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Air Quality Analysis in Ternate Urban Area Based on Lichen Biological Indicators

Wa Inda[1], Rosita Tabaika[2], Lintal Muna[3]

[1,2,3] Faculty of Tarbiyah and Teacher Training, IAIN Ternate, North Maluku, Indonesia. Email: wainda@gmail.com[1], rositatabaika@iain-ternate.ac.id[2], lintal@iain-ternate.acid[3]

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ABSTRACT
Urban air quality is an increasingly important environmental issue due to increasing transportation activity and urban growth. This study aims to analyze air quality in the urban area of Ternate City using lichen as a biological indicator. The study was conducted at several locations representing main roads, residential areas, and areas with relatively good vegetation cover. The method used was a field survey with a purposive sampling technique, identification of lichen species, and calculation of the Shannon-Wiener Diversity Index (H'). The results showed that the lichen diversity index value in the main road area was low, while that in the residential and vegetated areas was medium. No high diversity index values were found at all observation locations, indicating that urban air quality in Ternate City is still under pressure due to anthropogenic activities, especially transportation. These findings confirm that lichens are effective as bioindicators of air quality and are relevant for application as a simple and sustainable environmental monitoring method in the archipelago.

Keywords: Air Quality, Lichen, Bioindicators, Ternate City.

I. Introduction

Air quality is a crucial component in determining environmental sustainability and public health, particularly in urban settings. Urban development, characterized by increased transportation, residential, and economic activities, often results in increased air pollutant emissions. Pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM) contribute to declining air quality and have both direct and indirect impacts on humans and other organisms (Ardiansyah et al., 2024). Ternate City, one of the main cities in North Maluku Province, has experienced rapid urban growth in recent years. As a center of government, education, and commerce, motorized vehicle mobility in Ternate City has increased, particularly on the main roads, office centers, and commercial areas. Ternate's relatively narrow geographic location, with concentrated activity in certain areas, has the potential to exacerbate the accumulation of air pollutants, particularly during peak hours (Ananda & Kaswinarni, 2023). Air quality monitoring in urban areas is generally conducted using physical and chemical instruments that are expensive, require technical expertise, and require ongoing maintenance. This presents a particular challenge for island regions, such as Ternate City, which have limited continuous environmental monitoring facilities. Therefore, alternative methods that are effective, inexpensive, and easy to implement long-term are needed for monitoring urban

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air quality (Madjeni et al., 2019). One approach widely used in environmental ecology studies is the use of biological indicators (bioindicators). Lichens are symbiotic organisms formed between fungi and algae that are highly sensitive to changes in air quality. Lichens absorb nutrients and pollutants directly from the atmosphere; therefore, their presence, diversity, and growth patterns are significantly influenced by the level of air pollution in a given area (Nisa et al., 2024). Various studies have shown that areas with poor air quality tend to be dominated by crustose lichens, which are more tolerant to pollutants, whereas areas with cleaner air allow for the growth of more sensitive foliose and fruticose lichens. Thus, lichens can be used as natural indicators to assess air pollution levels without the need for complex chemical measuring instruments (Efry Roziaty, Santhyami, Annur Indra Kusumadhani, 2021).

Based on initial surveys conducted in several urban areas of Ternate City, such as main roads, office centers, and residential areas, striking differences were found in the presence and types of lichens. In areas with high traffic density, such as around main roads and commercial centers, the number of lichens found was relatively low and dominated by crustose lichens with pale colors and small thalli. Conversely, in residential areas far from heavy-traffic centers and areas with more vegetation, a greater diversity of lichens was found. Foliose lichens began to appear with relatively thicker and healthier thalli. These preliminary data indicate differences in air quality between regions in the Ternate urban area, which can be traced to the presence of the lichen. Furthermore, preliminary observations indicate that trees located along roadsides with high traffic volumes have lower lichen coverage than trees located near schools and residential areas. This finding indicates a direct influence of anthropogenic activities on the distribution and diversity of lichens in the Ternate City. Studies on air quality based on biological indicators in island regions, particularly in Ternate, are still relatively limited. However, this approach has significant potential for development as a sustainable environmental monitoring system based on local ecology. This research is expected to fill this gap and provide an initial overview of the urban air quality conditions in Ternate. Based on this description, this study was conducted to analyze the air quality in the Ternate urban area using lichen as a biological indicator. The results are expected to provide a scientific basis for air quality monitoring efforts, environmentally friendly urban planning, and increasing public awareness of the importance of maintaining the urban air quality.

II. Literature Review and Hypothesis Development

2.1. Urban Air Quality and Its Impact on the Environment

Air quality is the condition of the atmosphere, which is determined by the concentration of pollutants. Air is considered polluted if it contains one or more pollutants in quantities and for a specific duration that can negatively impact human health, living organisms, and the environment. In urban areas, air pollution generally originates from transportation activities, fossil fuel combustion, small-scale industrial activities and domestic activities. With increasing population and mobility, motor vehicle exhaust emissions have become a major source of air pollution in urban areas (Rimanda, 2024). Air pollutants, such as carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), and fine particulate matter (PM_{10} and $PM_{2.5}$) has a significant impact on environmental quality. These gases not only directly degrade air quality but also contribute to the formation of acid rain, reduced visibility, and changes in urban microclimate. The long-term accumulation of pollutants can cause environmental degradation, which reduces the carrying capacity of urban ecosystems (Thakur et al., 2024). The impacts of air pollution are felt not only by humans but also by other living organisms as well. Long-term exposure to air pollutants disrupts plant physiological processes, reduces vegetation productivity, and affects ecosystem structure and function. Organisms that obtain nutrients directly from the air, such as lichens, are the most vulnerable to changes in air quality and often exhibit earlier ecological responses than other organisms (Yang et al. 2023).

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Poor air quality has implications for an increased risk of public health problems, particularly respiratory diseases, eye irritation, and cardiovascular disorders. Furthermore, air pollution impacts the overall decline in environmental quality, including the aesthetics of urban environments and the comfort of living for residents. Therefore, air quality is an important indicator for assessing the sustainability of urban development (Lawal et al., 2023). Continuous air quality monitoring is a strategic step in urban environmental management efforts. However, the use of physicochemical monitoring instruments is expensive and requires specialized equipment and trained personnel. This presents a particular challenge for certain regions, particularly island regions, in conducting routine and comprehensive air quality monitoring (Nugroho et al., 2025). These limitations necessitate the development of simpler, more economical, and more sustainable alternative approaches for air quality monitoring. A bioindicator-based approach is a potential solution because it can provide an integrative and long-term picture of air quality. By utilizing living organisms sensitive to air pollution, air quality monitoring can be conducted more efficiently, supporting conservation efforts and sustainable urban environmental management.

2.2. Environmental Bioindicators and the Role of Lichens as Air Quality Indicators

Bioindicators are organisms or biological responses that are used to assess specific environmental conditions, including air pollution levels. The presence, abundance, and physiological changes in bioindicator organisms reflect the quality of the environment in which they live. The use of bioindicators is considered effective and economical because they can provide an integrative picture of environmental conditions over a specific period. (Jahja et al., 2025) Unlike physical-chemical monitoring methods, which only describe air conditions at the time of measurement, bioindicators reflect the accumulated impact of pollution on living organisms over a longer period. The bioindicator approach has advantages in assessing environmental quality ecologically because organisms' responses to pollution are influenced not by a single type of pollutant but by a combination of various pollutants present in the air. Therefore, bioindicators can more realistically depict environmental conditions, particularly in complex urban ecosystems with multiple pollution sources. This approach is also relevant in areas with limited facilities and infrastructure for instrument-based environmental monitoring (Jahja et al., 2025). In air quality monitoring, various organisms, such as higher plants, mosses, and lichens, have been utilized as bioindicators. Among these organisms, lichens are one of the most widely used bioindicators and have proven effective in many studies. Lichens are symbiotic organisms formed from a mutualistic relationship between fungi (mycobionts) and algae or cyanobacteria (photobionts). This symbiotic relationship allows lichens to survive under a wide range of environmental conditions, while also making them highly sensitive to changes in air quality (Saragih & Irwanto, 2024).

Lichens obtain water and nutrients directly from the atmosphere through their thallus surface. The absence of roots and a vascular system means that lichens lack a filtering mechanism for substances entering the air. Consequently, air pollutants such as sulfur dioxide, nitrogen oxides, and fine particles can directly accumulate in lichen tissue and affect its physiological processes. These conditions make lichens highly sensitive to changes in air quality, even at relatively low concentrations of pollutants (Kamaluddin, Gumelar & Priyambodo, 2023). The sensitivity of lichens to air pollution is reflected in changes in their presence, diversity, and morphology. In highly polluted environments, lichen diversity tends to decrease and is dominated by pollutant-tolerant species. Conversely, environments with better air quality allow for the growth of more sensitive lichens, resulting in a more diverse lichen community. This response pattern makes lichens effective biological indicators for assessing air quality spatially and temporally (Nisa et al., 2024). With these characteristics, lichens can reflect long-term air pollution levels and provide a comprehensive ecological picture of the environmental quality. The use of lichens as air quality bioindicators is highly relevant in urban areas, particularly in island regions such as Ternate City, which has limited physical-chemical air quality

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monitoring facilities. This approach not only supports sustainable environmental monitoring but can also serve as the basis for more ecologically sound urban planning and management.

2.3. Lichen Diversity and Types as Indicators of Air Pollution Levels

Lichens are classified into three main types based on their morphology: crustose, foliose, and fruticose. Crustose lichens have a higher tolerance to polluted environmental conditions and generally dominate urban areas with poor air quality. Conversely, foliose and fruticose lichens are more sensitive to air pollutants; therefore, their presence is often associated with relatively better air conditions. Comparing the dominance of lichen types in an area can be used as a basis for assessing air pollution levels (Gavriloaie & Voicu 2023). Lichen diversity was analyzed using the Shannon-Wiener Index (H'), which considers the number of species and the relative abundance of each species. Low index values indicate low diversity and indicate environmental stress due to pollution, while high values reflect more stable environmental conditions. In addition to air pollution, other environmental factors, such as humidity, light intensity, substrate type, and vegetation, also influence lichen growth, although in urban contexts, air pollution is the dominant factor (Boumakhleb et al., 2020). Previous studies have shown that lichen diversity tends to decrease with increasing air pollution in urban areas. Areas with heavy traffic generally have low lichen diversity index values, whereas green and residential areas with low vehicle activity show higher values. However, studies on lichen-based air quality in island regions, particularly in Ternate City, are still limited. Therefore, this study is significantly relevant for assessing urban air quality using a bioindicator approach tailored to local environmental characteristics.

III. Research Method

This study used a quantitative descriptive approach with the bioindicator method (Rimanda, 2024), utilizing lichen as a biological indicator to assess air quality in the urban area of Ternate City. This approach aims to describe air quality conditions based on lichen diversity and distribution at various observation sites. The study was conducted at several points in the urban area of Ternate City representing different levels of human activity, including main roads with high traffic density, office areas, residential areas, and areas with relatively good vegetation. Site selection was carried out purposively, considering the intensity of vehicle activity and land use. The study was conducted from January to August 2025, and adapted to field conditions. The study subjects were epiphytic lichens growing on tree trunks at the observation sites. The study subjects were host trees selected based on the criteria of having relatively uniform trunk diameters, open trunk surfaces, and no significant physical disturbances to minimize observation bias (Ardiansyah et al. 2024). Data were collected through direct field observations. Several trees were designated as sample points at each of the observation locations. Observations were conducted at a stem height of approximately 1–2 m above ground level. The collected data included lichen species, number of individuals or lichen colonies, lichen growth type (crustose, foliose, and fruticose), and environmental conditions around the observation site. Photographs of lichens and research locations were also used as supporting data. Lichen identification was performed morphologically based on thallus shape, color, and growth type, following relevant lichen identification guidelines. Identification was performed to the genus or morphospecies level, depending on the limitations of the equipment and field conditions. Observation data were analyzed quantitatively by calculating the Shannon-Wiener Diversity Index (H') using the following formula:

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$$H' = -\Sigma (pi \ln pi)$$ (Shannon, 1984)

where pi is the proportion of individuals of the ith lichen species to the total number of individuals found. The diversity index values were then classified into air quality categories: low ($H' < 1$), moderate ($1 \le H' \le 3$), and high ($H' > 3$). The analysis results are presented in tables and narrative descriptions to illustrate the differences in air quality between the research locations (Saragih & Irwanto, 2024). To increase the data validity, observations were conducted repeatedly at different times under relatively similar weather conditions. Additionally, visual documentation and field notes were used for data triangulation to ensure the consistency of the observation results.

IV. Result and Discussion

4.1. Lichen Diversity and Distribution in Ternate's Urban Area

Research results show that lichen diversity and distribution in Ternate's urban areas vary significantly between observation locations. This variation is evident in the number of species, degree of thallus coverage, and morphology of the lichens. Areas with high traffic density, such as main roads and commercial centers, exhibited limited lichen presence in terms of both numbers and species. Lichens found in these areas generally grow scattered, are small, and cover only a small portion of the tree-trunk surface. In locations with high levels of human activity, lichens experience significant environmental stress. Motor vehicle exhaust emissions containing pollutants, such as nitrogen oxides and particulates, are thought to play a role in reducing lichen growth and development. This condition results in only certain lichen species with high tolerance to air pollution surviving, while more sensitive lichens are either absent or experience a drastic decline in their population. Conversely, in residential areas and areas with better vegetation, lichen diversity was higher. At this location, lichens grew more evenly, with wider thallus coverage and relatively healthier morphology. The presence of more trees and lower traffic intensity is thought to create more favorable microclimate conditions for lichen growth, such as more stable humidity and lower exposure to pollutants.

The diverse distribution of lichens in areas with adequate vegetation demonstrates the important role of green spaces in maintaining urban air quality. Vegetation functions as a natural filter for air pollutants and provides a more stable substrate for the growth of lichens. This reinforces the view that environmentally friendly urban planning contributes to improved air quality and sustainability of urban ecosystems. Differences in lichen distribution between the observation locations indicate a strong influence of anthropogenic activities on the presence of these organisms. Lichens, as organisms that absorb nutrients directly from the atmosphere, are highly sensitive to changes in air quality; therefore, their presence reflects environmental conditions over time. This finding aligns with the concept of bioindicators, which states that lichens can provide an accumulative picture of air quality rather than just a momentary condition. Therefore, their presence and distribution can be used as ecological indicators of air quality in urban areas of Ternate.

4.2. Dominant Lichen Growth Types and Their Relationship to Air Pollution

Based on field observations, the lichen growth types found in the urban areas of Ternate City are dominated by crustose lichens, particularly in locations with high levels of motorized vehicle activity. This type of lichen generally adheres firmly to the substrate surface and has a thin thallus structure, making it relatively resistant to extreme environmental conditions, including exposure to high concentrations of air pollutants. The dominance of crustose lichens in these areas indicates significant air pollution.

The greater abundance of crustose lichens along main roads and centers of economic activity indicates their greater adaptability compared with other lichen types. The morphological structure of crustose

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lichens allows them to survive in air containing pollutants, such as nitrogen oxides and particulates from vehicle fuel combustion. These conditions hinder the growth of sensitive lichens, resulting in an imbalanced lichen community composition dominated by pollution-tolerant species. In residential areas and areas with denser vegetation, foliose lichens with more complex thallus structures have begun to be found. The presence of this type of tree indicates improved air quality compared to areas with heavy traffic. Foliose lichens require relatively cleaner and more stable air conditions to thrive, making their presence an indicator of improved air quality at the local scale. Fruticose lichens are found in very limited numbers and are generally located far from direct pollution sources, such as areas with natural vegetation or areas with little motorized traffic. The limited presence of fruticose lichens indicates that the air quality in most urban areas of Ternate City does not fully support the growth of lichens, which are highly sensitive to air pollutants.

The observed pattern of lichen growth type dominance indicates a gradient in air quality from areas with high pollution to areas with better air quality. This gradient reflects the direct influence of anthropogenic activities on the lichen community structure in urban environments. This finding aligns with previous research suggesting that lichen growth-type composition can be used as an effective biological indicator for assessing air pollution levels. Therefore, the dominance of crustose lichens in the urban areas of Ternate serves as an ecological signal of air pollution pressure that requires attention in urban environmental management.

4.3. Lichen Diversity Index as an Indicator of Urban Air Quality

The results of the Shannon-Wiener Diversity Index (H’) calculations show quite clear differences between observation locations in the urban area of Ternate City. Main road areas with high traffic density have low diversity indices. This condition reflects the low number of lichen species and the dominance of certain species with high tolerance to air pollution in the area. Low index values in these areas indicate that the environment is under stress due to intensive anthropogenic activity. (Saragih & Irwanto, 2024) In residential areas and areas with relatively better vegetation, lichen diversity index values are in the moderate category. This indicates that, despite environmental pressures, the air quality in these areas is better than that in the main road areas. The presence of vegetation and lower traffic intensity allows more lichen species to grow and survive, thus increasing overall diversity.

The absence of high diversity index values at all observation locations indicates that air quality in the urban area of Ternate City is generally not optimal. These findings indicate that air pollution remains an environmental issue that requires attention, even though Ternate City does not have heavy industrial activities. Transportation and the concentration of urban activities have been shown to exert significant ecological pressure on lichen communities. Low to moderate diversity index values reflect disruptions in ecosystem balance due to long-term exposure to air pollutants. Lichens, as organisms that absorb substances directly from the atmosphere, exhibit an accumulation ecological response to changes in air quality. Therefore, a decline in lichen diversity can be considered an early indicator of air quality degradation in urban environments.

Although other environmental factors, such as air humidity, light intensity, substrate type, and microclimate conditions, also influence lichen growth, the results of this study indicate that air pollution is the dominant factor determining lichen diversity in Ternate City. The consistency between diversity index values and vehicle activity levels and area density reinforces the role of air pollution as a primary limiting factor. The results of the Shannon–Wiener Diversity Index (H’) calculations indicate variations in lichen diversity levels between observation locations in the urban area of Ternate City. Areas with high traffic density, such as main roads and centers of economic activity, showed an H' value of 0.8, which was classified as low diversity. Residential areas showed an H' value of 1.2, and areas with relatively good vegetation had an H' value of 1.5, both of which were classified as medium diversity. No high diversity index values were found in any of the study sites (Branquinho et al., 2022). Low to moderate lichen diversity index values indicate environmental

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pressures due to anthropogenic activities, particularly motor vehicle exhaust emissions. Low H' values on main roads indicate high levels of air pollution that limit the growth of sensitive lichens. Conversely, increased H' values in residential areas and areas with better vegetation indicate relatively more stable air quality conditions. These results reinforce the concept that lichen diversity can be used as a biological indicator to assess urban air quality. In addition to other environmental factors, such as humidity and substrate type, air pollution has been shown to be a dominant factor influencing lichen distribution and diversity in Ternate City. Thus, the use of the Shannon-Wiener Diversity Index (H') in lichens has proven effective in describing variations in air quality in urban areas. This approach is particularly relevant in island regions such as Ternate City, which has limited physical-chemical air quality monitoring facilities. Lichens can be used as simple, economical, and sustainable biological indicators to support urban air quality monitoring and management efforts.

V. Conclusion

Based on the research results, it can be concluded that air quality in the urban area of Ternate City varies between observation locations and is generally under pressure from anthropogenic activities. Areas with high traffic density had low lichen diversity and were dominated by crustose lichens, indicating a high tolerance to air pollution. Conversely, residential areas and areas with better vegetation showed higher lichen diversity and the emergence of foliose lichens, indicating relatively better air quality. The Shannon-Wiener Diversity Index (H') calculation results showed that the index value on main roads was low, while residential areas and areas with relatively good vegetation were in the medium category. The absence of high diversity index values at all observation locations indicates that urban air quality in Ternate City is not yet optimal and is still significantly affected by transportation and other urban activities. Thus, lichens have proven effective as biological indicators for assessing urban air quality because they reflect the cumulative and long-term impacts of air pollution. The lichen-based bioindicator approach is highly relevant for application in island regions such as Ternate City, which has limited physical-chemical air quality monitoring facilities, and can serve as a scientific basis for efforts to monitor and manage sustainable urban environmental quality in the future.

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