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RESEARCH ARTICLE

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Accumulation of heavy metals in *Parmeliaceae* lichens and mahogany bark in multiple locations within Bandung City, Indonesia

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ABSTRACT

Background: Lichens and tree bark are well-known biomonitoring tools for accumulating pollutants in their tissues over an extended period.

Objective: This study aims to determine the concentration of heavy metals accumulated in lichens and tree bark across various locations in Bandung City, analyze the impact of heavy metal accumulation on lichen diversity, and assess the lichen cover area on tree bark.

Methods: Lichen and bark samples were collected from mahogany trees using plotless sampling at a height of 100 cm, employing a quadrat size of 20x32 cm^2 above the ground. A total of 25 sampling stations were distributed across five locations in Bandung City, including city parks, an urban forest park, and a bus station. The samples were analyzed using Atomic Absorption Spectrophotometry (AAS) to measure the concentration of heavy metals.

Results: The results revealed that lichens and bark from Persib City Park (PCP) contained the highest concentration of chromium (Cr), with 17.08 µg/kg in lichens and 30.03 µg/kg in the bark, as well as lead (Pb), with 24.38 µg/kg in lichens and 15.49 µg/kg in the bark. Conversely, lichens and bark from Djuanda Forest Park (DFP) exhibited the lowest concentration of chromium (3.74 µg/kg in lichens and 3.56 µg/kg in the bark) and lead (3.74 µg/kg in lichens and 2.06 µg/kg in the bark). PCA analysis indicated that the accumulation of heavy metals in lichens and bark was associated with environmental factors, such as traffic density and bark pH.

Conclusion: The accumulation of heavy metals in lichens and bark exhibited a negative correlation with lichen diversity and the area of lichen cover on the bark.

Keywords: lichens, lichens diversity index, mahogany bark

Introduction

The population of major cities continues to grow, in parallel with increasing urbanization rates, leading to a rise in the number of vehicles and industrial activities. The main contributors to air pollution in several global cities are anthropogenic activities [1]. Pollutants emitted from vehicles and industrial activities often contain heavy metals, such as copper (Cu), chromium (Cr), and lead (Pb). The World Health Organization (WHO) reported in 2018 that approximately 7 million people die annually from air pollution. Prolonged exposure to high levels of heavy metals can lead to various diseases, including cancer [3], respiratory disorders, and skin diseases [4].

Bandung, one of Indonesia's rapidly developing cities, has significantly increased vehicle numbers and industrial activities. According to the Central Statistics Agency (BPS), the number of vehicles in Bandung reached 1,811,498 in 2018, with an annual growth rate of 5% [2]. This surge in vehicles contributes to escalating air pollution levels from fuel emissions.

Monitoring air quality in large cities like Bandung is crucial for raising public and governmental awareness due to the significant impact of air quality on human health. Typically, air quality monitoring in large cities requires numerous devices and can be prohibitively expensive if implemented continuously across multiple locations. An alternative

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method for monitoring air quality involves using bioindicators. Bioindicators are organisms that reflect the environmental impact of pollutants, helping to assess the distribution and variation of pollutants and gather data on long-term environmental conditions [4]. Trees and lichens, which accumulate pollutants in their bark and on their surfaces, respectively, serve as effective bioindicators along roadways.

Previous studies have focused on using lichens as bioindicators in urban and industrial areas of Bandung. A 2010 study in the industrial areas and bus stations of Bandung found that lichens near industrial sites accumulated higher levels of lead than those in more distant locations [5]. More recent research using the lichen species *Lepraria* sp. in Bandung noted a decrease in lead accumulation from 2006 to 2020, likely due to regulations phasing out leaded petrol.

Lichens, ectohydric organisms lacking cuticles, stomata, and root systems, can absorb pollutants directly through their body surfaces, sometimes exceeding their nutritional needs. Similarly, tree bark can be a bioindicator due to its porous texture that facilitates pollutant absorption, allowing for long-term pollutant accumulation, even in urban areas devoid of lichens [6].

Methods

Samples of lichens from the *Parmeliaceae* family and the bark of mahogany trees were collected from five locations in Bandung, each exhibiting varying levels of traffic, ranging from low to heavy traffic: Persib City Park (PCP), Pustaka Bunga City Park (BCP), Maluku City Park (MCP), Djuanda Forest City Park (DFP), and Leuwi Panjang Bus Station (LPS) (Figure 1). The sampling took place from March to December 2021. Mahogany trees were selected for this study because they are present at all the study sites and are sufficiently overgrown with foliose lichens, which are adequate for analyzing heavy metal accumulation.

The samples were collected from one meter above the ground and gathered in three replications. The samples were carefully extracted using a cutter knife and stored in ziplock bags [7]. Subsequently, these samples were analyzed for heavy metal content using atomic absorption spectrophotometry (AAS) at Chemslab, Bandung.

Atomic absorption spectrophotometry heavy metal analysis

The dried thalli of the lichen samples and mahogany bark were ground and homogenized using an agate mortar and pestle. For the digestion process, 2 grams of samples, smoothed to < 0.5 mm, were digested in 5 mL of concentrated HNO_3 and allowed to stand for 24 hours. The solution was then heated to 100°C for two hours. After cooling, the digestion continued by adding 5 mL HNO_3 and 1 mL $HClO_4$. The solution was heated to 130°C for 1 hour, then increased to 150°C for approximately 2 hours and 30 minutes until the yellow fumes disappeared. The heating continued by raising the temperature to 170°C for 1 hour and then to 200°C for another hour until white fumes were observed. The resulting extract from the digestion was diluted with 25 mL of ion-free water and homogenized in a measuring flask.

The standard absorbance solution was measured to create a standard curve. After measuring the absorbance of the standard solution, the sample absorbance was measured. The concentrations of heavy metals, specifically chromium, copper, and lead, were then calculated using the standard curve [8].

Principal component analysis

Principal component analysis (PCA) was performed to evaluate the correlation between heavy metal accumulation, microclimates, and the number of vehicles.

Statistical analysis

Pearson correlation statistical analysis was conducted using SPSS Statistics 24, and principal component analysis data processing was carried out using the PAST 3.0 application.

Figure 1. Research locations. (A) Djuanda Forest City Park (DFP), (B) Pustaka Bunga City Park (BCP), (C) Persib City Park (PCP), (D) Maluku City Park (MCP), (E) Leuwi Panjang Bus Station (LPS)

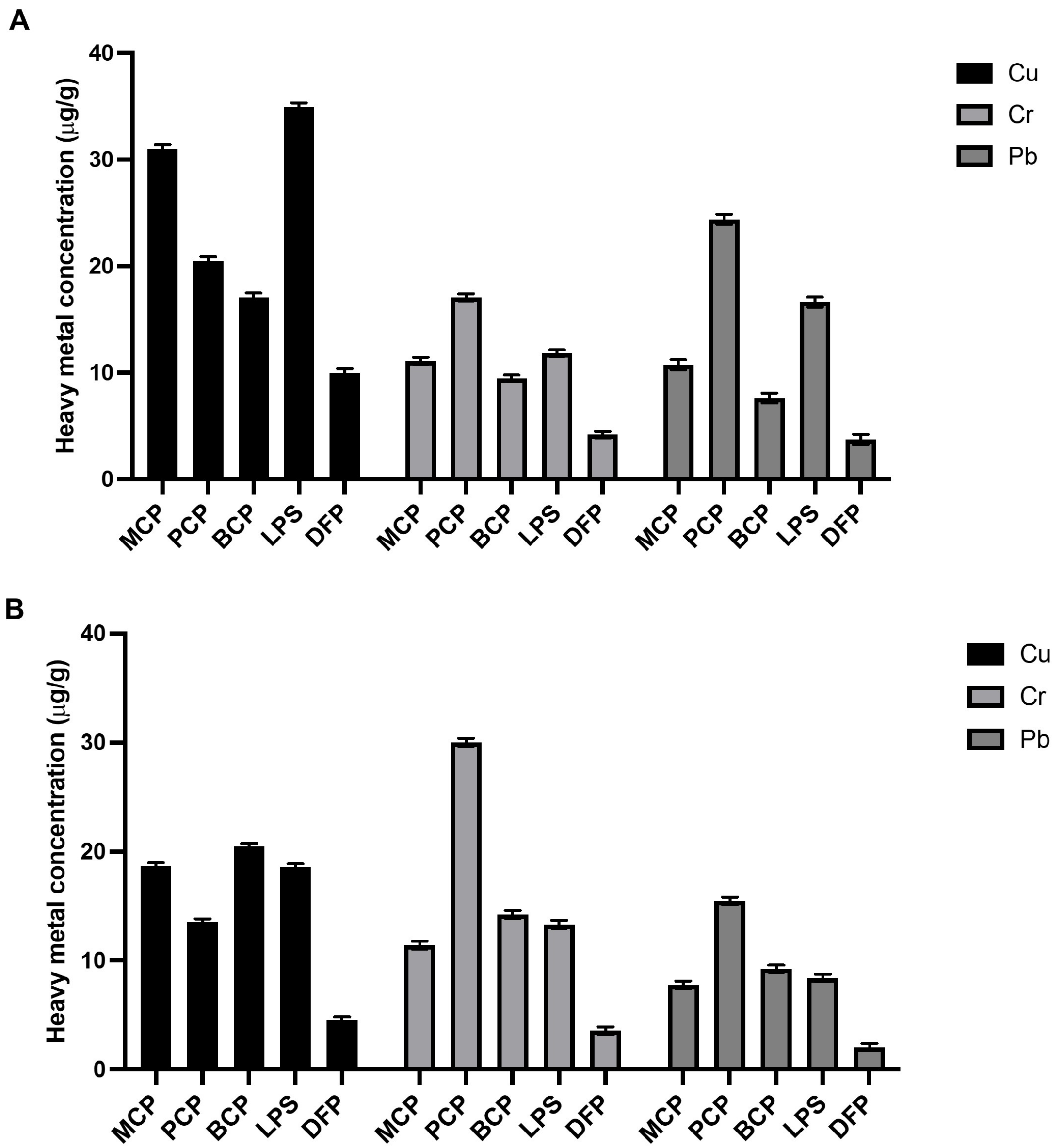

Figure 2. Proportions heavy metals at research location. (A) Sample in lichens. (B) Sample in mahagony bark. MCP (Maluku City Park), BCP (Pustaka Bunga City Park) PCP (Persib City Park), LPS (Leuwi Panjang Bus Station), DFP (Djuanda Forest City Park). Data shown as average±SD

Results

Accumulation of heavy metals on lichens

The analysis of lichen samples revealed that the highest concentrations of chromium and lead were found at the Persib City Park (PCP) site. In contrast, the highest accumulation of copper was observed at the Leuwi Panjang Bus Station (LPS) location, with concentrations exceeding those found at the Djuanda Forest City Park (DFP) control site, which exhibited the lowest levels of all heavy metals (Figure 2A). The heavy metal concentrations at the Djuanda Forest City Park (DFP) site differed significantly ($p<0.05$) from those at the other four sites. This significant difference in metal accumulation is likely related

Table 1. Vehicle number near research location

Location	Vehicle numbers
MCP (Maluku City Park)	6,007
BCP (Pustaka Bunga City Park)	3,501
PCP (Persib City Park)	17,776
LPS (Leuwi Panjang Bus Station)	10,224
DFP (Djuanda Forest City Park)	589

to the varying number of vehicles around each study site (Table 1). Vehicle counts conducted during peak hours on weekdays indicated that the Persib City Park (PCP) location had the highest vehicle density, while the Djuanda Forest City Park (DFP) location had the lowest.

Accumulation of heavy metals on the mahogany bark

Mahogany trees can serve as biomonitors through their bark, accumulating heavy metals from the environment. The analysis of heavy metals in tree bark samples yielded results similar to those for lichens, with the highest accumulations of chromium and lead at the Persib City Park (PCP) site (Figure 2B). Copper, however, accumulated most significantly at the Pustaka Bunga City Park (BCP) location. The concentrations of chromium, lead, and copper at the Djuanda Forest City Park (DFP) control site were significantly lower ($p<0.05$) than those at the other urban sites. There was a significant correlation between the accumulation of metals in the bark and lichens for chromium and lead ($p<0.05$). Specifically, the accumulation of chromium in the bark (30.034±0.363) was higher than in the lichens (17.080±0.322), while the accumulation of lead in the bark (15.488±0.344) was lower than in the lichens (24.377±0.478).

Principal component analysis

The results of the principal component analysis (PCA) test of lichen, mahogany bark, and microclimate show the correlation between copper accumulation in both sample and air temperature (Figure 3). Conversely, the accumulation of lead and chromium was correlated with light intensity and the number of vehicles at the research locations (Figure 2).

Discussion

Our results show a significant correlation between the accumulation of heavy metals in lichens and bark and the volume of vehicles ($p<0.05$). This finding aligns with research conducted in Malaysia, which indicates that heavy metal accumulation in lichens is strongly related to traffic density [9]. The accumulation of heavy metals in all lichen samples from the study area showed a significant relationship with vehicle frequency, where an increase in vehicle frequency corresponded to an increase in heavy metal levels in lichens. Vehicles dispense heavy metals in the form of particulates as a by-product of engine fuel combustion.

The relationship between microclimates, substrates, and the number of vehicles to heavy metal accumulation in lichens, as described by PCA results (Figure 3A), indicates a relationship between heavy metal accumulation in lichens and environmental variables. The highest heavy metal accumulations at Persib City Park (PCP) and Leuwi Panjang Bus Station (LPS) locations are related to vehicle volume and light intensity. These locations are relatively open, with trees growing only around the periphery, resulting in higher light intensity. Such conditions can influence metal accumulation, as lichens in areas with sparse tree cover accumulate more heavy metals than those in denser tree locations [10].

The difference in accumulation between lichens and tree bark can be influenced by the ability of lichens and tree bark to bind heavy metals and the properties of these metals. Higher heavy metal concentrations in the bark may be attributed to the longer duration of tree growth in the environment, allowing the bark to absorb metals over an extended period [11]. The rate of heavy metal accumulation in the bark can result from elements washed out of the canopy, soil splashing, and metal absorption by bryophytes and lichens growing on the bark, which results from atmospheric deposition [12]. Another reason for higher metal accumulation in tree bark is that bark is a significant sink for biologically available metals, with new tissue formed yearly. This new tissue is slow to enter the decomposition cycle, thus immobilizing heavy metals in metabolically inactive compartments for extended periods without adversely affecting the trees' health [13].

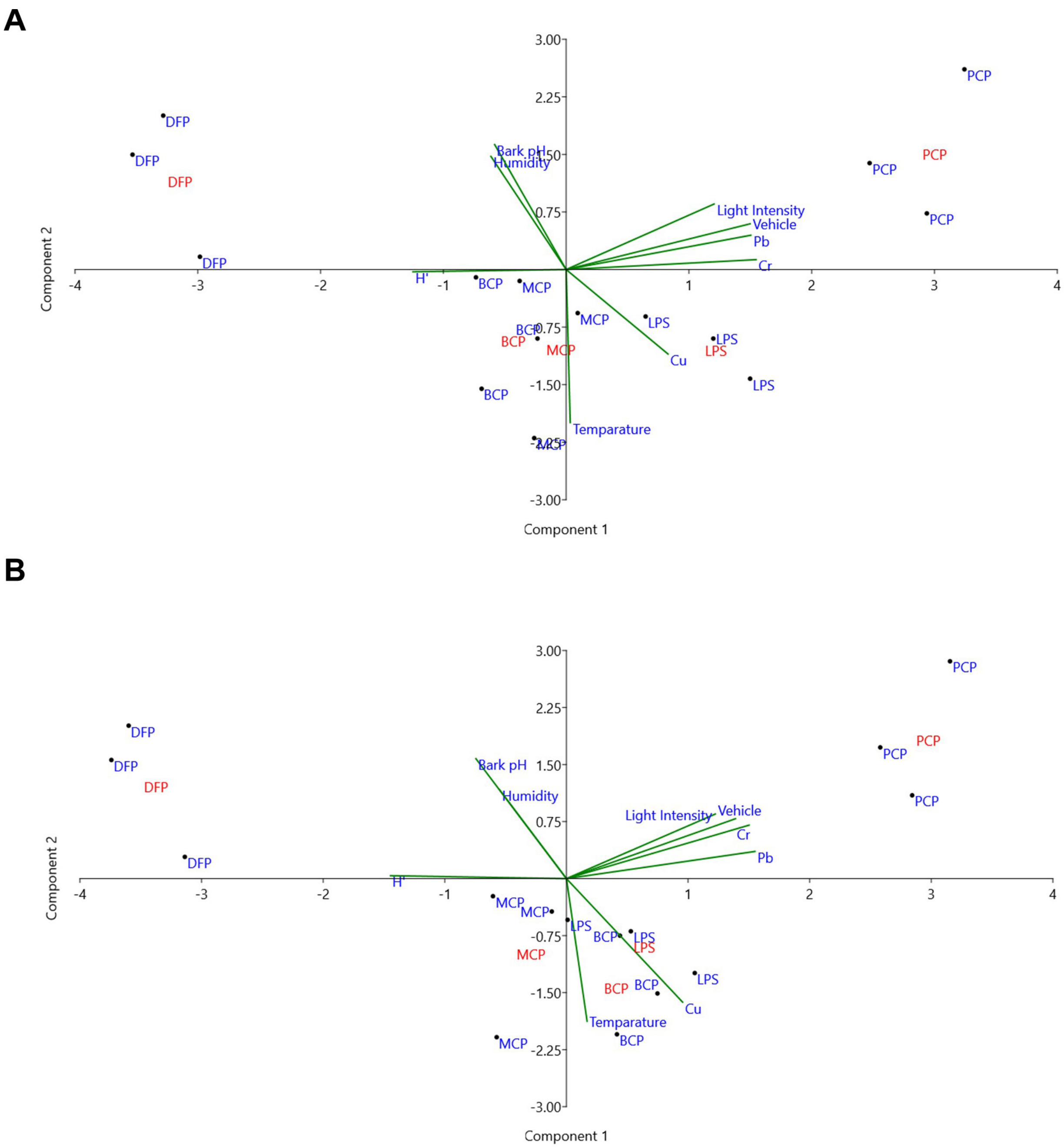

Figure 3. PCA of microclimate, vehicle number on heavy metal accumulation at research location. (A) Heavy metal accumulation by lichens, (B) Heavy metal accumulation by mahagoni bark. MCP (Maluku City Park), BCP (Pustaka Bunga City Park) PCP (Persib City Park), LPS (Leuwi Panjang Bus Station), DFP (Djuanda Forest City Park)

Various factors, such as the abundance of heavy metals, differences in water solubility, pH value, and temperature, may affect heavy metal accumulation in mahogany bark. A decrease in pH can increase the solubility of some metals, releasing them from particles obtained from the atmosphere or substrate, thereby increasing the bioavailability of heavy metals. Thus, decreased pH can enhance metal bioavailability.

PCA analysis results show a correlation between heavy metal accumulation and microclimatic factors (Figure 3). The highest sources of heavy metal were found at Persib City Park (PCP) and Leuwi Panjang Bus Station (LPS) locations, which are associated with the number of vehicles and light intensity. These locations are relatively open, with trees primarily on the outskirts, leading to higher light intensity. Tree density can affect metal accumulation, where lichens in sparsely treed areas accumulate more metals than those in denser tree locations [10]. Therefore, samples from Persib City Park (PCP) and Leuwi Panjang Bus Station (LPS) accumulated the highest levels of heavy metals compared to locations with denser trees.

The pH of tree bark samples was found to be acidic, ranging from 5.23 to 6.29. Research from 2010 on the correlation between tree bark pH and air pollution [14] reported similar findings, with tree bark pH in lichen growth areas being acidic, ranging from 3.6 to 4.9. Persib City Park (PCP), with the highest metal accumulation, had the most acidic tree bark pH of 5.23, followed by Leuwi Panjang Bus Station (LPS) at 5.25. In contrast, Djuanda Forest City Park (DFP), with the lowest vehicle density, had a bark pH close to neutral at 6.29. Tree bark pH tends towards neutrality in areas with minimal pollutants [15]. Besides vehicle emissions, other factors, such as chemical and physical properties of pollutants, including abundance, chemical forms, solubility in water, pH, and temperature, can influence metal accumulation. A decrease in pH can increase metal solubility, releasing them from particles and enhancing their bioavailability [10]. Hence, the highly acidic bark pH at the Persib City Park (PCP) location contributes to the high metal accumulation.

In this study, samples from the Pustaka Bunga City Park (BCP) site accumulated the highest copper levels, with an average air temperature of 28°C. Higher temperatures can increase metal absorption [16], as elevated temperatures boost metabolism and protein synthesis, resulting in greater metal uptake. Copper is also an essential metal for metabolism [17, 18].

Conclusion

Lichens from the *Parmeliaceae* family as well as mahogany bark can accumulate heavy metals. The accumulation of these heavy metals is negatively correlated with lichen cover and diversity and is influenced by microclimates and vehicle numbers. The presence of vehicles is positively correlated with the accumulation of heavy metals in lichens and bark. These effects of air pollution on lichens and mahogany bark, along with the accumulation of heavy metals within the thallus and tree bark, can be utilized as bioindicators to measure air pollution levels.

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Author contributions

PNF wrote original draft, resources, and visualization; T made concept and supervised the study and wrote the revision manuscript.

Declaration of interest

There was no competing interest.

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