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The Contribution of Tree Canopies to Microclimate in Urban and Karst Ecosystems in the Special Region of Yogyakarta

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Abstract: Canopy trees play an important role in regulating the microclimate in various ecosystems. This research aims to study the contribution of tree canopy to the microclimate in urban ecosystems and karst ecosystems in the Special Region of Yogyakarta. Trees can affect the microclimate around them, in this case, the ambient temperature. Currently, development in Yogyakarta continues to expand, and green open spaces are being increasingly eroded. The reduction of forest cover and green open spaces in Yogyakarta impacts both the macro and micro environments in the region. Therefore, this study examines the contribution of trees to the ecosystem in terms of air temperature at heights of 1 meter and 10 meters above ground level, soil temperature, air humidity, soil moisture, light intensity, pH, and wind speed in urban and karst ecosystems. This research was conducted at the end of the dry season, in mid-September, from 11:00 a.m. to 1:00 p.m. After the data was collected and tabulated into a collective table containing all the raw data, it was then calculated for its mean and standard deviation, and displayed in the form of a histogram. To determine the differences in parameters between each location, a Least Significant Difference (LSD) test was conducted. Based on the research conducted, both in urban and karst ecosystems, the air temperature 10 meters above the ground (the area around the tree canopy) was lower than the air temperature 1 meter above the ground. The difference in air temperature around the canopy and far from the tree canopy reached 4°C (°C) to 10°C (°C). Overall, the average air temperature in karst ecosystems was higher than in urban ecosystems. This is due to the differences in the shapes and structures of the tree canopies in the two ecosystems. Trees in urban ecosystems have more diverse shapes and are denser than trees in karst ecosystems. This study proves that trees contribute to the microclimate by lowering the temperature.

Keywords: Karst Ecosystem; Microclimate; Temperature, Tree Canopy; Urban Forest Ecosystem.

Introduction

Globally, climate is a parameter that influences all processes within populations and communities because the distribution and abundance of organisms are affected by climate. The 2005 Kyoto Protocol addressed global climate change, caused by increased CO_2 emissions and the destruction of tropical forests, both of which are attributed to human activities. The Paris Agreement also included an agreement to limit the global temperature rise this century to well below 2 °C above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C. In the future, the climate is expected to continue changing in line with population growth and human activities. All ecosystems will be directly or indirectly affected by climate change.

Microclimate refers to the local climate conditions influenced by various factors, such as vegetation, particularly trees. Trees contribute to microclimate regulation by lowering temperatures, regulating humidity, modifying wind patterns, and controlling light intensity, especially in urban and forested areas. Trees provide shade that can lower air temperatures. This cooling effect is influenced by wind speed, light intensity, and tree species [1], [2], [3].

Forest canopies stabilize temperature fluctuations by lowering maximum temperatures and increasing minimum temperatures, thereby helping to create a stable microclimate [4]. Trees can influence temperature regulation because tree canopies can absorb heat energy and increase humidity. Tree canopies reduce temperature by absorbing sunlight and acting as insulation because incoming light is blocked by the tree canopy. Tree canopies can dampen temperature fluctuations, resulting in lower maximum temperatures and higher minimum temperatures [5], [6]. This effect is particularly noticeable in urban areas, where shaded surfaces can be up to 20°C cooler than areas exposed to direct sunlight [7], [8].

Trees also reduce soil evaporation and help maintain soil moisture, which benefits understory vegetation and overall ecosystem health. Trees influence relative humidity (RH) through the process of transpiration. The moisture-increasing effect of trees tends to decrease as environmental RH increases [9], [10], [11]. Tree canopies influence moisture by reducing evaporation rates and maintaining higher soil moisture. This is particularly important during drought conditions, where the water use strategies of different tree species affect cooling mechanisms differently [12]. Increased canopy cover is associated with increased relative

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humidity, which is beneficial to understory vegetation and overall ecosystem health [13]. The cooling effect of tree canopies varies depending on the type and diversity of vegetation structure. Mixed stands generally provide better microclimate regulation than monocultures due to increased canopy cover and structural complexity [14], [15]. Trees increase soil water content, which improves the soil's ability to absorb heat. Soil has the ability to store heat (heat storage), and this ability is influenced by several factors, such as water content, soil type, and thermal properties of the soil [16].

In urban areas, trees can help mitigate drier air conditions caused by buildings, maintaining higher humidity under their canopy. Tree canopies significantly reduce the amount of solar radiation reaching the ground, helping to lower temperatures and protect surfaces from direct sunlight exposure. The level of shade varies depending on the tree species and canopy structure [17]. Differences in tree species and canopy density create variations in light conditions. [17], [18]. These differences in light intensity are influenced by the presence of trees and the angle of sunlight. Light intensity is calculated based on the total radiation entering per unit of time at different levels within the forest.

In addition to affecting temperature and humidity, trees function as windbreaks, reducing wind speed and creating more stable microclimate conditions. Trees can block or direct wind flow depending on their position and surrounding conditions[19], [20]. Wind speed will decrease in areas with many trees because the tree canopy will reduce wind speed. Temperature, humidity, wind, and light can exhibit vertical gradients in grasslands or herbaceous areas. These parameters have different levels at different heights. Canopied trees in urban areas can be utilised as a form of "biotechnology" to mitigate environmental pollution and enhance environmental health. Air quality improves as the percentage of tree canopy cover increases.

The Special Region of Yogyakarta is an area with karst regions in Gunung Kidul and mineral soil regions around Mount Merapi. In the Gunung Kidul area, which is a karst area ( ), the vegetation will be different from that in mineral soil areas. Currently, development in Yogyakarta continues to grow, and green open spaces are increasingly being eroded. The reduction in forest cover and green open spaces in Yogyakarta impacts both the macro and micro environments in the region. This study aims to examine the contribution of trees to the microclimate in urban ecosystems and karst ecosystems in Yogyakarta. In addition, this study also examines whether the microclimate in tree canopy areas in urban ecosystems and karst ecosystems has significant differences. By conducting this study, it is hoped that the contribution of tree canopies to various ecosystems in Yogyakarta can be better understood, allowing the community and stakeholders to appreciate the importance of trees for ecosystems.

Research Methods

This study was conducted in urban and karst ecosystems in the Special Region of Yogyakarta during the dry season in September 2012. The study was conducted from 11:00 a.m. to 1:00 p.m. In the urban ecosystem, samples were taken at the Arboretum of the Faculty of Biology, UGM and the Arboretum of the Faculty of Forestry, UGM. There were two sampling points at the Arboretum of the Faculty of Biology, namely AB1 and AB2. Meanwhile, there were three data collection points at the Arboretum of the Faculty of Forestry, namely AH1, AH2, and AH3. For the karst ecosystem, the research location was in Wanagama Forest, Gunung Kidul Regency. In Wanagama Forest, there are three sampling points, namely GKP, GKC, and CKJ (Figure 1).

The UGM Faculty of Biology Arboretum is located west of the Faculty of Biology. Plants in the biological forest are planted irregularly, and there are few individuals. Area The area of the Faculty of Biology's Arboretum is 12,501 $m^2$with a length of 278 m, a width of 47.11 m on the north side, a width of 36.8 m in the middle, and a width of 51 m on the south side. The Faculty of Forestry Arboretum is located west of the UGM Faculty of Forestry. The western part of this arboretum is inhabited by a community of grey herons (Ardea cinerea) and night herons (Nycticorax nycticorax). The Forestry Arboretum is 99.5 m long, 160 m wide, and covers an area of 15,920 m^2. Wanagama Forest is a forest covering approximately 600 hectares and located in four villages within the subdistricts of Patuk and Playen, Gunung Kidul Regency. The area is densely populated with teak, calliandra, sandalwood, and other trees. In this study, the data collection points were dominated by teak trees (GKJ), sandalwood trees (GKC), and cash crop agriculture (GKP).

Data Collection

The parameters measured in this study were air temperature, soil temperature, air humidity, soil moisture, light intensity, wind speed, and soil pH. Air temperature was measured at heights of 1 meter and 10 meters above ground level at points beneath the trees. Air humidity was measured using a hygrometer. Soil pH and soil moisture were measured using a soil tester. Light intensity was measured using a lux meter. Wind speed was measured using an anemometer.

Data Analysis

Air temperature, humidity, light intensity, and wind speed data from each observation point in urban and karst ecosystems were first compiled in time-series tables and averaged based on measurement repetitions. Extreme data (outliers) were tested, and their validity was considered based on field conditions. A descriptive analysis was conducted, including minimum, maximum, average, standard deviation, and data distribution values for each microclimate parameter at locations with tree canopy and open locations. After that, an analysis of the differences between ecosystems and tree cover was conducted to determine the effect of tree canopy on microclimate using one-way ANOVA. If the ANOVA yielded significant results ($p < 0.05$), the Least Significant Difference (LSD) test was conducted to determine which pairs of groups were significantly different. The mean difference was compared with the LSD value to determine the significance of the difference [21].

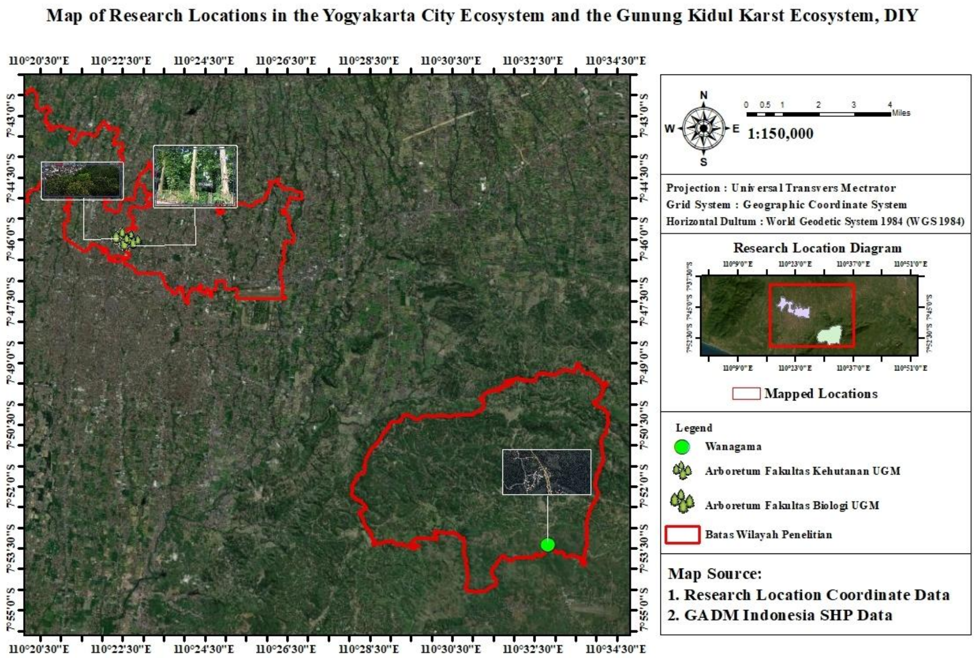

Figure 1. Research location in Yogyakarta City and Gunung Kidul Karst Ecosystem.

Results and Discussion

According to the research conducted, it was found that the air temperature 1 meter above the ground in both ecosystems was higher than the air temperature 10 meters above the ground (Figure 2). This is because the tree canopy can lower the air temperature by absorbing heat energy and increasing air humidity through transpiration. This is reinforced by the results of air temperatures above 1 meter in urban ecosystems, which range from 30°C to 31°C, while air temperatures at 10 meters range from 24°C to 29°C. These results indicate that the temperature around the tree canopy is lower than at locations farther away from it. This study demonstrates that the tree canopy has been proven to reduce temperatures by 1 °C to 5 °C. Urban forests and street trees help reduce heat stress and improve thermal comfort for urban communities [14], [22].

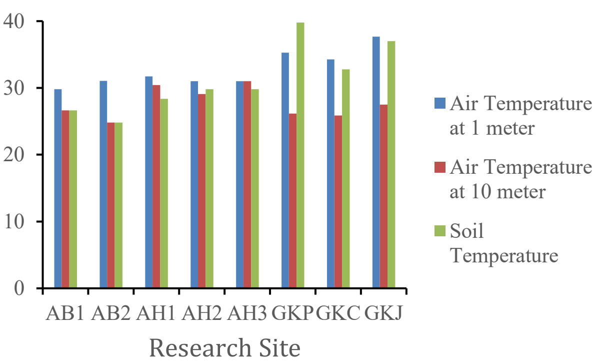

Figure 2. Air and soil temperature in Yogyakarta City Ecosystem and Gunung Kidul Karst Ecosystem.

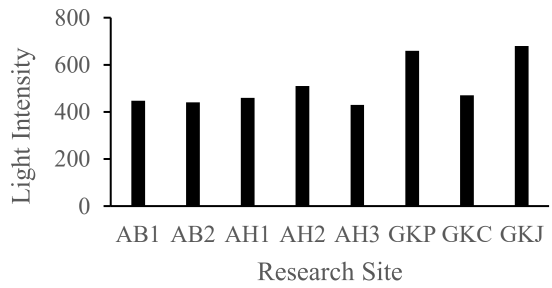

Figure 3. Light intensity in Yogyakarta City Ecosystem and Gunung Kidul Karst Ecosystem.

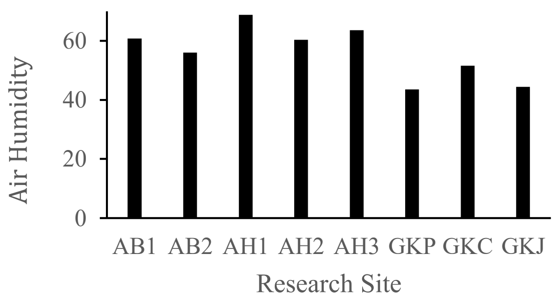

Figure 4. Air humidity in Yogyakarta City Ecosystem and Gunung Kidul Karst Ecosystem.

The air temperature 1 meter above the ground tends to be the same as the soil temperature in urban ecosystems. Soil temperature in urban ecosystems ranges from 26°C to 29°C, while in karst ecosystems it ranges from 32°C to 39°C. This is because the tree canopy at the research site reduces the intensity of light falling on the ground. Light intensity in urban ecosystems ranges between 430-510 lux in both the Faculty of Biology

Arboretum and the Faculty of Forestry Arboretum (Figure 3). The tree canopy modulates the intensity of light entering, affecting the conditions below, including the soil and vegetation. Light intensity in karst ecosystems is higher than in urban ecosystems, ranging from 470-680 lux.

This difference in light intensity is caused by the type and density of vegetation. In urban ecosystems, the tree canopy is dense and varied, especially in the Faculty of Biology Arboretum. The Faculty of Biology Arboretum was established with the aim of representing the natural tropical forests of Indonesia, featuring a diverse array of trees that grow naturally. The vegetation in the Faculty of Biology Arboretum even overlaps and forms vertical stratification layers like a real tropical forest. Meanwhile, in karst ecosystems, vegetation is planted in blocks because the area is a plantation forest. The trees planted at the research site are teak, sandalwood, and cash crop trees. The highest light intensity in the karst ecosystem is located at the teak plantation site, with a value of 680 lux (Figure 3). This is because the research was conducted during the dry season, and the leaves on the teak trees were shedding.

Conversely, in karst ecosystems, the air temperature 1 meter above ground level (34°C to 37°C) is higher than at 10 meters above ground level (25°C to 27°C). The air temperature above 1 meter is higher than at 10 meters because the type of vegetation in this location differs from that in urban ecosystems. In addition to this difference in vegetation types, the influence of soil temperature also affects the air temperature 1 meter above ground level. Soil temperature in urban ecosystems is generally lower than in karst ecosystems, ranging from 24°C to 29°C, while in karst ecosystems it ranges from 32°C to 39°C (Figure 2). Soil that can store heat causes the air temperature 1 meter above ground level to be lower than the temperature within the soil. Selecting tree species with high leaf area index and diverse canopy structure can maximize the cooling benefits and resilience of urban forests [22].

Air humidity in urban ecosystems is generally higher than in karst ecosystems. In karst ecosystems, air humidity ranges from 56% to 68%, while in urban ecosystems it ranges from 40% to 51% (Figure 4). Air humidity in karst ecosystems is lower than in urban ecosystems. This is consistent with the air temperatures in both locations. The air temperature in urban ecosystems is lower than in karst ecosystems, which affects the humidity in both locations. Tree canopies reduce the intensity of incoming light and lower the surrounding air temperature. The abundance of trees also increases air humidity through the process of transpiration. In karst ecosystems, the vegetation that grows includes teak, sandalwood, and cash crops. There are fewer trees in these locations than in the Faculty of Biology and Forestry Arboretum, which significantly impacts the microclimate of both areas. Tree canopies are effective in reducing the urban heat island effect by lowering surface temperatures. High-rise areas with more green space tend to have lower temperatures than low-rise areas [23].

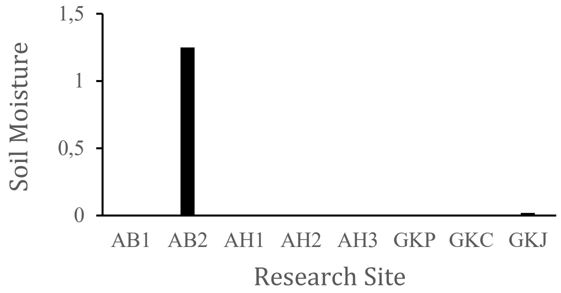

Figure 5. Soil moisture in Yogyakarta City Ecosystem and Gunung Kidul Karst Ecosystem.

Significantly different from that at the Faculty of Forestry Arboretum. The significant difference in temperature around the canopy at the Faculty of Biology Arboretum and the Faculty of Forestry Arboretum is due to the type of tree canopy. At the Faculty of Biology Arboretum, the tree canopy is umbrella-shaped, with various understorey.

Vegetation underneath, while at the Forestry Faculty Arboretum, the tree canopy is pointed upwards, resembling pine trees, and there are few types of vegetation underneath, consisting mainly of shrubs and small grasses. At the karst ecosystem location, there are only two locations that differ from the karst ecosystem location, namely the Faculty of Forestry Arboretum and the teak and sandalwood plantation. Similar to the difference between the Faculty of Biology and the Faculty of Forestry Arboretum, this difference is due to the types of vegetation that compose them. The types of vegetation and canopy shape at the location greatly influence the surrounding temperature [24].

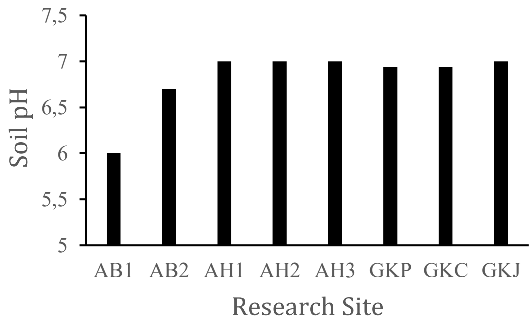

Figure 6. Soil pH in Yogyakarta City and Gunung Kidul Karst Ecosystem.

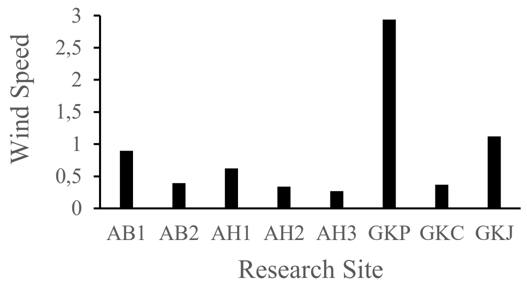

Figure 7. Wind speeds in Yogyakarta City Ecosystem and Gunung Kidul Karst Ecosystem

Tree canopies can reduce solar radiation, lower temperatures, and increase humidity depending on the type of vegetation and canopy structure. Upon closer inspection, this can be seen at the Faculty of Biology Arboretum, which has a lower air temperature than the Faculty of Forestry Arboretum. Both at 1 meter and 10 meters above ground level, the air temperature at the Faculty of Biology Arboretum is lower than at the Faculty of Forestry Arboretum. This is because the canopy of trees in the Faculty of Forestry Arboretum is shaped like pine trees, while the biology garden has a canopy shaped like an umbrella. As a result, the intensity of light entering is lower, the temperature is lower, and the humidity is higher. Different tree types and canopy morphologies (e.g., umbrella-shaped or rounded) have varying cooling capacities, which in turn affect air and ground temperatures [22].

Soil moisture in urban ecosystems and karst ecosystems is generally the same, ranging from 0 to 1.5% (Figure 5). Soil moisture in urban and karst ecosystems is generally the same, with only two locations having air humidity above 0. This is because the parameters were measured at the end of the dry season, when the soil was extremely dry. The southern Faculty of Biology Arboretum location has a soil moisture content of 1.25% because the Faculty of Biology Arboretum is regularly irrigated. The Gunung Kidul Jatimuna location has a soil moisture content of 0.2%, as it is situated next to the Oyo River.

The soil pH in urban and karst ecosystems tends to be similar, ranging from 6 to 7 (Figure 6). The soil pH is neutral, except in the northern and southern areas of the Faculty of Biology Arboretum. This is because there is a lot of tree litter, which causes the soil pH to become more acidic. Unlike the Faculty of Forestry Arboretum, the Faculty of Biology Arboretum does not conduct forest floor cleaning as done in the Forestry Faculty Arboretum, so its forest floor has a lot of litter from the vegetation above it.

Wind speeds in urban ecosystems range from 0.27 to 0.895 knots (Figure 7). Wind speeds in karst ecosystems range from 0.37 to 2.94 knots. The results of this study indicate that wind speeds in karst ecosystems are generally higher than those in urban ecosystems. These results prove that tree canopies can reduce wind speed. The highest wind speeds were found in cash crop farming locations in karst ecosystems. Tree canopies in karst ecosystems, especially in cash crop farming, are very rare or even non-existent at the sampling points. Unlike other locations that are covered with many trees, areas with tree canopies will have lower wind speeds than open areas. Trees can reduce wind speed by forming a physical barrier that disrupts air flow. The presence of rows of trees and their arrangement also play a significant role; a rectangular two-row arrangement with a distance of 0.5 m between canopies is very effective in reducing wind speed. Tree species and canopy structure have different effects on wind speed. Trees with denser canopies and higher Leaf Area Index (LAI) values tend to provide greater wind resistance. The aerodynamic characteristics of trees, such as crown porosity and stem elasticity, also determine their effectiveness in reducing wind speed. Trees with smaller branch angles and higher branching levels generally have lower drag coefficients [1], [23].

In this study, further analysis was also conducted using the Least Significant Difference (LSD) test to determine whether the differences in light intensity and temperature between the two ecosystems were significant. This research shows several significant differences in air temperature 1 meter above ground level in urban and karst ecosystems (Table 1). These differences were caused by differences in the vegetation conditions at the study sites. In the urban ecosystem, sampling points were located in green open spaces, specifically in areas with a high density of trees. This was reinforced by the results of the temperature 10 meters above ground level (Table 2), where there was no difference in air temperature around the tree canopy in the urban and karst ecosystems, except at the Faculty of Biology Arboretum and the Faculty of Forestry Arboretum at four locations, and the karst ecosystem at four different locations, where the air temperature 10 meters above ground level was significantly different from that at the Faculty of Forestry Arboretum. The significant difference in temperature around the canopy at the Faculty of Biology Arboretum and the Faculty of Forestry Arboretum is due to the type of tree canopy. At the Faculty of Biology Arboretum, the tree canopy is umbrella-shaped, with various understorey plantation. Similar to the difference between the Faculty of Biology and the Faculty of Forestry Arboretum, this difference is due to the types of vegetation that compose them. The types of vegetation and canopy shape at the location greatly influence the surrounding temperature [24].

vegetation underneath, while at the Forestry Faculty Arboretum, the tree canopy is pointed upwards like pine trees and there are not many types of vegetation underneath, only shrubs and small grasses. At the karst ecosystem location, there are only two locations that differ from the karst ecosystem location, namely the Faculty of Forestry Arboretum and the teak and sandalwood

Table 1. LSD for air temperature at 1 meter between locations in urban and karst ecosystems

	AB1	AB2	AH1	AH2	AH3	GkP	GkG	GkJ
AB1								
AB2	**							
AH1	**	Ns						
AH2	Ns	Ns	Ns					
AH3	Ns	Ns	Ns	Ns				
GkP	**	**	**	**	**			
GkG	**	**	**	**	**	Ns		
GkJ	**	**	**	**	**	**	**	

Table 2. LSD for air temperature at 10 meter between locations in urban and karst ecosystems

	AB1	AB2	AH1	AH2	AH3	GkP	GkG	GkJ
AB1								
AB2	Ns							
AH1	Ns	**						
AH2	Ns	**	Ns					
AH3	**	**	Ns	Ns				
GkP	Ns	Ns	**	Ns	**			
GkG	Ns	Ns	**	Ns	**	Ns		
GkJ	Ns	Ns	Ns	Ns	Ns	Ns	Ns	

Table 3. LSD for soil temperature between locations in urban and karst ecosystems

	AB1	AB2	AH1	AH2	AH3	GkP	GkG	GkJ
AB1								
AB2	Ns							
AH1	Ns	Ns						
AH2	Ns	Ns	Ns					
AH3	Ns	Ns	Ns	Ns				
GkP	Ns	**	Ns	Ns	Ns			
GkG	Ns	Ns	Ns	Ns	Ns	Ns		
GkJ	Ns	Ns	Ns	Ns	Ns	Ns	Ns	

Table 4. LSD for light intensity between locations in urban and karst ecosystems

	AB1	AB2	AH1	AH2	AH3	GkP	GkG	GkJ
AB1								
AB2	Ns							
AH1	Ns	Ns						
AH2	Ns	Ns	Ns					
AH3	Ns	Ns	Ns	Ns				
GkP	Ns	Ns	Ns	Ns	Ns			
GkG	Ns	Ns	Ns	Ns	Ns	Ns		
GkJ	Ns	Ns	Ns	Ns	Ns	Ns	Ns	

Explanation:
Ns = Not significant
*= Significant

Soil temperature in urban ecosystems and karst ecosystems does not differ significantly (Table 3), except in the karst ecosystem located in GKP (Cash Crop Farming) and the Faculty of Biology Arboretum. The southern part of the Faculty of Biology Arboretum has a soil moisture content of 1.25 (Figure 5), while other locations only have a moisture content of around 0. The soil moisture content at this location is attributed to regular watering carried out by the Faculty of Biology Arboretum management, which increases moisture and lowers soil temperature at that location. Although the light intensity in the karst ecosystem and the urban ecosystem differs (Table 4), after conducting a Least Significant Difference (LSD) test, it was found that the difference was not significant because this study was conducted at the end of the dry season, so that the light intensity at each location did not differ significantly.

Efforts to maintain high canopy cover and promote species diversity in forest management practices can increase microclimate stability and support biodiversity. The application of mixed stands and the preservation of vegetation structure diversity can increase the long-term resilience of forests to climate change [15], [23]. The integration of tree canopies in urban planning can significantly improve microclimate regulation. Strategic placement of trees in parks, residential areas, and along roads can maximize the cooling effect and improve thermal comfort [[25], [26]. Tree canopies play a crucial role in regulating the microclimate by reducing temperatures, controlling humidity, and mitigating the urban heat island effect. Their effectiveness depends on species diversity, canopy structure, and strategic area planning.

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Conclusion

The results of the study show that tree canopies are effective in regulating the microclimate in both karst and urban ecosystems. Tree canopy cover can significantly reduce air temperature, increase air humidity, reduce light intensity, and decrease wind speed. The temperature under the canopy in both urban and karst ecosystems is lower than in locations far from the tree canopy. The temperature difference between areas near and far from the tree canopy in both ecosystems reaches 4°C to 10°C. The air temperature 1 meter above the ground in both ecosystems shows a significant difference compared to other parameters, which, although they have different values, do not show significant differences. The shape and size of the tree canopy can influence the microclimate around it, especially air temperature. The impact of microclimate regulation is more pronounced in urban areas with dense vegetation, underscoring the crucial role of trees as ecological elements that promote thermal comfort and environmental stability. These findings underscore the urgency of maintaining and increasing tree cover through green space planning, integrating vegetation into urban design, and strengthening environmental protection policies. Thus, this study not only supports the initial hypothesis and objectives but also provides a scientific basis for urban management and decision-making by stakeholders in efforts to improve environmental quality and community welfare.

Author's Contribution

Isoralla: conceptualization, original draft preparation, methodology. T. S. Djohan: methodology, curation, writing review. H. L. Dzaky: designing the research site

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