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Microbiological quality of the air in the area of influence of the former wastewater treatment plant in Cajamarca, Peru

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It has been determined that there is air pollution within wastewater treatment plants and their surrounding areas. This impacts the health of nearby populations. Therefore, this research aimed to evaluate the air's microbiological quality in the area of influence of the former Wastewater Treatment Plant (WWTP) in the city of Cajamarca. Microbiological air sampling was conducted during the rainy and dry seasons using the RCS Standard Hycon air sampler, planting on tryptic soy agar medium to determine the total count of all microorganisms, bacteria, and fungi separately. OSHA (Occupational Safety and Health Administration), PN-89/Z-04111/02, and PN-89/Z-04111/03 were the standards used to determine the air quality of the study area since Peru currently does not have such regulation standards. The highest values obtained were 4560 CFU/m^3 and 4360 CFU/m^3 during the dry season. Sixteen concentrations of the total microorganism count exceeded the limits established by OSHA standards, and ten concentrations of bacteria exceeded the Polish standard PN-89/Z-04111/02. Although the concentrations of fungi were high, they did not exceed any reference limits. We determined a positive correlation between the concentration of microorganisms and the relative humidity, with a maximum of 85.67% humidity during the dry season. Additionally, a negative correlation with wind speed was found, with values ranging from 0.37 m/s to 2.58 m/s during the dry season and from 0.37 m/s to 1.87 m/s during the rainy season. Genera of public health importance such as *Staphylococcus* and *Penicillium* were identified. Finally, a survey was conducted among the nearby population to assess the impact on public health. And, it was established that the health impact on the surrounding populations is mainly low.

KEYWORDS

wastewater treatment plant (WWTP), air pollution, bioaerosols, microbiological quality of air, concentration of microorganisms

1 Introduction

Worldwide, there are numerous wastewater treatment plants (WWTPs) consisting of various infrastructures and treatment processes (Ministry of Housing, Construction and Sanitation of Peru, 2006). Studies have determined air pollution both within the WWTP, where concentrations of airborne bacteria can reach up to 4878 CFU/m^3 in areas such as aeration tanks (Yang et al., 2018) and concentrations of fungi up to 5386 CFU/m^3 in areas like pumping stations (Staszowska, 2022). This reduces the microbiological quality of the surrounding air and impacts the health of nearby populations (Fracchia et al., 2006) due to the dispersion of contaminants from these points of high concentration (Fula and Rey, 2005). The World Health Organization (2021) indicates that air pollution is a major environmental risk, affecting human health, and emphasizes the importance of governments promoting its study and monitoring. This contributes to formulating mitigation measures and improving air quality (Xie et al., 2021).

Microbiological air pollution is a problem described in various countries such as Poland (Michałkiewicz, 2018; Staszowska, 2022; Pasmionka, 2019), China (Li et al., 2013; Yang et al., 2018; Han et al., 2018), and Iran (Malakootian et al., 2013; Fathi et al., 2017; Niazi et al., 2015). In Peru, the microbiological quality of indoor air has been studied in places like solid waste treatment plants - SWTP (Mendoza et al., 2020), hospitals (Izquierdo, 2016), markets (Chuquilin et al., 2021), and classrooms (Olivera et al., 2020; Sotelo, 2020). However, the microbiological quality of outdoor air is relatively new. National regulations such as the Air Quality Index or the Environmental Air Quality Standards established by the Ministry of the Environment in Peru do not include measures, control plans, or parameters to determine the microbiological quality of air (Izquierdo, 2016).

The city of Cajamarca has not had a wastewater treatment system since 2007, and its former WWTP facility still receives effluents but has ceased to operate as an active treatment plant for over 20 years. In its current state, wastewater is temporarily stored and then discharged untreated into the river (Tapia, 2017). This exposes the contiguous population and people transiting the area to high levels of pollution as WWTPs generate bioaerosols containing pathogenic bacteria, fungi, and viruses (Gregova et al., 2009) which can disperse and reach long distances (De la Rosa et al., 2002). These can infect the nearby population through inhalation, ingestion, and skin contact (Niazi et al., 2015).

For that reason, this research project aimed to describe the microbiological quality of the air in the area of influence of the former WWTP of Cajamarca. Additionally, it aimed to

Legend

Monitoring points

Coordinates UTM WGS84 Zone 17S		
N°	North (X)	East (Y)
P1	776067	9207758
P2	776535	9207668
P3	776953	9207537
P4	777318	9207639
P5	777971	9207335

Map: Location of the monitoring points		
Department/State: Cajamarca	**Province:** Cajamarca	**District:** Cajamarca
System-Datum-Zone: UTM-WGS84-17S	**Escale:** 1/5000	**Date:** 2022

FIGURE 1
Distribution of monitoring points in the area of influence of the former Cajamarca WWTP.

determine the concentration of microorganisms and relevant genera. Finally, it aimed to understand the incidence of health problems related to the microbiological quality of the air in the study area.

2 Materials and methods

2.1 To determine the concentration of microorganisms present in the air

Microbiological air sampling was conducted in triplicate for each season (dry and rainy) at 5 monitoring points (Figure 1). At each established point, three samplings were carried out in the morning from 7:00 to 9:00 a.m., in the afternoon from 1:00 to 3:00 p.m., and in the evening from 6:00 to 8:00 p.m.

In Figure 1, the coordinates of sampling points P1-P5 can be observed. These points were carefully selected based on wind direction and speed obtained from a compass rose (Figure 2) and the proximity to the San Lucas River, where untreated wastewater from the old treatment plant is discharged. Using this information, the sampling points were located at different distances from the plant to capture the dispersion of contaminants representatively. Specifically, P1 is situated before the plant, at 0.5 km P2 and P3 are 0.05 km and 0.1 km far from the plant, respectively. P4 is at 0.34 km, and P5 is at 1.0 km from the plant, both near the urban area.

For monitoring, a height of 2 m above ground level was chosen to represent human exposure in urban areas. This choice is based on the guidelines of the National Air Quality Monitoring Protocol of Peru (MINAM, 2019), which recommends a height between 1.5 and 3 m to reflect the human breathing zone. Similarly, the Environmental Protection Agency (2017) suggest heights close to 2 m in urban settings to reflect people's exposure to air contaminants.

Sampling was conducted at a flow rate of 40 L/min for 5 min using the HYCON RCS Standard microbiological sampler by Merck Millipore and tryptic soy agar strips. Temperature and humidity were measured with a Boeco SH-110 thermohygrometer by Boeco Germany. Wind direction and speed were measured with an Extech AN200 anemometer from Extech Instruments Corporation. Using these data, a compass rose was created (Figure 2) to define wind variation in the study area for locating the monitoring points (Figure 1).

The samples were preserved and transported to the laboratory of the Universidad Privada del Norte, where they were incubated at 37°C for 24 h. After the incubation period, colony counts were performed for each tryptic soy agar strip, which contains 34 grids. Then, the conversion from CFU to CFU/m³ was carried out using the conversion factor described in Equation 1.

$$\frac{\mathbf{CFU}}{\mathbf{m^3}} = \mathbf{CFU} * \frac{\mathbf{40\,L}}{\mathbf{min}} * \frac{\mathbf{1\,m^3}}{\mathbf{1000\,L}} \tag{1}$$

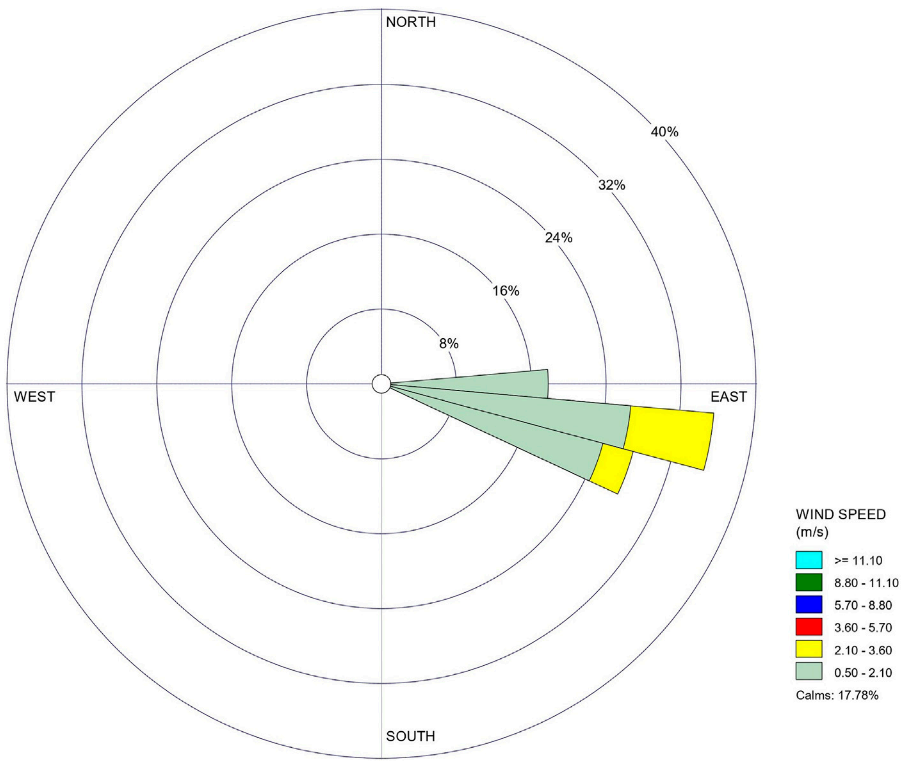

FIGURE 2
Compass rose of the study area.

TABLE 1 Average concentration of bacteria and fungi and total count of microorganisms (CFU/m^3) in regards to sampling Schedule, monitoring point, and season.

Monitoring points	Bacteria		Fungi		Total count of microorganisms	
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
Morning (07:00–09:00 a.m.)						
P1	635	1,435	395	590	1,030	1,960
P2	620	1,755	1,675	430	2,295	2,185
P3	405	1,472	2,425	1,370	2,830	2,842
P4	680	655	2,705	2,792	3,385	3,480
P5	635	673	1,435	1533	2,070	2,207
Afternoon (01:00–03:00 p.m.)						
P1	365	627	1895	905	2,260	1532
P2	445	780	4,115	1,108	4,560	1,888
P3	400	1,550	1030	575	1,430	2,125
P4	565	1,318	2,840	752	3,405	2,070
P5	395	1,380	1,310	875	1,705	2,255
Night (06:00–08:00 p.m.)						
P1	915	1,023	120	468	1,035	1,492
P2	200	978	1,010	372	1,210	1,350
P3	260	1,522	725	423	985	1,945
P4	670	1,833	3,690	405	4,360	2,238
P5	370	1,432	770	497	1,140	1,762

Note: P1, P2, P3, P4, and P5 refer to the monitoring points.

The results were compared to the OSHA (Occupational Safety and Health Administration) indoor air quality standard since there is no official international standard for outdoor microbiological air quality that establishes values for total microorganism counts. The results for bacteria and fungi concentrations were compared to two Polish standards, PN-89/Z-04111/02 and PN-89/Z-04111/03, respectively. Additionally, for data analysis, the ANOVA test was used to determine if there were significant differences in microorganism concentrations concerning seasons, time of day, and sampling points. Tukey's Honestly Significant Difference (HSD) test was also employed to identify statistically significant differences between points and monitoring times. Finally, Pearson's Correlation was used to compare the microorganism values with the meteorological variables recorded in the field.

2.2 To determine the microorganism genera present in the air

The microbial morphology of the colonies that grew on the stripes was analyzed by performing Gram staining for bacteria and lactophenol blue staining for fungi, using a ZEISS Primostar compound microscope manufactured by Carl Zeiss AG. This facilitated the identification of the species present. After the isolation and morphological observation of the colonies, bacterial strains were sent to a commercial clinical laboratory, where standard biochemical tests were performed to identify genera. The data analysis was carried out using IBM SPSS Statistics version 26 to create tables for the identified genera of bacteria and fungi.

2.3 To understand the incidence of health problems related to the microbiological quality of the air

A survey was designed with closed-ended and multiple-choice questions, based on the Likert scale (Likert, 1932), which assigns values to the incidence of health problems: very frequently (5), frequently (4), occasionally (3), rarely (2), and never (1).

The questionnaire was then administered in person to 130 individuals living in the most populated blocks within the area influenced by the former WWTP. Questions that included the Likert scale were identified, and the corresponding scores

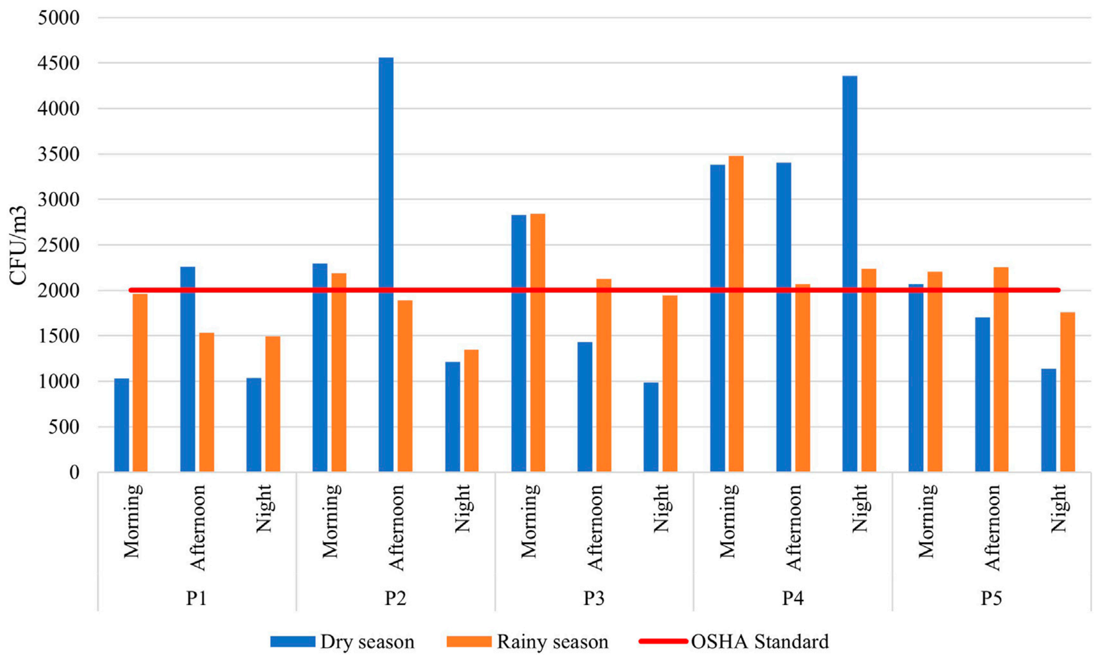

FIGURE 3
Concentration of total microorganisms (CFU/m^3) concerning the OSHA standard.

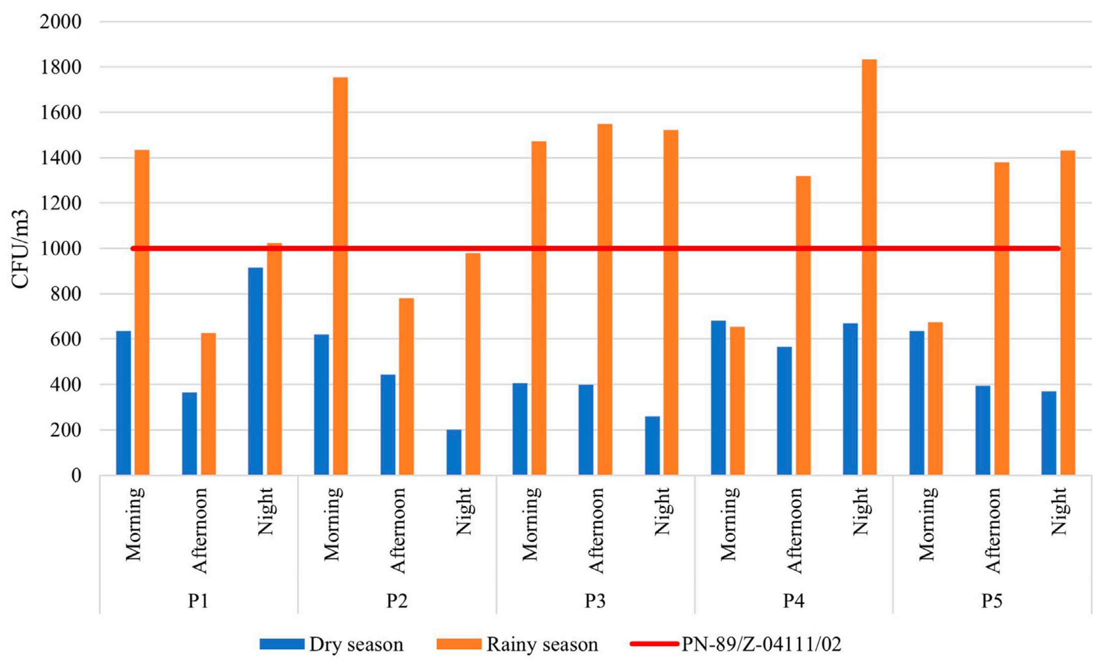

FIGURE 4
Concentration of bacteria (CFU/m^3) concerning the PN-89/Z-04111/02 standard.

were assigned to proceed with summing the results. The sum of these scores established the levels of incidence of health problems related to the microbiological quality of the air (Supplementary Table S1). Additionally, Cronbach's alpha statistical test was applied to the questions following the Likert scale to indicate the degree of internal consistency among the scale's items (Casas et al., 2003), using IBM SPSS Statistics version 26.

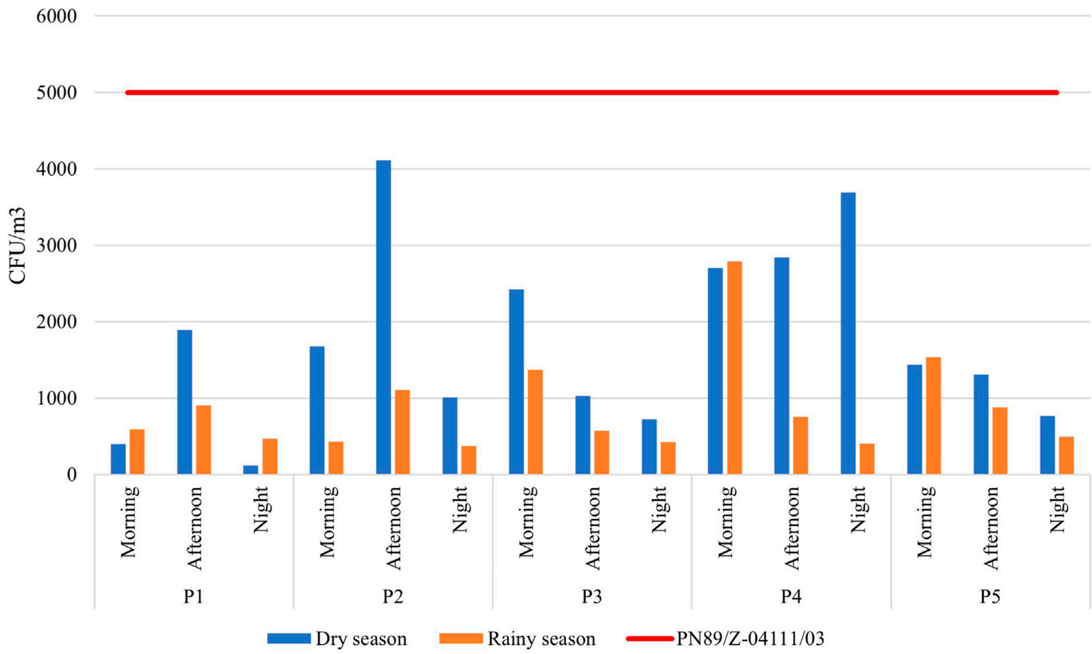

FIGURE 5
Concentration of fungi (CFU/m^3) concerning the PN-89/Z-04111/03 standard.

3 Results and discussion

3.1 Concentration of bacteria and fungi

The results presented in Table 1 show elevated levels of bioaerosol concentrations in the area of influence of the former WWTP in Cajamarca. The highest concentrations were 4560 CFU/m^3 at the monitoring point P2 during the afternoon and 4115 CFU/m^3 at the point P4 during the evening. Sixteen measurements exceeded the limits established by OSHA (2001) for determining air quality concerning the total count of microorganisms (Figure 3). Ten measurements exceeded the PN-89/Z-04111/02 standard for bacteria (Figure 4). This standard classifies air as moderately contaminated when concentrations range between 1,000 CFU/m^3 and 3,000 CFU/m^3. On the other hand, although fungal levels were elevated, they did not exceed the 5,000 CFU/m^3 limit established by the PN-89/Z-04111/03 standard (Figure 5).

These results underscore the impact of the former WWTP on local air quality, especially in the absence of an adequate wastewater treatment system. Staszowska (2022) conducted a study in a municipal WWTP in Poland, where the highest outdoor bacterial concentration was 3617 CFU/m^3. Our study also revealed higher fungal concentrations compared to similar studies. In an Indonesian WWTP, the highest recorded fungal concentration was 1955 CFU/m^3 (Kristanto and Rosana, 2017), while a study in Brazil recorded a maximum concentration of 330 CFU/m^3 (Papais et al., 2022). These differences could be related to the characteristics of the infrastructure and the specific environmental conditions of Cajamarca, which favor the accumulation of bioaerosols in the air (Castro et al., 2021).

Water quality studies have determined high levels of fecal coliforms such as *Escherichia coli* and *Enterococcus* in the San Lucas River in areas near our monitoring points (García, 2014; Escalante, 2018; Autoridad Nacional del Agua del Perú, (2019). For instance, up to 490,000 MPN/100 mL of fecal coliforms and 110,000 MPN/100 mL of *Escherichia coli* were found in the river (ANA, 2020). Additionally, studies at WWTPs in various locations have demonstrated that wastewater management releases pathogenic microorganisms into the air (Niazi et al., 2015; Kermani et al., 2016; Kristanto and Rosana, 2017; Małecka-

TABLE 2 P-value results from comparing multiple monitoring points and schedules.

Criteria		Sig (P)
Monitoring point	P1 - P2	0.348
	P1 - P3	0.720
	P1 - P4	0.000
	P1 - P5	0.929
	P2 - P3	0.977
	P2 - P4	0.115
	P2 - P5	0.837
	P3 - P4	0.024
	P3 - P5	0.992
	P4 - P5	0.006
Schedule	Morning - Afternoon	0.929
	Morning - Night	0.056
	Afternoon - Night	0.127

TABLE 3 Average concentration of bacteria, fungi, and total count of CFU m^{-3} and meteorological variables.

Monitoring points	Dry season					Rainy season				
	Bacteria (CFU/m³)	Fungi (CFU/m³)	Total count (CFU/m³)	Relative humidity (%)	Wind speed (m/s)	Bacteria (CFU/m³)	Fungi (CFU/m³)	Total count (CFU/m³)	Relative humidity (%)	Wind speed (m/s)
Morning (7:00–9:00 a.m.)										
P1	635	395	1,030	46.33	2.13	1,435	590	1,960	49.67	1.76
P2	620	1675	2,295	57.00	1.07	1,755	430	2,185	50.00	1.70
P3	405	2,425	2,830	57.00	0.49	1,472	1,370	2,842	54.00	0.39
P4	680	2,705	3,385	80.33	0.65	655	2,792	3,480	61.00	0.41
P5	635	1,435	2,070	50.67	0.70	673	1,533	2,207	51.67	0.47
Afternoon (1:00–3:00 p.m.)										
P1	365	1,895	2,260	59.00	1.23	627	905	1532	55.67	1.79
P2	445	4,115	4,560	86.67	0.37	780	1,108	1,888	51.67	1.79
P3	400	1030	1,430	54.00	1.50	1,550	575	2,125	51.33	1.71
P4	565	2,840	3,405	79.67	1.26	1,318	752	2,070	44.37	1.71
P5	395	1,310	1,705	59.00	2.52	1,380	875	2,255	51.00	0.37
Night (6:00–8:00 p.m.)										
P1	915	120	1,035	66.00	2.16	1,023	468	1,492	54.00	1.79
P2	200	1,010	1,210	53.00	1.41	978	372	1,350	39.00	1.87
P3	260	725	985	44.67	2.58	1,522	423	1,945	53.00	1.77
P4	670	3,690	4,360	81.33	0.38	1,833	405	2,238	51.67	0.84
P5	370	770	1,140	57.00	1.98	1,432	497	1,762	46.33	1.77

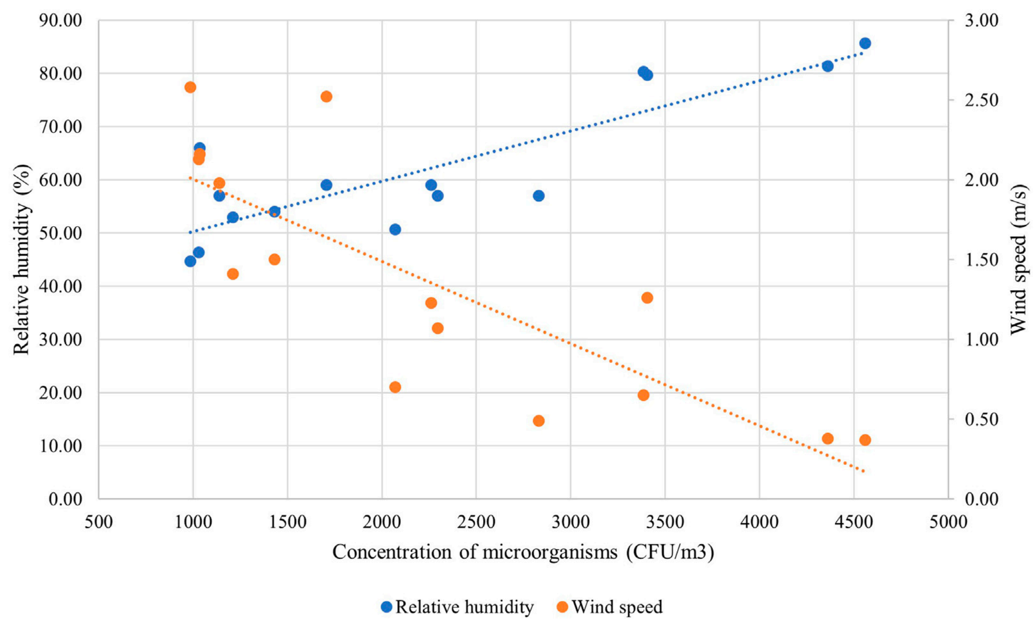

FIGURE 6
Concentration of microorganisms according to relative humidity and wind speed in the dry season.

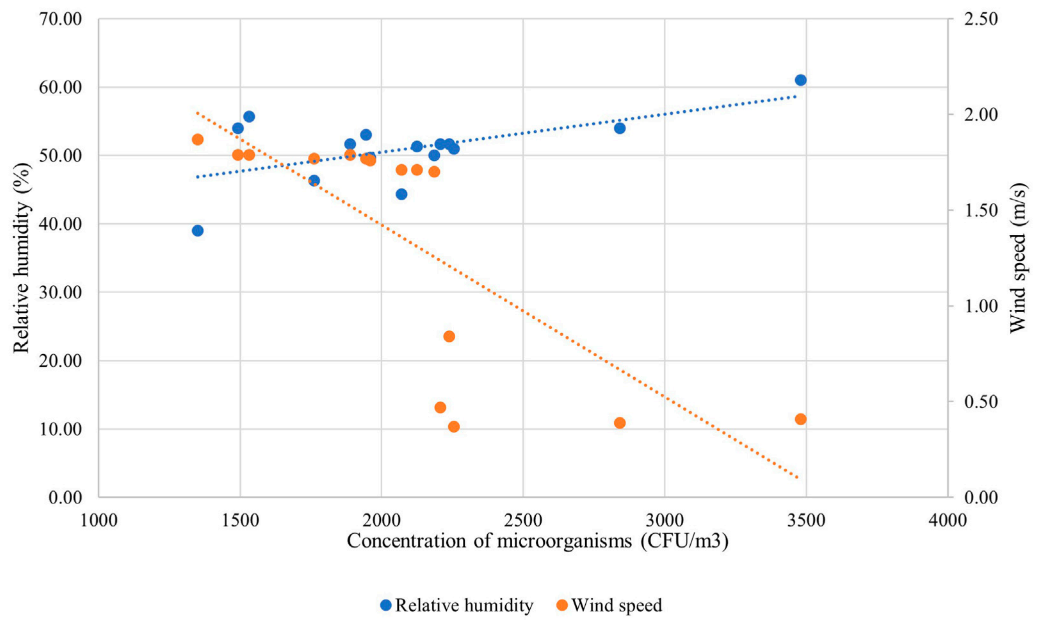

FIGURE 7
Concentration of microorganisms according to relative humidity and wind speed in the rainy season.

Adamowicz et al., 2017; Pasmionka, 2019; Staszowska, 2022). Therefore, the high concentration of bioaerosols in the study area and surrounding zones is due to the presence, discharge, and runoff of wastewater, such as that generated by the former WWTP, into the San Lucas River. This exposes the nearby population to a higher risk of inhaling potentially pathogenic bioaerosols.

3.1.1 Variation of concentrations

To evaluate the differences in microorganism concentrations according to season, sampling point, and monitoring time, a one-way ANOVA was applied with a 95% confidence interval (Table 2). The analysis revealed no significant differences in microorganism concentrations between the dry and rainy seasons, as the P-value was greater than 0.05.

However, when analyzing the concentrations between different sampling points and monitoring times, the P-values were less than 0.05, suggesting that at least one of the values is significantly different. This result may be related to the dispersion of microorganisms from the former WWTP towards the San Lucas River and the proximity of the sampling points to its course (Figure 1). Regarding the monitoring times, the highest concentrations were recorded in the afternoon (4560 CFU/m^3) and at night (4360 CFU/m^3), which could be related to an increase in humidity during these times (Table 3; Figures 6, 7), as documented in previous studies at the SWTP in Cajamarca (Mendoza et al., 2020).

To identify specific differences between points and times, Tukey's Honestly Significant Difference (HSD) test was applied, allowing the comparison of P-values for all times and points in pairs (Table 2). For the monitoring times, no significant differences were found. In contrast, for the sampling points, Table 2 shows significant differences between P1 and P4 (p = 0.000), P3 and P4 (p = 0.024), and P4 and P5 (p = 0.006). Michalska et al. (2021) link high microorganism concentrations with increased humidity in a study conducted in five cities in the Gulf of Gdansk, Poland. This would explain why point P4 presents significantly different concentrations since humidity levels at this location were higher (Table 3).

Table 1 shows the average concentrations of microorganisms by monitoring point, determined considering the proximity to the former WWTP (Figure 1) and the wind direction (Table 3; Figure 2). The lowest concentration of 2260 CFU/m^3 was recorded at point P1, located before the plant. Point P2, situated near the former WWTP, presented the highest concentrations of microorganisms, reaching up to 4560 CFU/m^3, and Point P3 also located near the plant had a maximum concentration of 2842 CFU/m^3. The highest concentration for point P4 in a populated area was 4360 CFU/m^3. Finally, for point P5, the highest concentration was 2255 CFU/m^3. This is consistent with previous studies in WWTPs, which document elevated concentrations in areas near discharge sources (Pasmionka, 2019; Fathi et al., 2017).

3.1.2 Influence of meteorological variables in the concentration of microorganisms

The concentrations of airborne microorganisms showed a positive correlation with relative humidity and a negative correlation with wind speed, as shown in Table 3 and Figures 6, 7. During the dry season, the relative humidity reached a maximum value of 85.67%, whereas, in the rainy season, the maximum was 61%. The Pearson correlation coefficient between relative humidity and microorganism concentration was 0.86 in the dry season and 0.59 in the rainy season. It is worth noting that the study area in Cajamarca has a semi-dry climate with abundant humidity that is constant throughout the year (Castro et al., 2021). Similar situations were documented by Kristanto and Rosana (2017) and Dehghani

TABLE 4 Microorganisms found at the 5 monitoring points.

Dominion	Filus	Class	Order	Family	Genera/species
Bacteria	Actinobacteria	Actinobacteria	Actinobacteridae	Actinomycetales	*Micrococcus sp*
					Rhodococcus sp
	Firmicutes	Bacillis	Bacillales	Bacillaceae	*Bacillus sp*
					Bacillus sutilis
				Staphylococcaceae	*Staphylococcus aureus*
				Streptococcaceae	*Streptococcus sp*
			Lactobacillales	Enterococcaceae	*Enterococcus sp*
	Proteobacteria	Gammaproteobacteria	Enterobacteriales	Enterobacteriaceae	*Escherichia Coli* *Ptoteus sp*
Fungi	Ascomycota	Euascomycetes	Eurotiales	Trichomaceae	*Aspergillus sp*
					Penicillium sp
	Basidiomycota	Pucciniomicetos	Esporidiales	Sporidiobolaceae	*Rhodotorula sp*
	Mucoromycota	Stolonifer	Mucorales	Mucoraceae	*Mucor sp*
					Rhizopus sp

Note: Taxonomic classification for bacteria based on Brenner et al. (2005); Krieg et al. (2011); and Whitman et al. (2012); and based on Watkinson, S. C. et al. (2015) for fungi.

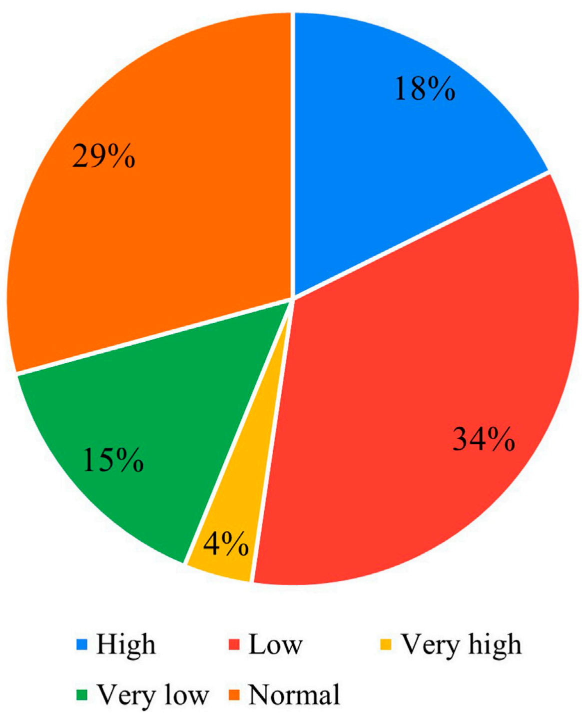

FIGURE 8
Level of incidence of health problems related to the microbiological quality of the air in the area of influence of the former WWTP.

et al. (2018), who concluded that higher humidity levels are correlated with higher microorganism concentrations.

Regarding wind speed, the highest value recorded in the dry season was 2.58 m/s, and 1.87 m/s during the rainy season. The correlation coefficients were −0.82 in the dry season and −0.76 in the rainy season, indicating that an increase in wind speed reduces microorganism concentration. This phenomenon occurs because the wind disperses microorganisms, decreasing their concentration in areas close to the emission source and expanding it to more distant areas (Wang et al., 2018; Yang et al., 2018). Altogether, these results suggest that microorganism concentrations in the air are influenced by humidity, which favors their persistence in the air, and wind speed, which facilitates their dispersion. Both factors play a crucial role in the distribution and exposure to these microorganisms in the study area.

3.2 Microorganism genera present in the air

Table 4 presents the genera of microorganisms found in the air at the five sampling points. Eight bacterial genera were identified: *Micrococcus, Rhodococcus, Bacillus, Staphylococcus, Streptococcus, Enterococcus, Escherichia*, and *Proteus*. These bacteria are common in natural and urban environments, and some are known for their pathogenic potential, making their monitoring crucial in urban settings (Chen et al., 2020). Regarding fungi, five genera were identified: *Aspergillus, Penicillium, Rhodotorula, Mucor,* and *Rhizopus*. These microorganisms are particularly relevant due to their ability to produce mycotoxins and cause infections, especially in immunocompromised individuals (Brown et al., 2021). The presence of these pathogenic microorganisms in inhabited areas near the former WWTP highlights the potential risk for residents, as prolonged exposure to these bioaerosols could lead to health issues, particularly in vulnerable groups (Jahne et al., 2015).

Regarding bacteria, a study conducted at a wastewater treatment plant (WWTP) in Bydgoszcz, Poland, revealed that *Staphylococcus* was the most abundant bacterial genus at all monitoring points throughout the WWTP (Małecka-Adamowicz et al., 2017). As for fungi, our results align with those found at a WWTP in Tehran, Iran (Niazi et al., 2015). Here, genera known for thriving in unfavorable environments due to their metabolic capabilities, such as *Cladosporium spp., Penicillium spp., Aspergillus spp.,* and *Alternaria spp.*, were identified. Similarly, in the Gulf of Gdansk, Poland, fungi of the genera *Penicillium* and *Aspergillus* were identified in the wastewater discharge area, reinforcing the prevalence of these genera in contaminated aquatic environments (Michalska et al., 2021).

3.3 Incidence of health problems related to the microbiological quality of the air

The statistical analysis of the information obtained from the survey was conducted using IBM SPSS version 26, where Cronbach's alpha was applied to evaluate the reliability of the scale used. The obtained value was 0.823, which is within the acceptable range, as the minimum acceptable value is 0.70 and the maximum expected value is 0.90 (Oviedo and Campo, 2022). This result indicates that the scale used is reliable and has good internal consistency.

Figure 8 presents the impact of microorganisms on the health of the population in the area of influence of the former WWTP. Of the total respondents, 34% reported a low level of health problems, followed by 29% with a normal level. 18% indicated a high level of incidence, and 15% reported a very low level. Only 4% showed a very high level of incidence. These results may be influenced by various factors, such as age, location, and length of residence, which affect the population's vulnerability to the microorganisms present in the air (Vargas, 2005). Herrera et al. (2009) suggested that exposure to microbiological contamination does not necessarily translate into high levels of health incidence. The lack of health knowledge and constant exposure to this environment influence the subjective perception of the respondents. This causes individuals to not fully identify the effects of these microorganisms on their wellbeing.

Table 5 presents the relationship between the symptoms reported by the population and the microorganisms identified in the microbiological sampling. 77% of the reported symptoms were nasal problems, such as sneezing, rhinitis, congestion, and dryness, which are commonly associated with bacteria such as *Bacillus sp., B. subtilis, Rhodococcus sp., Micrococcus sp.* (Chen et al., 2020) and

TABLE 5 Health issue-causing microorganisms linked to the air quality in the area of influence near Cajamarca's former WWTP.

Symptoms	Frequency (%)	Causing microorganisms	Source
Stomach discomfort (vomiting, nausea, diarrhea)	65	*Bacillus sp*	Bennet et al. (2015)
		Escherichia coli	
		Shigella sp	
Eye discomfort	41	*Rhodotorula sp*	Cohen et al. (2017)
		Staphylococcus aureus	Bennet et al. (2015)
		Pseudomonas sp	
		Bacillus sp	
Skin disorders	38	*Enterococcus sp*	Cohen et al. (2017)
		Staphylococcus aureus Aspergillus sp	Bennet et al. (2015) Kac et al. (1995)
		Rhodococcus sp	Bennet et al. (2015)
		Micrococcus sp	
		Aspergillus sp	Talbot et al. (1987), Kac et al. (1995), Drakos et al. (1993); Bennet et al. (2015)
		Mucor sp	Cohen et al. (2017)
		Rizhopus sp	Cohen et al. (2017)
Throat symptoms	65	*Micrococcus sp*	Cohen et al. (2017)
		Rhodoccocus sp	Bennet et al. (2015)
Respiratory disorders	64	*Klebsiella sp*	Bennet et al. (2015)
		Rhodoccocus sp	Bennet et al. (2015)
		Pseudomonas sp	Bennet et al. (2015)
		Acinetobacter sp Aspergillus sp	Bennet et al. (2015) Kac et al. (1995), Bennet et al. (2015)

fungi such as *Aspergillus sp., Mucor sp.,* and *Rhizopus sp.* (Brown et al., 2021). Suaza and Valoyes (2019) in Antioquia, Spain, established a close relationship between air pollution and respiratory problems in the population, particularly in children and the elderly. Additionally, particulate matter has been identified as a factor that influences the development and persistence of bioaerosols. That is why it is necessary to further explore the interaction between these variables and their potential long-term health effects (Liu et al., 2020).

4 Conclusion

The results of this research project show that the microbiological quality of the air in the area influenced by the former WWTP in Cajamarca is not optimal. There are elevated concentrations of microorganisms, especially bacteria, exceeding the limits established by international standards OSHA and PN-89/Z-04111/02. Fungal levels, although elevated, do not exceed the limits of the PN-89/Z-04111/03 standard. Additionally, it was observed that microorganism concentrations are statistically similar between seasons and monitoring times, but differ according to the monitoring point. Furthermore, the concentrations have a positive correlation with relative humidity and a negative correlation with wind speed for both seasons.

Eight bacterial genera and five fungal genera were identified, with notable bacteria genera including *Micrococcus, Rhodococcus, Bacillus, Staphylococcus, Streptococcus, Enterococcus, Escherichia coli,* and *Proteus*, and notable fungi genera including *Aspergillus, Penicillium, Rhodotorula, Mucor,* and *Rhizopus*. Despite the high concentrations of microorganisms, a low incidence of health problems related to the microbiological quality of the air was observed in the surrounding population, with occasional respiratory illnesses mainly commonly associated with *Bacillus sp., B. subtilis, Rhodococcus sp., Micrococcus sp.,* and fungi such as *Aspergillus sp., Mucor sp.,* and *Rhizopus sp.*

The limitations of this research include the scarcity of bibliographic data in the national and regional context, although international studies provided valuable information for the discussion. Our study suggests the need to implement regular air and water quality monitoring in areas near WWTPs to have a comprehensive view of environmental risks. Additionally, we suggest evaluating the dispersion of bioaerosols at different sampling heights and during various seasons of the year. This would provide more complete data to develop effective public health policies in areas adjacent to WWTPs.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Author contributions

CR-Z: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. JS-A: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Validation, Writing–original draft, Writing–review and editing. MS-P: Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing–review and editing. KD: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Supervision, Visualization, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2024.1496978/full#supplementary-material

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