacteria such as *Escherichia coli* and enterococci, which pose a direct risk to swimmers and visitors to these recreational areas. Additionally, the degradation of water quality can have long-term consequences on the biodiversity and productivity of aquatic ecosystems. In this context, investigating and understanding the dynamics of bacterial contamination on beaches is essential for developing effective mitigation and protection strategies for public and environmental health, thereby ensuring the sustainability and well-being of coastal communities.

II. Literature Review

Peru is a country that boasts a great diversity of beaches, ranging from serene and peaceful to lively and bustling, making them suitable for all types of visitors. The beaches located on the northern coast are especially popular and frequently visited by families, groups of friends, and foreign tourists [2, 21]. Currently, the country's beaches face significant challenges related to bacterial contamination. Recent studies have shown high levels of fecal bacteria in several popular beaches, such as those located in Lima and northern Peru. In the latest evaluation conducted at the beginning of 2024, out of 312 beaches assessed, 78 had bacterial concentrations exceeding the recommended safety levels for swimmers [22–24].

This situation has worsened due to insufficient infrastructure for wastewater treatment and the uncontrolled growth of urban and tourist areas, affecting the health of swimmers and the integrity of coastal ecosystems. This underscores the urgent need to implement effective management measures and policies to control and reduce bacterial contamination in these regions [11, 14].

In other studies, reporting the presence of thermotolerant coliforms in both seawater and marine species, bacteria have been isolated and identified to evaluate their sensitivity and resistance to different antibiotics [24–26]. The results obtained reveal the existence of enteropathogenic *Escherichia coli* (EPEC) cultures resistant to penicillins and sulfonamides [27] as well as strains of *Proteus vulgaris*, *Enterobacter* sp., and *Klebsiella* spp. resistant to quinolones [26].

III. Materials and Methods

A. Study Area

The chosen area was the mixing zone of seawater from Buenos Aires beach with river water, where treated wastewater from the Cortijo and Covicorti Treatment Plants is discharged. This is located in the Buenos Aires resort, district of Víctor Larco, La Libertad, Peru (see Fig. 1). Coordinates: UTM 17 L 0712895, 9100614 (GPS device: GARMIN ETREX 30X).

The sampling area was selected because all the wastewater from PTAR-Cortijo and PTAR-Covicorti is discharged into this river [28]. Additionally, it is adjacent to the beaches of the Huanchaco district, La Libertad, which are considered among the most popular and frequented by families, groups of friends, and foreign visitors [4, 17].

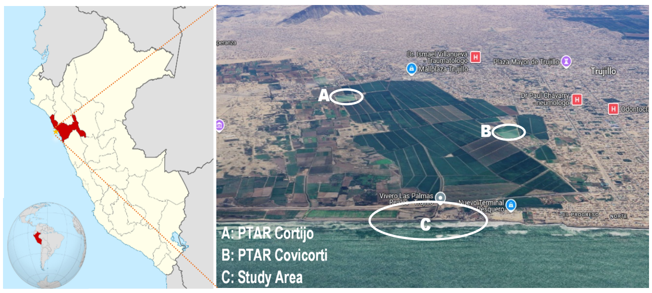

Fig. 1. Geographic location of the chosen study area - Buenos Aires resort, Víctor Larco district, La Libertad region, Peru.

B. Sample Collection

The sampling was conducted over approximately 10 weeks, with five collection sessions, taking one sample every two weeks. The primary objective was to capture the variability in water quality before the summer tourist season of 2025 (during the months of October and December 2024). In each session, four samples were collected from strategic points: river water before the mixing zone (P1), water directly from the mixing zone (P2), and seawater sampled one kilometer to the left (P3) and one kilometer to the right (P4) of the mixing zone (see Fig. 2). By the end of the five sampling sessions, a total of 20 samples were obtained, allowing for an assessment of the influence of effluents in different aquatic environments.

The samples were collected during the spring season on October 7 and 22, November 6 and 21, and December 9, 2024. During this period, the sea surface temperature ranged from 16.0 to 16.4 °C, while the sea surface salinity varied between 35.05 and 35.09 SSM, according to data obtained from the Instituto del Mar del Peru (IMARPE) (https://siofen.imarpe.gob.pe/nivel2/estaciones-costeras).

The difference between the samples collected in the mixing zone and those taken from the sea lies in their composition: at P2, the water represents a more direct combination of river discharges with seawater, whereas at P3 and P4, the degree of dilution and potential mitigation of contaminant impact was analyzed. Through this sampling strategy, a contamination gradient was established, providing a clearer understanding of the interaction dynamics between wastewater and the marine ecosystem.

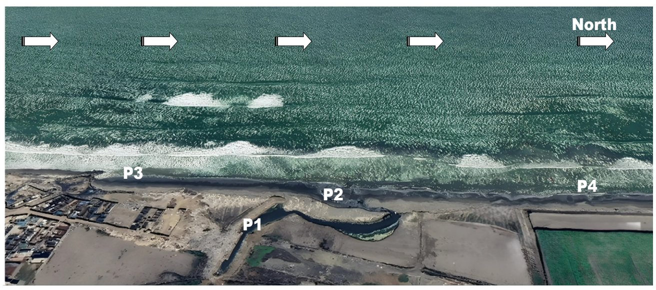

Fig. 2. Geographic location of the sampling points in the study area located in the Buenos Aires resort, Víctor Larco district, La Libertad, Peru. (**P1**: river before the mixing zone; **P2**: mixing zone; **P3**: one kilometer to the left of the mixing zone; and **P4**: one kilometer to the right of the mixing zone).
Note: *The arrows indicate the direction of the ocean current. In La Libertad, Peru, we are influenced by the Peruvian Current, which flows from south to north.*

Collection of Samples The collection of seawater samples was carried out according to the Technical Guide "Procedures for Sampling Seawater on Bathing and

Recreational Beaches" RM N° 553-2010/MINSA issued by the Directorate General of Environmental Health [29].

The samples were collected near the shore by submerging a sterile 500 ml bottle at points where the water depth was approximately 1 meter. The sampling bottle was submerged approximately 30cm below the water surface against the current until it was 2/3 full. The bottle was then sealed, labeled, and stored in an isothermal cooler at 4°C for transport to the laboratory at the Institutes and Research Centers of Cesar Vallejo University - Trujillo Campus (see Fig. 3) where microbiological studies were conducted.

Fig. 3. Collection of water samples. (A) Collection of water samples in the mixing zone; (B) Collection of seawater; and (C) Labeling and storage of the sample for transport to the laboratory.

C. Determination of Thermotolerant Coliforms and E. coli

To determine the presence of thermotolerant coliforms and *Escherichia coli*, analyses were conducted bi-weekly using the Most Probable Number (MPN) technique, also known as multiple tube fermentation, following the guidelines established in the Standard Methods for the Examination of Water and Wastewater [30].

This procedure was carried out by inoculating seawater samples into a series of 5 tubes with decreasing dilutions. It started by inoculating 10 mL of samples into 10 mL of double-strength Lauryl Sulfate Tryptose broth (LST-2N), followed by inoculating 1 mL of the respective dilution (10^{-1}, 10^{-2} to 10^{-6}) into tubes with 10 mL of Lauryl Sulfate Tryptose broth (LST) during a presumptive phase. The inoculated tubes were incubated at 36°C for 24 to 48h. Tubes that were presumptively positive were subjected to a confirmatory test for thermotolerant coliforms and *E. coli* using EC broth. In this stage, an aliquot from the positive tubes of the presumptive phase was inoculated into tubes with EC broth and then incubated in a water bath at 44.5°C for 24h.

To confirm the presence of thermotolerant coliforms, turbidity and gas production (bubbles) within the inverted Durham tube in the EC broth were observed. Results were calculated using the Most Probable Number (MPN) tables and expressed in MPN/100 mL. To confirm the presence of *E. coli*, the indole test was conducted, and characteristic growth on MacConkey agar and Eosin Methylene Blue (EMB) agar was verified (see Fig. 4).

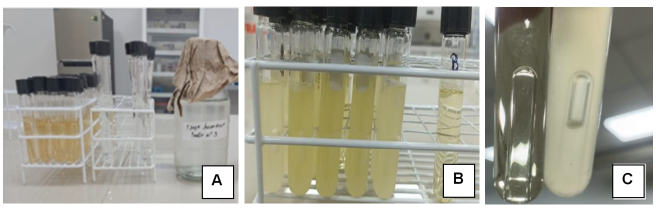

Fig. 4. Microbiological methods used for the determination of Thermotolerant Coliforms and *E. coli.* (A) Inoculation of the water sample; (B) Reading of the LST broth tubes after incubation in the preliminary phase; and (C) Criteria for identifying positive tubes: presence of turbidity and gas production (bubble formation within the inverted Durham tube).

D. Isolation and Identification of Bacteria in Seawater

The procedure for isolating and identifying bacteria in seawater was performed using the streak plate technique. Initially, an aliquot of seawater was spread on the surface of Petri dishes containing MacConkey agar and EMB agar. Subsequently, the plates were incubated at 36°C for a period of 24 to 48h to allow bacterial growth. Representative colonies were then selected and isolated by re-streaking on tubes containing nutrient agar to assess the purity of the culture before proceeding with identification (see Fig. 5).

Identification was carried out using the Vitek 2 system, available at the Microbiology Laboratory of the Institutes and Research Centers of César Vallejo University - Trujillo Campus. The Vitek 2 system is an automated bacterial identification system that operates by inoculating a bacterial suspension into identification cards containing colorimetric reagents for 62 biochemical tests. This system allows for the identification of bacterial species with up to 99% specificity [31].

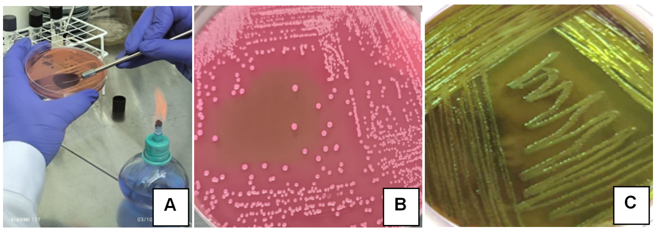

Fig. 5. Microbiological methods for the isolation and identification of bacteria. (A) Zig-Zag surface streaking; (B) Bacterial growth on MacConkey agar; (C) Bacterial growth on EMB agar.

E. Antibiotic Sensitivity Tests

The disk diffusion method was employed, where the procedure involved inoculating a known concentration of the bacteria onto the surface of Mueller-Hinton agar by means of a mass inoculation. A sterile swab was used to ensure uniform dispersion of the sample, and then disks impregnated with different antibiotics were placed on the agar surface. The inoculated plates were incubated at 36°C for a period of 24h. At the end of this incubation period, the zones of bacterial growth and the inhibition halos around the antibiotic disks were observed. These inhibition zones were measured in millimeters and compared with established reference tables to determine bacterial sensitivity in three categories: Susceptible, Intermediate, or Resistant [32, 33].

IV. Result and Discussion

Table 1 shows the results of thermotolerant coliforms and *E. coli* present in the water samples collected in the study area between October and December 2024. In this table, it can be observed that the seawater samples were classified as NOT SUITABLE for recreational use according to the current national regulations, which establish the maximum limit as 200 and <1.8 MPN/100 mL of thermotolerant coliforms and *E. coli,* respectively, as per the Peruvian regulation D.S. 004-2017-MINAM - ECA for Water [34].

The results presented in Table 1 are extremely concerning, as the presence of thermotolerant coliforms and *E. coli* in seawater indicates contamination from fecal origin. The monitoring point P1 shows a higher microbiological load, evidencing that the water from this river, originating from the wastewater treatment plants of Trujillo city (PTAR-Cortijo and PTAR-Covicorti), which discharges into the sea of Buenos Aires, La Libertad, was not properly treated before being discharged into surface water channels.

Table 1. Thermotolerant coliforms and *E. coli* present in the collected water samples

Date	Sampling site	Thermotolerant coliforms (NMP /100 ml)	*E. coli* (NMP /100 ml)	[1] Rating
October 7, 2024	P1	54×10^6	24×10^6	N.A.
	P2	43×10^4	27×10^4	NOT SUITABLE
	P3	26×10^2	12×10^2	NOT SUITABLE
	P4	27×10^4	13×10^4	NOT SUITABLE
October 20, 2024	P1	92×10^6	54×10^6	N.A.
	P2	54×10^4	22×10^4	NOT SUITABLE
	P3	39×10^2	21×10^2	NOT SUITABLE
	P4	38×10^4	24×10^4	NOT SUITABLE
November 04, 2024	P1	92×10^6	35×10^6	N.A.
	P2	35×10^4	21×10^4	NOT SUITABLE
	P3	41×10^2	27×10^2	NOT SUITABLE
	P4	26×10^4	13×10^4	NOT SUITABLE
November 18, 2024	P1	54×10^6	24×10^6	N.A.
	P2	43×10^4	28×10^4	NOT SUITABLE
	P3	32×10^2	17×10^2	NOT SUITABLE
	P4	27×10^4	13×10^4	NOT SUITABLE
December 02, 2024	P1	92×10^6	35×10^6	N.A.
	P2	54×10^4	35×10^4	NOT SUITABLE
	P3	70×10^2	33×10^2	NOT SUITABLE
	P4	38×10^4	24×10^4	NOT SUITABLE

[1] Evaluation based on the *E. coli* count obtained in comparison with the maximum value established in D.S. No. 004-2017-MINAM

This issue of inefficient wastewater disposal has persisted since 2005 to the present, leading the Peruvian government to take more than 20 years to manage the necessary public investment to construct a modern wastewater treatment plant for the benefit of Trujillo's population [35–37]. It is important to highlight that the issue of untreated wastewater discharge is a common practice, especially in developing countries, due to the lack of infrastructure, technical capabilities, and funding needed to address this problem [38, 39].

In Latin America and the Caribbean, only about 60% of the population is connected to a sewer system, and only 30% to 40% of the region's collected wastewater is treated efficiently [40]. The presence of thermotolerant coliforms and *E. coli* represents a health risk for people, as they can cause gastrointestinal infections in swimmers who come into contact with contaminated water, either by swimming in beach waters or engaging in recreational water sports [11, 14].

During the monitoring period, it was evidenced that the beaches adjacent to the area were microbiologically classified as NOT SUITABLE, as they exceeded the maximum permissible limit established by the current Peruvian regulations ECA-Water [34]. The presence of *E. coli* on the beaches of La Libertad due to wastewater contamination is a persistent and concerning problem. Recent reports have indicated high counts of thermotolerant coliforms and *E. coli* in the effluents of the wastewater treatment plants of Cortijo and Covicorti [36]. Additionally, the presence of these bacteria has been reported on the beaches of Huanchaco in 2015 [37] and in 2017 [41]. The issue of microbiological contamination is not limited to Trujillo, as various studies have revealed the presence of thermotolerant coliforms and *E. coli* on other beaches along the Peruvian coast. For instance, high levels, ranging from 1600 to 5400 MPN/100 mL of these bacteria have been recorded on the beaches of Costa Verde, Chorrillos, and Ancón [27, 42], as well as in Moquegua [43], Huacho [44], Pucusana [45], and Arequipa [46]. The widespread presence of these contaminants in multiple locations underscores the urgency of addressing inefficient wastewater management and strengthening treatment infrastructure to protect public health and coastal ecosystems.

Table 2 details the bacterial species isolated and identified in seawater samples from the study area located in the Buenos Aires resort, district of Víctor Larco, La Libertad, Peru, collected between October and December 2024. Out of a total of 51 bacterial cultures isolated, *E. coli* stood out as the most prevalent bacterium, identified in all samplings and in all collected samples.

Table 2. Bacterial species identified at each sampling point

Sampling site	Enterobacteria identified	
	n (51)	bacterial species
P1	05	*Escherichia coli,*
	05	*Enterococcus faecalis*
	05	*Enterobacter cloacae*
	05	*Enterobacter aerogenes*
	05	*Proteus mirabilis*
P2	05	*Escherichia coli,*
	04	*Enterococcus faecalis,*
P3	05	*Escherichia coli,*
	01	*Enterococcus faecalis,*
P4	05	*Escherichia coli,*
	03	*Enterococcus faecalis,*
	03	*Enterobacter cloacae*

The results presented in Table 2 are extremely concerning, as the bacterium *E. coli* was isolated and identified in all collected samples. The presence of this bacterium represents a significant public health risk, especially for swimmers and other beachgoers [47]. Additionally, the identification of other bacterial species in the samples reinforces the need to monitor and properly manage water quality in these coastal areas to protect both the local population and the tourists who frequent these beaches.

The bacteria *E. coli, E. faecalis, E. cloacae, E. aerogenes*, and *P. mirabilis* represent a significant public health risk due to their pathogenic potential and ability to cause a variety of infections in humans [48]. *E. coli* is known for its association with gastrointestinal infections, urinary tract infections, and occasionally, severe systemic infections. *E. faecalis*, commonly found in the gastrointestinal tract, can cause urinary infections and other serious infections, especially in individuals with compromised immune systems. *E. cloacae* and *E. aerogenes* are opportunistic pathogens that can cause urinary tract infections and sepsis, and are known for their resistance to multiple antibiotics, complicating their treatment. *P. mirabilis*, frequently associated with urinary tract infections, can cause persistent and complicated infections due to its ability to form kidney stones and its intrinsic resistance to various antimicrobials. The presence of these bacteria in natural environments, such as beaches and bodies of water, underscores the need for rigorous monitoring and effective control strategies to prevent the spread of diseases and protect public health [47, 48].

In Table 3, the sensitivity to antibacterials of the bacterial species identified in the seawater samples from the study area located in the Buenos Aires beach resort, Víctor Larco district, La Libertad, Peru is reported.

Table 3. Antibacterial sensitivity of the isolated bacteria

Enterobacteria identified			[1] **Antibacterial sensitivity**		
bacterial species	**n (51)**	**code**	**S**	**I**	**R**
Escherichia coli	01	EC-P1S1	AMC, CXM, IMI, MER, ETP, AMI, CIP, TMS.	CRO, GEN	AMP, CIP
Escherichia coli	01	EC-P1S3	CXM, IMI, MER, ETP, AMI, CIP, TMS.	AMC, GEN	CRO, AMP, CIP
Escherichia coli	01	EC-P1S5	AMC, IMI, MER, ETP, AMI, CIP, TMS.	CMX, CRO	AMP, CIP, GEN
Escherichia coli	17	-	AMP, AMC, CIP, CXM, CRO, IMI, MER, ETP, GEN, AMI, TMS.	-	-
Enterococcus faecalis	13	-	AMP, AMC, CIP, CXM, CRO, IMI, MER, ETP, GEN, AMI, TMS.	-	-
Enterobacter cloacae	8	-	AMP, AMC, CIP, CXM, CRO, IMI, MER, ETP, GEN, AMI, TMS.	-	-
Enterobacter aerogenes	5	-	AMP, AMC, CIP, CXM, CRO, IMI, MER, ETP, GEN, AMI, TMS.	-	-
Proteus mirabilis	5	-	AMP, AMC, CIP, CXM, CRO, IMI, MER, ETP, GEN, AMI, TMS.	-	-

[1] Antibacterial sensitivity: (S) Sensitive, (I) Intermediate and (R) Resistant.
Antibiotics: Ampicillin 10ug (AMP); Amoxicillin/Clavulanic Acid 20/10ug (AMC); Cefuroxime 30ug (CMX); Ceftriaxone 30ug (CRO); Imipenem 10ug (IMI); Meropenem 10ug (MER); Ertapenem 10ug (ETP); Gentamicin 10ug (GEN); Amikacin 30ug (AMI); Ciprofloxaxin 5ug (CIP); and Trimethoprim-sulfamethoxasole 1.25/23.75ug (TMS).

Worldwide, there is a continuous increase in diseases caused by resistant and multi-resistant bacteria, resulting in a significant problem in the effectiveness of treating bacterial infections with conventional antimicrobials [49]. In South America, the presence of beta-lactam-resistant Enterobacteriaceae has been detected in hospital wastewater that has not undergone adequate treatment. This untreated wastewater reaches domestic water treatment plants, where it should be treated before disposal. However, the lack of adequate treatment at these plants turns the effluents into a potential risk for human health, as they contaminate surface and coastal waters [50].

In the present study, it was found that 3 out of 20 *E. coli* strains showed higher resistance to antibiotics. It was determined that *E. coli* is resistant to Ampicillin (AMP), Ceftriaxone (CRO), Ciprofloxacin (CIP), and Gentamicin (GEN). The results obtained are similar to those reported in studies conducted on the beaches of Costa Verde [42], as well as on the beaches of Ancón and Chorrillos [27]. Moreover, the majority of *E. coli* strains (*n*=17) and all strains of *E. faecalis, E. cloacae, E. aerogenes* and *P. mirabilis* were found to be sensitive to the 11 antibiotics evaluated. This information is crucial as these drugs can be employed in antibiotic therapy to treat injuries acquired at the beaches, as suggested by other studies conducted in North America, where isolated gram-negative bacteria showed sensitivity to cefepime, lomefloxacin, and levofloxacin [25].

It is known that *Escherichia coli* is one of the microorganisms with the greatest capacity to develop in seawater. This remarkable tolerance is due to the presence of small genes that can mutate and alter the microorganism's sensitivity to the marine environment, thus allowing its adaptation to such environments [51, 52]. In particular, the mutation of the rpoS gene is the most notable when E. coli is transferred to a marine environment. In the marine environment, this mutated gene improves the resistance of *E. coli* to adverse conditions such as salinity, osmotic pressure, and nutrient limitation. Currently, it is known that antibiotic resistance in oceans and seas is influenced by gene transfer between bacteria and the proximity of coastal areas to places where untreated or poorly treated wastewater is discharged [53]. These resistance genes can be transferred horizontally through mechanisms such as conjugation, transformation, and transduction [54, 55]. Studies have reported that, in urban beaches, antibiotic resistance genes are transferred through the class 1 integron-integrase gene (intI1), especially in areas where seawater mixes with wastewater [56, 57]. Genetic adaptations allow bacteria not only to survive but also to proliferate in marine environments, posing a potential risk to human health and the marine ecosystem [58].

While the findings of this study reveal significant microbiological contamination at Buenos Aires Beach, it is essential to acknowledge that these results cannot be broadly extrapolated to all beaches in Peru or worldwide. Coastal water quality is influenced by multiple factors, including wastewater treatment infrastructure, hydrographic and climatic conditions, urban and tourism development levels, as well as environmental regulations and management practices in each region. In many cases, variability in ocean currents and the dilution capacity of seawater can significantly alter bacterial contamination levels, necessitating site-specific studies before drawing broader conclusions. Nevertheless, these results highlight the urgent need for regular monitoring of various beaches, improvements in sanitation infrastructure, and the implementation of effective environmental policies to reduce coastal pollution and safeguard public health in communities facing similar conditions.

V. Conclusion

Escherichia coli is the bacterium most frequently found in seawater samples, which can be attributed to its remarkable tolerance and adaptation to marine water conditions. This characteristic allows this bacterium to proliferate in environments that are not typically hospitable.

Although no bacterial species with a high degree of antibiotic resistance were found in the collected samples, the presence of *E. coli* and other bacteria in beach waters represents a significant public health risk. Exposure to contact with these contaminated waters can cause infections and diseases in swimmers, especially during the high summer season when the influx of people to the beaches is greater.

To mitigate bacterial contamination on beaches and protect public health, it is essential to enhance wastewater treatment systems to significantly reduce pathogenic microorganisms, implement continuous monitoring programs to assess microbiological water quality and provide timely alerts on potential health risks, and establish temporary beach closure protocols in cases of contamination. These measures, combined with environmental education initiatives, would contribute to more sustainable coastal ecosystem management and ensure safe spaces for tourism and recreation.

This study presents limitations due to its three-month duration, which prevented the assessment of seasonal variations in bacterial contamination. Additionally, operational and financial constraints restricted the monitoring period to less than a full year, meaning that the results only reflect conditions prior to the 2025 summer tourist season and cannot be considered representative of year-round dynamics. To address this issue, active collaboration between local authorities, researchers, and the community is recommended, fostering joint actions to ensure the safety of swimmers and visitors while preserving marine ecosystems.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

LCCH conducted the research; LCCH and V.M.L. collected the samples; Y.R.V. and V.M.L. performed the analyses; LCCH and K.D.A analyzed the data; LCCH and K.D.A wrote the paper; all authors had approved the final version.

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