Original Paper

Airborne bacteria and fungi in coastal Ecuador: a correlation analysis with meteorological factors

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Abstract. *Air quality is of crucial significance for both ecosystem and human health. The aim of the research was to assess how meteorological conditions affected the aerobiological concentration in Chone, Manabí, Ecuador. For five days, sedimentation in Petri dishes was used to carry out sampling at nine different points. Temperature, relative humidity, wind speed, and UV index were among the meteorological data taken from the Catholic University of Chone meteorological station and included in the analysis. Following the* *hospital (point 6), the city market (point 4) had the highest concentration of bacteria, with 301 CFU/m³ in the morning and 441 CFU/m³ in the afternoon. With values of 0.541 and 0.56, respectively, wind speed and solar radiation showed the biggest fluctuation with bacteria concentrations. With the exception of a relative humidity value of 0.023, the park (point) had the highest abundance of mushrooms and no significant associations with meteorological variables. In summary, aerobiological concentrations showed a minor influence from meteorological factors while being below allowable bounds.*

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1. Introduction

Ecosystem and human health are greatly impacted by outdoor air quality (Yin et al., 2021; Leal, 2019). Air pollution has numerous negative impacts on terrestrial and aquatic ecosystems, ranging from local and global scales, degrading the physical environment, threatening organismic health and reducing biodiversity. Airborne pollutants, which include volatile organic compounds, poisonous gases, and suspended particulates, can harm cardiovascular and respiratory health as well as induce conditions including cancer, allergies, and asthma (Ruiz-Gil et al., 2020; Leal, 2019). The World Health Organization (WHO) reports that 4.2 million die each year, across the world, due to heart disease, stroke, lung cancer, and acute/chronic respiratory disease linked to ambient air pollution (Abdul et al., 2022; WHO, 2020). Moreover, the impact extends beyond human health since certain pollutants trap heat in the atmosphere, accelerating global warming. This warming can further exacerbate air quality issues and create a vicious cycle (Keishams et al., 2022; Huh et al., 2020).

As well as affecting residents of high-pollution areas, outdoor air pollution can have an impact on an entire region or indeed the whole biosphere (Keishams et al., 2022; Huh et al., 2020). Long-distance windborne pollution can carry harmful particles and gasses, lowering air quality in isolated locations. This understanding is crucial not only for public health but also for ecosystem health. Airborne bacteria and fungi can play a role in nutrient cycling, plant-microbe interactions, and even influence the spread of plant diseases (Sangkham et al., 2021). Therefore, studying how meteorological factors influence these microbial communities can provide valuable insights into the overall ecosystems.

Human health can also be impacted by airborne microorganisms such viruses, fungus, and bacteria (Olivera et al., 2021). According to studies by Liu et al. (2018) and Madhwal et al. (2020), these bioaerosols can result in infections, allergies, and respiratory disorders. Environmental elements including temperature, humidity, and wind speed have an impact on the concentration and make-up of these microorganisms in the air (Olivera et al., 2021; Ramos & Meza, 2017). While it is true that there is several research on environmental quality in metropolitan areas conducted internationally, this subject has not yet received much attention at the provincial level (Vivas et al., 2022; Gómez et al., 2021).

Understanding the role of airborne microbes is crucial for advancing towards a sustainable future (Palladino et al., 2021). This research contributes to several Sustainable Development Goals (SDGs), notably SDG 3 (Good Health and Well-being) and SDG 11 (Sustainable Cities and Communities), emphasizing the need for managing healthy urban environments. By exploring the relationship between airborne bacteria, fungi, and the health of humans, animals, and the environment, effective strategies for improving air quality can be developed. Consequently, the research question arises: How do airborne bacteria and fungi in coastal Ecuador correlate with meteorological factors? Thus, this study aims to assess how meteorological conditions influence aerobiological concentrations in the town center of Chone.

2. Literature review

For centuries, concerns about airborne illness spurred interest in what eventually became aerobiology (Myszkowska, 2020). This field truly blossomed in the 20th century. The coining of the term *aerobiology* in the 1930s by Fred Campbell Meier, along with his innovative air sampling tool, laid the groundwork. Pioneering figures like Philip Herries Gregory further developed the field with concepts like *air spora* and studies on spore dispersal. The invention of the Hirst spore trap in 1952 revolutionized air sampling, enabling the creation of monitoring networks. Collaboration among researchers solidified with the establishment of the International Association of Aerobiology in 1972. While traditional methods like Hirst traps remain important, recent advancements like molecular techniques and real-time sensing offer more sophisticated aerobiological monitoring (Lancia et al., 2021).

Aerobiology, a vast field with over 2,122 articles on Scopus using the keyword, traditionally relied on gravimetric methods (popular in Poland around the 20th/21st century transition) but has shifted towards volumetric methods for precise particle measurement (Grewling et al., 2023). While aerobiological monitoring is carried out both indoors and outdoors, for the purposes of this research, a literature review will be conducted on the main advances in publications on outdoor monitoring.

A study conducted in Tianjin, China, revealed a diverse range of airborne fungi, with Alternaria being the most prevalent. The concentration of these fungi varies significantly throughout the year, influenced heavily by the month. However, the study found no substantial difference in fungal communities between busy urban areas and green spaces (Nageen et al., 2021).

In Seoul's elementary schools, outdoor air had a richer bacterial community than classroom air, though fungal diversity was similar indoors and outdoors. Abundant bacteria included Enhydrobacter, Micrococcus, and Staphylococcus, while prevalent fungi were Cladosporium, Clitocybe, and Daedaleopsis. Classroom air bacterial composition was uniform across rooms but distinct from outdoor air (Lee et al., 2021).

A study at Eskişehir Technical University found most departments had low to moderate levels of airborne bacteria (up to 1663 CFU/m^3). However, cafeterias had significantly higher bacterial counts, indicating a higher degree of air pollution in those areas (Bhat et al., 2022). At a public university in Islamabad, Pakistan, outdoor fungal and bacterial concentrations ranged from 280–510 CFU/m^3 and 20–100 CFU/m^3, respectively. The high outdoor fungal concentrations significantly contributed to indoor fungal buildup, as evidenced by the abundance of *Cladosporium spp.,* a plant pathogen (Hassan et al., 2021).

At the wastewater treatment plant in Lublin, Poland, the highest concentrations of total bacteria (3617 CFU/m^3) and fungi (5386 CFU/m^3) in bioaerosols were detected near the sewage pumping station, close to the aeration tanks. Pseudomonas fluorescens was found in the air around the grit chamber at 78 CFU/m^3 (Staszowska, 2022).

In Southeastern Italy during winter, Bacillus and Chryseobacterium were the only genera significantly correlated with chemical species likely associated with soil-dust and anthropogenic pollution sources, respectively. In spring, Enterobacter and Sphingomonas were the only genera significantly correlated with chemical species likely associated with anthropogenic pollution and marine and soil-dust sources, respectively (Romano et al., 2020).

Focusing on studies in America, Suehara and Pinto (2023) report that the most prevalent airborne fungi genera in Brazil are Aspergillus, Penicillium, Cladosporium, Curvularia, and Fusarium. Their findings also highlight the relationship between fungi and meteorological factors and seasonality, the sensitivity of atopic individuals to fungi, and the main nosocomial mycoses reported in the literature.

In Mexico City, Calderón-Ezquerro et al. (2021) found that the Actinobacteria phylum dominated the bacterial communities in both urban (41%) and semi-urban (42%) areas, followed by Proteobacteria, Firmicutes, Bacteroidetes, Cyanobacteria, and Chloroflexi. Interestingly, the urban environment harbored 13 unique bacterial genera, while the semi-rural area had 17.

In a public library in Colombia, Camargo-Caicedo et al. (2023) reported air fungal concentrations reaching up to 1197 CFU/m³, with an average around 150 CFU/m³, noting higher values during morning samples. Seven fungal genera were identified, with Aspergillus and Curvularia being the most abundant. The temperature ranged from 30.80 to 33.51 °C, and relative humidity from 62.61 to 64.80%. Statistical analysis revealed a significant correlation between fungal aerosol concentration and relative humidity, indicating that a 10% increase in moisture could double the fungal aerosol concentration.

In Ecuador, Vivas et al. (2021) found high bacterial concentrations, reaching up to 151,111 CFU/m³ of air, near the central market of Calceta city, with lower fungal concentrations. Significant differences were observed in monitoring frequency, with higher average concentrations of CFU/m³ and UPC/m³ on weekends. Without additional nationally relevant studies, the primary contribution of this research is its role as the first study to reveal the influence of meteorological factors on the concentration of bacteria and fungi at the municipal level in Ecuador.

3. Methodology

The research area exhibits tropical climate features as indicated by the bioclimatic map of Ecuador and is described by Holdridge as an ecological region of the tropical dry forest type. Variations in the Pacific Ocean and regional mobility characterize this area, with intertropical convergence playing a major role (Aveiga et al., 2023). According to Reyna et al. (2018), the Carrizal-Chone valley experiences 25.6 °C of annual average temperature, 1365.2 mm of potential evapotranspiration, and 838.7 mm of precipitation. Based on these facts, there is a wet season from January to May and a dry season from June to December.

The methodology proposed by Vivas et al. (2021) was employed to establish the points. Numerous elements were considered, such as crowded areas and public, urban, and rural transportation terminals found within cities. The WHO-proposed methodology was utilized by Morocho's (2021) research as a reference for determining criteria, which also took into account the emission and dispersion patterns of pollution (table 1). A total of nine monitoring sites were set up (see figure 1), where samples were taken five days a week between 1:30 p.m. and 7:00 a.m.

Table 1. Criteria for the location of monitoring points

Site rating	Description
City or urban centre	Walking or commercial zones are examples of urban locations that reflect the general exposure of the populace in towns or urban centres.
Background urban areas	Urban location that is far from sources of pollution and, hence, broadly reflective of the overall city's backdrop circumstances.
Suburban or residential areas	Location on a town or city's periphery that is residential in nature.
Places near the tracks (kerbside)	A site sample that is between one and five meters away from a major street.
Industrial	A region where long-term or peak concentrations are significantly influenced by industrial sources.

Source: Morocho (2021)

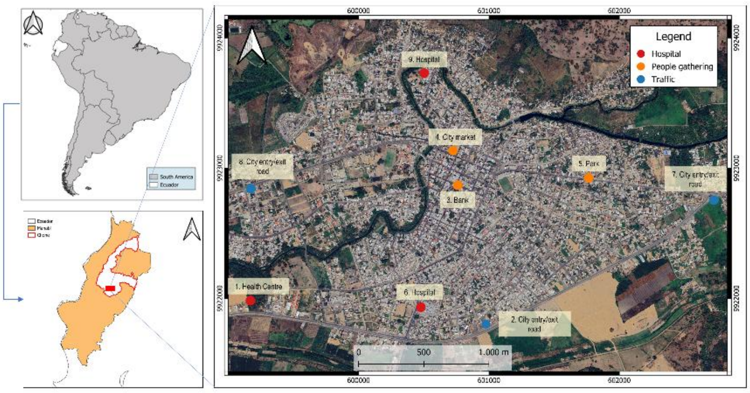

Figure 1. Geographic location of the cantonal capital of Chone.

In May 2024, sampling took place utilizing the sedimentation method in Petri dishes during a 5-day period. Nutrient agar was used to cover the boxes if aerobic bacteria were detected, whereas malt extract agar was utilized to detect fungus. The Petri dishes were left in an open position 1.50 meters above the floor and left to be exposed to the environment for half an hour. It is important to note that the approach used in the studies by Vivas et al. (2022) for exposure duration and Vivas et al. (2021) for box height served as the foundation for this process.

The samples were incubated for twenty-four hours at 35 ± 2°C. The amount of fungal and bacterial colonies was counted using the Stuart SC6PLUS counter after incubation. Stated otherwise, the number of colonies denotes the overall mean of the colonies found at the sampling locations. Equation 1 was used to calculate the concentration of colony forming units (CFU, for bacteria) and propagation units (CPU, for fungi) per m^3 of air, respectively.

$$CFU \ or \ CPU = \frac{NC \ X \ 25}{time \ (min)} \qquad [1]$$

Where:

NC = number of colonies per plate

time (min) = 25

Temperature, humidity, wind speed, and UV index were among the climatic parameters that were obtained from the Catholic University of Chone meteorological station. A non-parametric analysis was used to determine the connection among these factors and the aerobiological concentration. A measure of statistical correlation used to assess the linear relationship between two variables, Pearson statistical analysis with the SPSS statistical software, according to García (2014) cited by López (2020), provides a quantitative measure of the strength and direction of a potential linear relationship between these variables.

4. Results and discussion

The mean of the meteorological parameters included for the analysis are temperature of 27.12 °C, relative humidity of 82.42%, wind speed of 0.9 m/s and UV index of 1.14 sun hours/day. Comparing the two examined timeframes, Figure 2 illustrates how the concentration of bacteria varied among the nine monitoring points in a comparable manner. On the other hand, the concentration of microorganisms increases everywhere about 1:30 (figure 2).

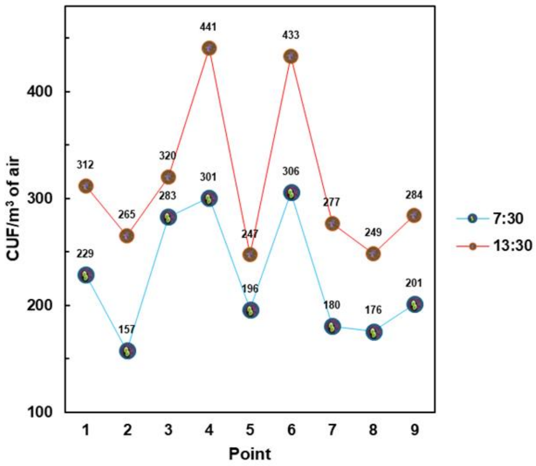

Figure 2. Data on bacteria concentrations.

The city market (point 4) stood out as one of the points with the highest densities of bacteria, as seen in the above figure. The concentration was already noticeably high in the morning at 301 CFU/m^3. On the other hand, this value sharply rose to 441 CFU/m^3 in the afternoon. This noticeable rise indicates that there is a lot more activity and social interaction in the market in the evening, which promotes the growth of germs. Food markets are known to be places where microorganisms thrive since they are the hub for a range of commercial operations that can lead to environmental issues such an overabundance of organic waste creation, according to Gómez et al. (2021). Chulquín & Rojas (2020) suggest that the current circumstances facilitate the growth and dissemination of bacteria and other harmful agents, as evidenced by the discovery by Vivas et al. (2021) of a significant bacterial concentration in the vicinity of the central market.

In point 6 (the hospital) there was a concentration of 433 UFC/m3 of air which rises raises the possibility of a connection to the higher volume of patients, guests, and medical personnel that occurs during the day. In accordance with Polytechnic University of Madrid researchers (UPM, 2023), raises the risk of nosocomial infections. As a medical facility, the hospital receives a lot of patients with different diseases, many of which are brought on by infectious agents including viruses, fungi, and bacteria (UPM, 2023). Because of their minuscule size, these microbes are easily swallowed when breathing and can spread throughout the air, raising the risk of nosocomial infections (Banchón et al., 2022). Hospital air contains a high concentration of microorganisms, which is concerning since it can spread illnesses to patients, visitors, and medical staff. Moreover, Núñez et al. (2021) state that elements like sunlight and high temperatures tend to raise the concentration of microorganisms because mid-afternoon is typically when the most daylight hours and significant temperatures are experienced.

According to Vivas et al. (2021), there are various criteria on the threshold of microbial concentration in outdoor air that is considered harmful to human health. The concentration mostly considered harmful to health is 500 CFU/m^3, in the case of fungi and bacteria. The values found in the present study are within this range, since the highest concentration recorded was 441 CFU/m^3. However, according to the limit values of microorganisms allowed by the WHO, the concentration is at an intermediate level (101 – 500 CFU/m^3 of air) (Marcillo et al., 2021), which is a cause for concern and justifies the implementation of prevention measures.

Several intriguing patterns emerged from an analysis of the correlation between climate variables and the number of germs in the air (Table 2). First, a weak negative correlation (coefficient of -0.42) was observed between the concentration of bacteria and temperature, suggesting that temperature had no effect on the number of bacteria in the air. Certain research, like Tang's (2009) study that Siller et al. (2024) mentioned, indicates that temperatures higher than 24°C may reduce the lifespan of microorganisms. However, studies like the one by Smets et al. (2016), which Yang et al. (2024) mentioned, show that bacterial growth is favored by rising temperatures. Temperature affects the dispersal of germs in the air because it encourages convective air movement, regardless of its impact on life (Miri et al., 2023).

An even weaker negative connection (coefficient of -0.05) was found for relative humidity. This indicates that the CFU concentration tends to decrease significantly as the relative humidity decreases. However, this association is extremely weak and nearly inconsequential because the coefficient of -0.05 is so close to zero. As to Guarnieri et al. (2023), an overabundance of relative humidity (RH) fosters the growth of detrimental microbes, including bacteria, viruses, and mold. Moreover, Cortés et al. (2024) claim that an excessively low relative humidity increases the risk of infection by causing dryness and irritation in the skin and respiratory system.

Table 2. Pearson correlation coefficient test for bacteria.

		Bacteria
Temperature	Pearson Correlation	-0.042
	Sig. (2-tailed)	0.692
	N	90
Relative humidity	Pearson Correlation	-0.055
	Sig. (2-tailed)	0.610
	N	90
Wind speed	Pearson Correlation	0.541**
	Sig. (2-tailed)	0.000
	N	90
UV index	Pearson Correlation	0.056
	Sig. (2-tailed)	0.601
	N	90

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

By contrast, there was a statistically significant positive association between wind speed and the concentration of airborne bacteria, with a coefficient of 0.541 and statistical significance at the 0.01 level. According to Miri et al. (2024), high winds cause bacteria to be lifted from the soil and plant surfaces into the air, which explains why the concentration of bacteria in the air increases as wind speed increases. Although the role of wind speed in the modulation and transport of bacteria has not been well investigated, Dueker et al. (2017) note that this variable is expected to increase the creation and transport of microbes from nearby bodies of water.

Furthermore, a positive association (coefficient of 0.56) was found between the UV index and the concentration of microorganisms. This suggests that more sun exposure may be linked to a higher prevalence of bacteria in the environment because there is a direct and reasonably strong relationship between the UV index and the quantity of bacteria in the air. Yet in a study conducted by Fahimipour et al. (2018), they assessed the impact of light exposure and wavelengths on the composition of the dust microbiome (in indoor environments). They found that exposure to sunlight led to a reduction in the number of some abundant microorganism groups and an apparent increase in the number of rare groups, suggesting that some microorganisms may have grown slightly in the presence of light.

The fungal concentration shows a notable increase around 1:00 p.m. at points 4, 5, and 6, with point 5 (park) recording the highest value at 87 CUP/m³. In contrast, the highest incidence of fungi at other locations (points 1, 2, 3, 7, and 9) occurs at 7:30 a.m., which follows a different pattern compared to the bacterial concentration at the two measured times (Figure 3).

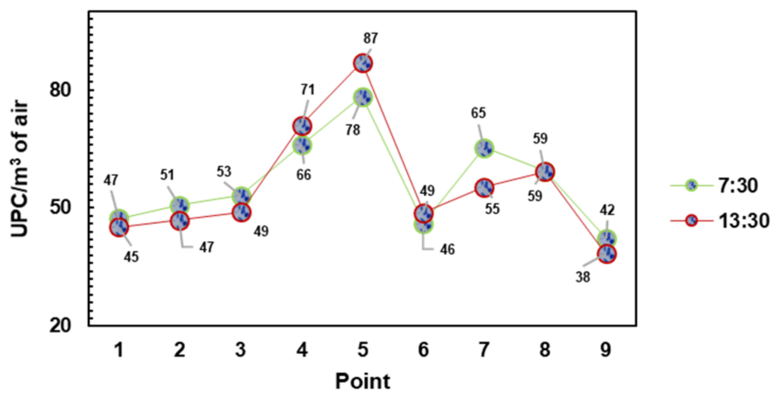

Figure 3. Data on fungal concentrations.

As opposed to the concentrations of bacteria, the preceding figure in this instance demonstrates that there is minimal fluctuation regarding the sample sites; in fact, depending on the two monitoring schedules, the concentrations may decline in certain instances or remain constant in others. The point 9 showed the biggest decline of all the locations, going from 65 to 55 UPC/m³ of air, a remarkable 10 CPU/m³ decrease from morning to afternoon. This notable variance could be attributed to a decrease in afternoon human activity or site-specific environmental variations, like variations in natural ventilation or sunlight (Marcillo et al., 2021).

This reduction is notable in comparison to other points because most locations saw minor gains or losses. One example of this is point 5 (park), which showed a notable increase of 8.6 CPU/m³ from morning to afternoon. Since vegetation is one of the primary substrates for the development of fungi, it is assumed that in urban parks, the concentrations of fungal spores in the air could be higher, as per Kasprzyk et al. (2021) since the production of fungal spores is significantly higher than that of pollen grains.

In the instance of the city market (point 4), there was a 5 CPU/m^3 variation in the concentration of fungus from the morning (66 CPU/m^3 of air) to the afternoon (71 CPU/m^3 of air). Although not as large as that of point 5, this increase is nonetheless noteworthy, and Gómez et al. (2021) attribute it to the escalation of commercial activity and the rise in afternoon population density. Conversely, point 9 (a city entry/exit road) had the lowest fungal content during both periods (42 UPC m^3 of air in the morning and 38.4 UPC m^3 of air in the afternoon). This could be because of its urban setting with fewer green spaces in addition to the rising temperatures.

Regarding the Pearson correlation between meteorological variables and fungal concentrations, the following was obtained:

Table 3. Pearson correlation coefficient for fungi.

		Fungi
Temperature	Pearson Correlation	0.018
	Sig. (2-tailed)	0.870
	N	90
Relative humidity	Pearson Correlation	0.023
	Sig. (2-tailed)	0.830
	N	90
Wind speed	Pearson Correlation	0.003
	Sig. (2-tailed)	0.978
	N	90
UV index	Pearson Correlation	-0.195
	Sig. (2-tailed)	0.066
	N	90

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A very weak positive association, indicated by a correlation coefficient of 0.18 in the temperature variable, suggests that while the concentration of fungus tends to increase slightly with temperature, the relationship is not very strong. However, in September, there was a strong direct correlation between temperature and the total amount of fungi ($r = 0.853$, $p < 0.01$), according to a study by Nageen et al. (2023) on the seasonal change of fungal diversity in urban contexts. However, in November, the connection was inverse, meaning that the overall number of fungi decreased with increasing temperature ($r = -0.7718$*, p

< 0.05). Likewise, Noor et al. (2019) in a similar study, found that the number of fungal spores in the air varied throughout the month of March and was related to climatic factors such as temperature, which influences the release of spores and growth. of mushrooms.

The correlation coefficient for relative humidity was 0.023, suggesting a weak positive association. This implies that there is a modest positive correlation between an increase in relative humidity and an increase in the variable under investigation. Similarly, Hass et al.'s study from 2023 found that there were negative associations between fungal spore counts and relative humidity for both Cladosporium and xeric fungi, with rho values of -0.35 ($p < 0.001$) and -0.33 ($p < 0.001$), respectively. Regarding its part, a statistically significant influence ($p < 0.002$) was identified on the number of fungal spores in the air, accounting for 1.5% of the overall change in the presence of fungal spores, in the study by Grinn and Bosiacka (2015), referenced by Núñez et al. (2021).

On the other hand, there is just a very slight positive association (0.003) between wind speed and fungal concentration. There is essentially no link between the two variables because this number is so close to zero. In contrast, the average wind speed was found to have a statistically significant influence ($p \leq 0.03$) on the number of fungal spores in the air during the study period, accounting for 1.5% of the total variation in the presence of fungal spores over a three-year period. This study was conducted by Grinn and Bosiacka (2015), cited by Haas et al. (2023). The wind helps release fungal spores and carries them through the air, expanding their dispersion and range, according to Nageen et al. (2021) by creating air currents.

However, the correlation value for UV index variable is -0.195, indicating a very weak negative link. In fact, in the study conducted by Kowalski and Pastuszkan (2018), at similar temperatures, the concentration of bioaerosols decreased with increasing sun radiation intensity, indicating that UV solar radiation negatively affects fungal spores and decreases their airborne presence. According to Noreiga et al. (2020), when administered in greater quantities, the same light wavelengths that promote spore formation in tiny amounts can completely prevent it.

5. Conclusions

Bacteria and fungi are part of airborne particles that exist momentarily and are subject to variations in concentration based on meteorological factors. Temperature and relative humidity had no discernible effects on bacterial concentrations in the research area, while wind speed and UV index demonstrated the strongest and positive connections with bacterial concentrations. The connections between meteorological factors and fungi were typically minor, with the most notable, though still weak relationship, being that of relative humidity.

The usefulness of the presented results is supported by their complete reproducibility. Future research should account for as many factors as possible in aerobiological studies. Additionally, monitoring should cover the entire season of the study area. Lastly, employing advanced techniques for identifying bacteria and fungi would enhance the specificity and accuracy of the information presented. This will make a significant contribution to monitoring the relationship between air quality and ecosystem and human health.

References

Abdul, S., Tul Qadar, L., Ghafoor, S., Rasheed, L., Sarfraz, Z., Sarfraz, A., Sarfraz, M., Felix, M., & Cherrez-Ojeda, I. (2022). Air quality, pollution and sustainability trends in South Asia: A population-based study. *International Journal of Environmental Research and Public Health*, *19*(12). https://doi.org/10.3390/ijerph19127534

Aveiga, A., Banchón, C., Sabando, R., & Delgado, M. (2023). Exploring the Phytoremediation Capability of *Athyrium filix-femina*, *Ludwigia peruviana* and *Sphagneticola trilobata* for Heavy Metal Contamination. *Inżynieria Ekologiczna*, *24*(7), 165–174. https://doi.org/10.12911/22998993/164758

Banchón, C., Borodulina, T., Díaz, T. y Yasugji, A. (2022). Aerobiología en hospitales de Guayaquil: microorganismos resistentes a cobre. *Revista REIMAT*, *7*(2), 1-6. https://revistas.utm.edu.ec/index.php/Riemat/article/download/1914/7039/26205

Bhat, M. A., Eraslan, F. N., Awad, A., Malkoç, S., Üzmez, Ö. Ö., Döğeroğlu, T., & Gaga, E. O. (2022). Investigation of indoor and outdoor air quality in a university campus during COVID-19 lock down period. *Building and Environment*, *219*. https://doi.org/10.1016/j.buildenv.2022.109176

Calderón-Ezquerro, M. del C., Serrano-Silva, N., & Brunner-Mendoza, C. (2021). Aerobiological study of bacterial and fungal community composition in the atmosphere of Mexico City throughout an annual cycle. *Environmental Pollution, 278, 116858*. https://doi:10.1016/j.envpol.2021.116858

Camargo-Caicedo, Y., Borja Pérez, H., Muñoz Fuentes, M., Vergara-Vásquez, E., & Vélez-Pereira, A. M. (2023). Assessment of fungal aerosols in a public library with natural ventilation. *Aerobiologia*, *39*(1), 37–50. https://doi.org/10.1007/s10453-022-09772-5

Cortés-Hernández, Fabiola del Carmen, Alvarado-Castillo, Gerardo, & Sánchez-Viveros, Gabriela. (2023). *Trichoderma spp.,* una alternativa para la agricultura sostenible: una revisión. *Revista Colombiana de Biotecnología*, *25*(2), 73-87. https://doi.org/10.15446/rev.colomb.biote.v25n2.111384

Dueker, M., O'Mullan, G., Martínez, J., Juhl, R. & Weathers, K. (2017). Onshore Wind Speed Modulates Microbial Aerosols along an Urban Waterfront. *Atmósfera*, *8*(11), 215. https://doi.org/10.3390/atmos8110215

Fahimipour, A. K., Hartmann, E. M., Siemens, A., Kline, J., Levin, D. A., Wilson, H., Betancourt-Román, C. M., Brown, G. Z., Fretz, M., Northcutt, D., Siemens, K. N., Huttenhower, C., Green, J. L., & Van Den Wymelenberg, K. (2018). Daylight exposure modulates bacterial communities associated with household dust. *Microbiome*, *6*(1). https://doi.org/10.1186/s40168-018-0559-4

Gómez, D., García, D., Lache, J. & Cuéllar, L. (2021). Análisis microbiológico de contaminantes atmosféricos en la plaza de mercado del sur de la ciudad de Tunja, Boyacá. Cuaderno Activa, 13, 25-40. https://ojs.tdea.edu.co/index.php/cuadernoactiva/article/download/749/1360/3671

González, S., Lira, C., Villareal, R. & Canseco, J. (2022). Contaminación ambiental y alergia. *Revista alergia México*, *69*(1), 24-30. https://doi.org/10.29262/ram.v69isupl1.1010

Graham, F. F., Kim, A. H. M., Baker, M. G., Fyfe, C., & Hales, S. (2023). Associations between meteorological factors, air pollution and Legionnaires' disease in New Zealand: Time series analysis. *Atmospheric Environment (Oxford, England: 1994)*, *296*(119572), 119572. https://doi.org/10.1016/j.atmosenv.2022.119572

Grewling, Ł., Myszkowska, D., Piotrowska-Weryszko, K., Sulborska-Różycka, A., & Weryszko-Chmielewska, E. (2023). Aerobiology in Poland: Achievements and challenges. *Acta Societatis Botanicorum Poloniae. Polskie Towarzystwo Botaniczne*, *92*(1). https://doi.org/10.5586/asbp/172278

Guarnieri, G., Olivieri, B., Senna, G., & Vianello, A. (2023). La humedad relativa y su impacto en el sistema inmunológico y las infecciones. *Revista internacional de ciencias moleculares*, *24*(11), 9456. https://doi.org/10.3390/ijms24119456

Haas, D., Ilieva, M., Fritz, T., Galler, H., Habib, J., Kriso, A., Kropsch, M., Ofner-Kopeinig, P., Reinthaler, F. F., Strasser, A., Zentner, E., & Schalli, M. (2023). Background concentrations of airborne, culturable fungi and dust particles in urban, rural and mountain regions. *Science of the Total Environment*, *892*, 164700. https://doi.org/10.1016/j.scitotenv.2023.164700

Hassan, A., Zeeshan, M., & Bhatti, M. F. (2021). Indoor and outdoor microbiological air quality in naturally and mechanically ventilated university libraries. *Atmospheric Pollution Research, 12*(8). https://doi:10.1016/j.apr.2021.101136

Huh, K., Hong, J., & Jung, J. (2020). Association of meteorological factors and atmospheric particulate matter with the incidence of pneumonia: an ecological study. *Clinical Microbiology and Infection: The Official Publication of the European Society of Clinical Microbiology and Infectious Diseases*, *26*(12), 1676–1683. https://doi.org/10.1016/j.cmi.2020.03.006

Kasprzyk, I., Grinn-Gofroń, A., Ćwik, A., Kluska, K., Cariñanos, P. y Wójcik, T. (2020). Allergenic fungal spores in the air of urban parks. *Aerobiologia*, *37*(1), 39–51. https://doi.org/10.1007/s10453-020-09671-7

Keishams, F., Goudarzi, G., Hajizadeh, Y., Hashemzadeh, M., & Teiri, H. (2022). Influence of meteorological parameters and PM2.5 on the level of culturable airborne bacteria and fungi in Abadan, Iran. *Aerobiologia*, *38*(2), 233–245. https://doi.org/10.1007/s10453-022-09744-9

Kowalski, M. & Pastuszkan, J. (2018). Effect of ambient air temperature and solar radiation on changes in bacterial and fungal aerosols concentration in the urban environment. *Annals of Agricultural and Environmental Medicine*, *25*(2), 259–261. https://doi.org/10.26444/aaem/75877

Lancia, A., Capone, P., Vonesch, N., Pelliccioni, A., Grandi, C., Magri, D., & D'Ovidio, M. C. (2021). Research progress on aerobiology in the last 30 years: A focus on methodology and occupational health. *Sustainability*, *13*(8). https://doi.org/10.3390/su13084337

Leal, J. (2019). Efectos físicos de la contaminación atmosférica percibidos de manera inconsciente por la ciudadanía, en el área metropolitana de la ciudad de Monterrey Nuevo León, México. *Rev. salud pública, 21*(24), 423-429. https://doi.org/10.15446/rsap.V21n4.74959

Lee, B. G., Yang, J. I., Kim, E., Geum, S. W., Park, J., & Yeo, M. (2021). Investigation of bacterial and fungal communities in indoor and outdoor air of elementary school classrooms by 16S rRNA gene and ITS region sequencing. *Indoor Air, 31*(5), 1553–1562. https://doi:10.1111/ina.12825

Liu, H., Zhang, X., Zhang, H., Yao, X., Zhou, M., Wang, J., He, Z., Zhang, H., Lou, L., Mao, W., Zheng, P., & Hu, B. (2018). Effect of air pollution on the total bacteria and pathogenic bacteria in different sizes of particulate matter. *Environmental Pollution (Barking, Essex: 1987)*, *233*, 483–493. https://doi.org/10.1016/j.envpol.2017.10.070

López, E. (2020). *Análisis de dispersión anual para los contaminantes criterio de la Red Automática de Monitoreo Atmosférico de la Zona Metropolitana del Valle de Toluca (RAMA-ZMVT), 2017*. [Tesis de grado, Universidad Autónoma del Estado de México]. http://ri.uaemex.mx/bitstream/handle/20.500.11799/110686/UAEM-FaPUR-TESIS-Enrique%20L%c3%b3pez%20Vera%20.pdf?sequence=1&isAllowed=y

Madhwal, S., Prabhu, V., Sundriyal, S. & Shridhar, V. (2020). Ambient bioaerosol distribution and associated health risks at a high traffic density junction at

Dehradun city, India. *Environmental Monitoring and Assessment*, *192* (3), 2-15. https://doi.org/10.1007/s10661-020-8158-9

Marcillo, S., Zambrano, K. & Zambrano, D. (2021). *Identificación bacteriana del aire en el taller de procesos cárnicos de la ESPAM-MFL.* [Tesis de grado, ESPAM MFL]. https://repositorio.espam.edu.ec/bitstream/42000/1439/1/TTMA28D.pdf

Ministerio del Ambiente de Ecuador. (2015). Registro Oficial 387. MAE Quito https://www.gob.ec/sites/default/files/regulations/2018-09/Documento_Registro-Oficial-No-387-04-noviembre-2015_0.pdf

Miri, A., Shirmohammadi, E. & Sorooshian, A. (2023). Influence of meteorological factors and air pollutants on bacterial concentration across two urban areas of the Sistan region of Iran. *Urban Climate*, *51*, 101650. https://doi.org/10.1016/j.uclim.2023.101650

Morocho, G. (2021). *Caracterización de una red de monitoreo para control de la calidad del aire en la zona urbana del cantón Azogues*. [Tesis de grado, Universidad Politécnica Salesiana]. https://dspace.ups.edu.ec/bitstream/123456789/21184/1/UPS-CT009308.pdf

Myszkowska, D. (2020). Aerobiological studies – current state and future challenges. *Alergoprofil, 16*(1), 8-14. https://www.journalsmededu.pl/index.php/alergoprofil/article/view/982/921

Nageen, Y., Asemoloye, M. D., Põlme, S., Wang, X., Xu, S., Ramteke, P. W., & Pecoraro, L. (2021). Analysis of culturable airborne fungi in outdoor environments in Tianjin, China. *BMC Microbiology*, *21*(1). https://doi.org/10.1186/s12866-021-02205-2

Negeen, Y., Wang, X. & Pecoraro, L. (2023). Seasonal variation of airborne fungal diversity and community structure in urban outdoor environments in Tianjin, China. *Front. Microbiol.*, *13*, 1043224. https://doi.org/10.3389/fmicb.2022.1043224

Nasser, N. I., Al-Hadrawi, M. K., Oleiwi, S. A., & Mohsin, A. A. (2019). The diversity in dust fungal spores concentration at four districts of Al-najaf environment and their potential correlation with asthma. *Journal of pure & applied microbiology*, *13*(4), 2169–2176. https://doi.org/10.22207/jpam.13.4.29

Noriega-Cantú, D. H., Toledo-Aguilar, R., Vasquez-Ortiz, R., Alejo-Jaimes, A., Garrido-Ramírez, E. R., Pereyda-Hernández, J. & González-Mateos, R. (2020). Relación entre fluctuaciones de esporas, condiciones ambientales y severidad del manchado y tizón de cáliz de jamaica (Hibiscus sabdariffa). *Revista mexicana de fitopatología*, *38*(1), 1-24. https://doi.org/10.18781/r.mex.fit.1909-1

Núñez, A., García, A. & Moreno, D. (2021). Seasonal changes dominate long-term variability of the urban air microbiome across space and time. *Environment International*, *150*, 106423. https://doi.org/10.1016/j.envint.2021.106423

Olivera, L., Oré, L., Loarte, W., Oré, J., García, G & Diaz, J. (2021). Calidad microbiológica del aire en seis áreas de la microestación biológica Zoocriadero de la

Universidad Nacional Agraria de la Selva – Tingo María – Perú. *Boletín de Malariología y Salud Ambiental, 61*(4), 620-632. https://docs.bvsalud.org/biblioref/2022/09/1395693/298-1324-1-pb.pdf

Palladino, G., Morozzi, P., Biagi, E., Brattich, E., Turroni, S., Rampelli, S., Tositti, L., & Candela, M. (2021). Particulate matter emission sources and meteorological parameters combine to shape the airborne bacteria communities in the Ligurian coast, Italy. *Scientific Reports*, *11*(1), 1–12. https://doi.org/10.1038/s41598-020-80642-1

Peña, S. (2018). Impacto de la contaminación atmosférica en dos principales ciudades del Ecuador. *Revista Universidad y Sociedad*, *10*(2), 289-293. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2218-36202018000200289&lng=es&tlng=es

Ramos, R & Meza, V. (2017). Efectos de algunos factores meteorológicos sobre la concentración de esporas de hongos en la Plaza San Martín de Lima. *Ecología Aplicada, 16*(2), 143-149. https://dx.doi.org/10.21704/rea.v16i2.1018

Ramos, R. (2023). Relación entre el material particulado (PM_{10}), los parámetros meteorológicos y la concentración de esporas fúngicas en la atmósfera de la Plaza San Martín de Lima. *Ecología Aplicada, 22*(1), 35-41. https://dx.doi.org/10.21704/rea.v22i1.1927

Reyna, L., Vera-Montenegro, L., & Reyna, L. (2018). Soil-organic-carbon concentration and storage under different land uses in the Carrizal-Chone valley in Ecuador. *Applied Sciences (Basel, Switzerland)*, *9*(1), 45. https://doi.org/10.3390/app9010045

Romano, S., Becagli, S., Lucarelli, F., Rispoli, G., & Perrone, M. R. (2020). Airborne bacteria structure and chemical composition relationships in winter and spring PM10 samples over southeastern Italy. *The Science of the Total Environment*, *730*(138899), 138899. https://doi.org/10.1016/j.scitotenv.2020.138899

Ruiz-Gil, T., Acuña, J. J., Fujiyoshi, S., Tanaka, D., Noda, J., Maruyama, F., & Jorquera, M. A. (2020). Airborne bacterial communities of outdoor environments and their associated influencing factors. *Environment International*, *145*. https://doi.org/10.1016/j.envint.2020.106156

Sangkham, S., Thongtip, S., & Vongruang, P. (2021). Influence of air pollution and meteorological factors on the spread of COVID-19 in the Bangkok Metropolitan Region and air quality during the outbreak. *Environmental Research*, *197*(111104), 111104. https://doi.org/10.1016/j.envres.2021.111104

Siller, P., Skopeck, B., Rosen, K., Bartel, A., Friese, A. & Rösler, U. (2024). Impact of air humidity on the tenacity of different agents in bioaerosols. *PLoS One*, *19*(1), e0297193. https://doi.org/10.1371/journal.pone.0297193

Staszowska, A. (2022). Microbiological quality of indoor and outdoor air in a municipal wastewater treatment plant - A case study. *Inżynieria Ekologiczna*, *23*(2), 185–190. https://doi.org/10.12911/22998993/145202

Suehara, M. B., & Pinto, M. C. (2023). Prevalence of airborne fungi in Brazil and correlations with respiratory diseases and fungal infections. *Ciencia & saude coletiva*, *28*(11), 3289–3300. https://doi.org/10.1590/1413-812320232811.08302022en

Universidad Politécnica de Madrid. (UPM). (2023). *¿Qué encontramos en el aire de un hospital?* https://www.upm.es/?id=8d0ba201a9f98810VgnVCM10000009c7648a____&prefmt=articulo&fmt=detail

Vivas, H., Calderón, J., Delgado, M & Abril, R. (2021). Caracterización microbiológica del aire en el casco urbano de Calceta, Manabí, Ecuador. *Ingeniería Hidráulica y Ambiental, 42*(3), 47-63. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382021000300047&lng=es&tlng=es

Vivas Saltos, H. T., Marcillo García, S. K., Zambrano Zambrano, D. M., Pincay Cantos, M. F., & Calderón Pincay, J. M. (2022). Nivel de contaminación microbiana del aire en un taller agroindustrial y sus posibles riesgos laborales. *Revista Iberoamericana Ambiente & Sustentabilidad*, *5*. https://doi.org/10.46380/rias.vol5.e253

Yang, Y., Yang, L., Hu, X. & Shen, Z. (2024). Characteristics of bioaerosols under high-ozone periods, haze episodes, dust storms, and normal days in Xi'an, China. *Particuology*, *90*, 140-148. https://doi.org/10.1016/j.partic.2023.11.023

Yin, Y., Qi, J., Gong, J., & Gao, D. (2021). Distribution of bacterial concentration and viability in atmospheric aerosols under various weather conditions in the coastal region of China. *The Science of the Total Environment*, *795*(148713), 148713. https://doi.org/10.1016/j.scitotenv.2021.148713

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