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Analysis of Urban Forest Distribution in Makassar City and its Effects on Microclimate Conditions and Thermal Comfort in the Surrounding Area

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ABSTRACT

One of the alternatives to control the impact of environmental problems is the existence of open space. In particular, the green open space included in the study is the urban forest. This research aimed to provide new scientific insights in identifying urban forest locations based on the criteria of Government Regulation Number 63 of 2002, as well as analyzing microclimate data through field observation activities and quantitative analysis. Urban forests based on these criteria are the South Sulawesi Governor's Office, Hasanuddin University, Pakui Sayang Park, Hasanuddin Park, Macan Park, and MoI (Maccini Sombala of Indonesia) Park. The highest level of vegetation density is in the Hasanuddin University area, and the South Sulawesi Governor's Office, which is 0.38. Meanwhile, the lowest is in Pakui Sayang Park, Hasanuddin Park, and MoI Park, which is 0.34. The air temperature in the Governor's Office and MoI Park is in the hot category, which is 30.9 °C, whereas the air temperature in other urban forests is in the very hot category, which is 31.1 °C to 31.8 °C. The air humidity in Pakui Sayang Park is 67.5 with a dry category, while the other urban forests are in the slightly dry category of 71.3% to 74.4%. Thermal comfort at all study sites is in the moderately comfortable category, wind speed is in the calm to shady category. The findings of this study highlight the importance of urban forests as one of the indicators that play an important role in overcoming the problem of increasing temperatures that have an impact on the comfort of people in urban areas.

Keywords: green space, microclimate, NDVI, temperature humidity index, urban development, urban forest, urbanization.

INTRODUCTION

Urban areas are the center of community activities in the areas characterized by growing development in the industrial sector. City development tends to lead to physical development that provides facilities and infrastructure for various community activities. Makassar City, the capital of South Sulawesi Province, is a city that is developing rapidly and is busy with activity. It causes green land conversion to occur because of built-up land [Higginbottom, 2014]. The green land in Makassar City has been converted into land to support human needs in the housing sector and for economic and industrial centers.

Urbanization has caused urban development and an increasing growth rate in Makassar city. The development and growth of cities have had various positive and negative impacts on the environment. The adverse effects that occur include air pollution [Hajat et al., 2013], environmental noise [Casey et al., 2017], and extreme temperatures [Conlon et al., 2020]. Increasing temperatures are one of the impacts of decreasing environmental quality in Makassar city. The more vegetated land cover there is, the lower the temperature. However, the increase in built-up land from 1999–2019 in Makassar has continued to increase, and vegetated land has decreased, which has increased the air temperature [Liong et al., 2021]. The average maximum

temperature for Makassar City in 2023 was 34.8 °C [BPS Makassar City, 2023]. One alternative for controlling the impact of environmental problems in Makassar is the existence of green open space.

Urban green open space is a type of urban open space filled with naturally growing and deliberately planted vegetation [Santoso et al., 2012]. Green open space in the city of Makassar plays a significant role in reducing air pollution and making the environment cleaner and more comfortable. Vegetation is considered to have a cooling effect and has been tested in hot climates [Oke, 1989; Wong et al., 2021]. Humans feel more comfortable in vegetated areas than in non-vegetated areas. The cooling effect occurs due to heat absorption from solar radiation [Tauhid, 2008; Sulistyana et al., 2017]. In addition, temperature is interrelated with vegetation density, humidity, and wind speed and affects the level of thermal comfort of the people in an area. A high level of thermal comfort has a calming effect on people. Microclimate comfort standards of an area can be known by analyzing the THI (Temperature Humidity Index) which uses the factors of temperature and humidity [Rushayati, et al., 2011]. Vegetation is one of the factors that affect the value of THI, the more vegetation land in an area, the more comfortable THI will be [Suharyadi, 2019].

According to Minister of Home Affairs Regulation No. 1 of 2007, urban forest is one of the green open spaces in urban areas. An urban forest is an expanse of land where various compact and dense trees grow in a metropolitan area [Regulation of Government of The Republic of Indonesia, 2002]. In addition, the criteria for urban forests are regulated by the 2002 Ministerial Regulation of the Republic of Indonesia, namely, urban forests that are built in the form of paths, clusters, and groups of spreading vegetation, with a minimum area of 0.25 hectares for each group of urban forests in the form of separate paths or groups. The green open spaces verified as urban forests in Makassar urban areas consist of several forms of urban forests, including city parks, gardens, yards, green belts, botanical gardens, protected forests, and urban forests in urban conservation areas. The diversity of forms and functions of urban forests influences the surrounding microclimate. The structure of each urban forest influences the level of vegetation density. The vegetation density and temperature are closely related. The land covered by extensive vegetation is key to producing a comfortable environment. Therefore, the research specifically related to the level of vegetation density in several forms of urban forest needs to be carried out. This research aimed to analyze the distribution of urban forests in Makassar City and their influence on the microclimate around urban forest locations.

METHOD

The research method was carried out by reviewing the literature, publications of related agencies, books, and journals, as well as identifying urban forests by conducting direct observations at the research location. Location determination was based on urban forest criteria according to Government Regulation No. 63 of 2002, namely urban forests located in urban areas of a city or regency, are green open spaces dominated by trees on state land ownership, have an urban forest function, and have a minimum area of 0.25 ha in an expanse, Measurement of vegetation density and distribution of urban forests involved a GIS application, namely Arcmaps. These applications are commonly used and can produce detailed and informative maps that can help in understanding the spatial patterns and distribution of various attributes [Setianto and Triandini, 2015], using tools in Arcmaps to obtain location coordinates and produce spatial maps as well as NDVI values at urban forest locations, the measurement method was carried out as illustrated in Figure 1. Vegetation density is measured by processing Landsat 8 data obtained from the USGS website for the latest data or in 2024, in addition to data collection on air temperature, humidity and wind speed using the help of environment meter tools. The first data collection stage involved lining the urban forest area to determine measurement points. The measurement points were chosen randomly, provided that the data collection is under the shade of a tree canopy—the second stage is measured based on predetermined points, namely, 20 points at each location. The measurements were carried out three times. Measurements were taken in the morning (07.00–09.00 am), afternoon (11.00–1.00 pm), and afternoon (3.00–5.00 pm), during which they were carried out when the conditions were sunny. In addition, data collection was also carried out outside the urban forest area to determine the effect of urban forest vegetation density on air temperature.

Analysis of urban forest distribution

Data on the distribution of urban forests were obtained by identifying and surveying locations

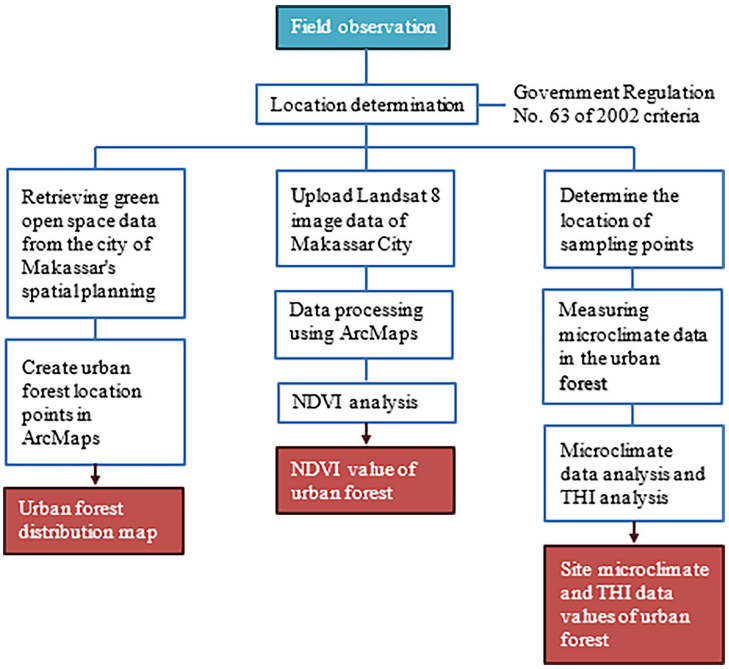

Figure 1. Flow chart of the applied method

that fit the criteria of urban forests according to Government Regulation No. 63 of 2002.

Analysis of vegetation density levels

The data required to calculate vegetation density are Landsat 8 image data, downloaded from the USGS website for 2024, or the latest image data with the fewest clouds. The vegetation density was calculated to determine its effect on the air temperature distribution in urban forest areas. Vegetation density analysis is generally adequate for use, namely, the NDVI (Normalized Difference Vegetation Index), which is sensitive to the presence of chlorophyll [Ridwan and Muharoroh, 2017]. The equation for calculating the NDVI is as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

NIR is the reflectance of the NIR (near-infrared) region, and RED is the reflectance of the visible light channel. In the Landsat 8 image, the NIR band is band 5, and the RED band is band 4 [Rizqiyah et al., 2022]. After the vegetation density was calculated via the above equation, the vegetation density level was reclassified (Table 1).

Analysis of microclimate data

Air temperature data obtained from measurements, tabulated so as to obtain the average measurement results at each measurement time through the following equation [Pambudi et al., 2018]:

$$T = \frac{(Tmax + Tmin)}{2} \quad (2)$$

where: *Tmax* – maximum air temperature at each measurement point (°C), *Tmin* – minimum air temperature at each measurement point (°C).

Next, the average temperature at a particular time is calculated via the following equation:

Table 1. Score classification of the NDVI

NDVI value range	Estimation of canopy density	Density level
-0.7–0.01	Not vegetated	–
> 0.01–0.18	> 0%–20%	Very rarely
> 0.18–0.32	> 20%–40%	Seldom
> 0.32–0.42	> 40%–50%	Medium
> 0.42–0.49	> 50%–60%	Dense
> 0.49–0.7	> 60%–80%	Very dense

Source: Tahir et al., 2019.

$$T = \frac{(2T_{morning} + T_{afternoon} + T_{evening})}{4} \quad (3)$$

The analysis was carried out with the air temperature variable descriptively by referring to the temperature assessment category based on temperature values obtained in the field (Table 2). The average humidity at any given time can be calculated via the following equation:

$$RH = \frac{(2RH_{morning} + RH_{afternoon} + RH_{evening})}{4} \quad (4)$$

where: RH – relative humidity.

The analysis was carried out with descriptive humidity variables by referring to the humidity assessment category based on the humidity value obtained at the urban forest site (Table 3). The wind speed was measured to determine the degree of comfort felt by the presence of wind. Wind speed analysis refers to the value category on the Beaufort scale (Table 4) [Azalia, 2019]. The limit of human comfort in feeling the wind on the skin is 2–3 m/s, which is in the weak breeze category of the Beaufort Scale.

Table 2. Air temperature categories

Temperature (°C)	Category
<21.1	Very cold
21.1 up to < 23.1	Cold
23.1 up to < 25.1	Quite cold
25.1 up to < 27.1	Cool
27.1 up to < 29.1	Quite hot
29.1 up to < 31.1	Hot
≥ 31.1	Very hot

Source: Setyowati and Sedyawati, 2010.

Table 3. Category of relative humidity

Humidity	Category
<70.0	Dry
70.0 up to <75.0	Slightly dry
75.0 up to <80.0	Slightly humid
80.0 up to <85.0	Humid
≥85.0	Wet

Source: Sittanggang, 2020.

This analysis aimed to determine the level of user comfort through temperature and humidity calculations. The complete temperature and humidity data are then sought for the average measurement results at each observation point.Thermal humidity index (THI) values can be calculated with the equation of Mc Gregor and Nieuwolt (1998):

$$THI = 0.8 \times T + (\frac{RH + T}{500}) \quad (5)$$

where: THI – thermal humidity index, T – Average air temperature (°C), RH – relative humadity (%)

Thermal comfort is analyzed using the thermal humidity index calculation results based on the *THI* category. *THI* categories in the tropics are as follows as like in Table 5.

RESULTS AND DISCUSSION

Urban forest distribution

According to the Makassar city regional planning document 2015–2034, the Makassar urban forest is spread across 7 locations and has a total

Table 4. Beaufort scale

Beaufort scale	Speed (m/s)	Category
0	<0.3	Calm
1	0.3–2	Shady
2	2–3	Weak breeze
3	3–5	Soft breeze
4	5–8	Medium breeze
5	8.1–10.6	Fresh breeze
6	10.8–13.6	Strong breeze
7	13.9–16.9	Weak hurricane
8	17.2–20.6	Medium hurricane
9	20.8–24.4	Strong hurricane
10	24.7–28.3	Storm
11	28.6–32.5	Raging Storm
12	>32.8	Typhoon

Source: Beufort; Azalia, 2019.

Table 5. THI of tropical society

Level of THI	Category
21 ≤ up to ≤ 24	Comfortable
24 < up to ≤ 26	Quite convenient
26 < up to ≤ 30.5	Uncomfortable
> 30.5	Very uncomfortable

Source: Emmanuel, 2005

area of 66.86 hectares. The area of Makassar City, which is 17.577 hectares, must have a minimum urban forest area of 1.757 hectares (10%). The total area of the urban forest is 66.86 hectares or 3.80% of the 10% urban forest area required in a city.

The location of urban forests is based on the Makassar city regional planning document from 2015–2034, which spans several subdistricts in Makassar city, including Biringkanaya District, with four units: (1) Awawul Islam Urban Forest; (2) KNP (National Committee of Indonesian Youth**)** Urban Forest; (3) Camping Urban Forest Caddika; and (4) Darul Arqam Urban Forest; Tamalanrea District, with one unit, namely, (1) Hasanuddin University Urban Forest; Panakkukang District, with one unit, namely, (1) South Sulawesi Governor's Office Urban Forest; and in Tamalate District, with one unit, namely, the (1) Bank of the Jeneberang River. Among the seven urban forest locations in the 2015–2034 Makassar city spatial planning document, only two units meet the criteria for urban forest, namely, Hasanuddin University Urban Forest and South Sulawesi Governor's Office Urban Forest. In contrast, the other units are still in the form of empty land, swamps, and school fields.

Locations of green open spaces that are included in the criteria for urban forests according to Indonesian Government Regulation No. 63 of 2002 include (1) Hasanuddin University Urban Forest, (2) South Sulawesi Governor's Office Urban Forest, (3) Pakui Sayang Park, (4) Hasanuddin Park, (5) Macan Park, and (6) MoI (Maccini Sombala of Indonesia) Park. The total area of urban forest is based on the criteria of Indonesian Government Regulation No. 63 of 2002, namely, 40.27 hectares or only 2.3% of the required 10% urban forest area. Information regarding the location, area, and boundaries of the research urban forest location is shown in Table 6. A map of the urban forest distribution in Makassar city is shown in Figure 2

Vegetation density level

The results of the NDVI analysis of the six urban forest sites in Makassar are in order from highest to lowest values, namely, Hasanuddin

Table 6. Location, area, and location Boundaries

Research site	Location	Area	Location boundaries
Hasanuddin University	5° 7' 45.63" LS and 119° 29' 16.94" BT	± 20 hectares	North: Sahabat Street East: Hasanuddin Univesity Hospital West: Statistik Street South: Paroki Maria Ratu Rosari Kare Church
Governor of South Sulawesi office	5° 8' 20.31" LS and 119°27' 7.28" BT	± 15 hectares	North: Tallo River East: Paldam XIV Hasanuddin Office West: Nipah Mall South: Urip Sumoharjo Street
Pakui Sayang Park	5°9'6.50"LS and 119°26'13.12"BT	1 hectare	North: Bina Marga and Bina Construction Office of South Sulawesi, and Spatial Planning and Settlement Office of South Sulawesi East: A. P. Pettarani Street West: Nikel Raya Street South: Nikel Raya Street
Hasanuddin Park	5°8'32.66"LS and 119°24'39.99"BT	0.60 hectares	North: Sultan Hasanuddin Street East: Sultan Hasanuddin Street West: Lamaddukelleng Street South: Public Libaray of Makassar
Macan Park	5°8'8.33"LS and 119°24'28.63"BT	1.27 hectares	North: State Treasury Service Office Makassar I East: Balaikota Street West: Pattimura Park South: Sultan Hasanuddin Street
Maccini Sombala of Indonesia (MoI) Park	5°10'2.35"LS and 119°24'10.71"BT	± 2.4 hectares	North: swamps and ponds East: Residential areas of Maccini Sombala Village and Maritime Academi of Indonesian Makassar West: swamps and ponds South: BNNP of South Sulawesi dan Atma Jaya University

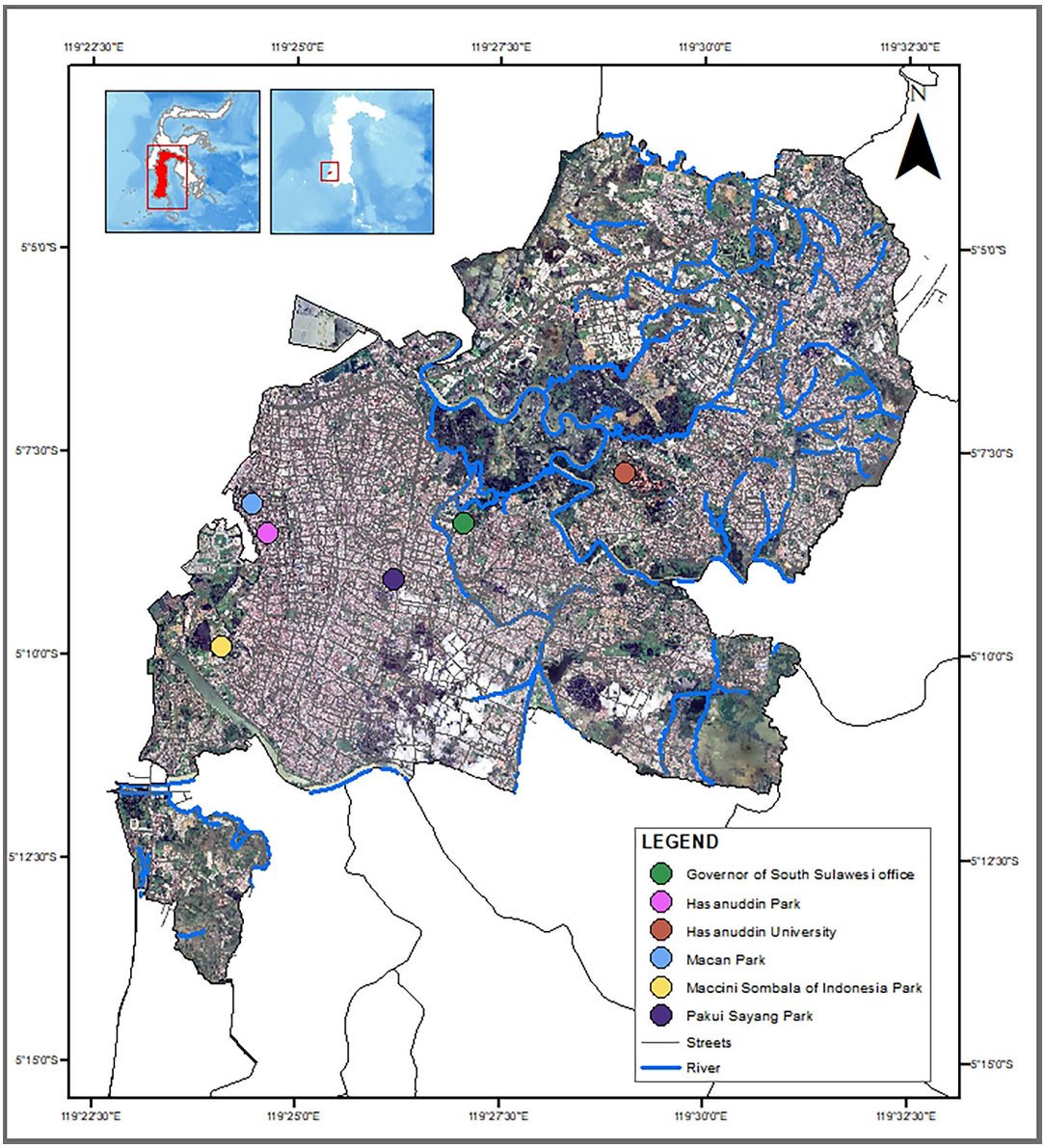

Figure 2. Map of urban forest distribution

University Urban Forest at 0.38, South Sulawesi Governor's Office Urban Forest at 0.38, Macan Park at 0.36, Pakui Sayang Park at 0.34, Hasanuddin Park at 0.34, and MoI Park at 0.34 (Table 7). The different NDVI values are caused by each location having distinct characteristics of vegetation types, resulting in differences in the level of greenness of the vegetation. The vegetation density values of all the urban forests are at medium-density levels. Urban forests with city park functions, namely, Pakui Sayang Park, Hasanuddin Park, Macan Park, and MoI Park, are

Table 7. Calculation of the location NDVI value

Urban forest location	NDVI	Category
Hasanuddin University	0.38	Medium
Governor of South Sulawesi office	0.38	Medium
Pakui Sayang Park	0.34	Medium
Hasanuddin Park	0.34	Medium
Macan Park	0.36	Medium
MoI	0.34	Medium

influenced by diverse vegetation. The site not only has tree vegetation that functions as shade, but also has shrubs and bushes that enhance the visual or aesthetics for visitors so that it looks beautiful and neatly arranged. Most trees at each site have a shading function, especially on the side of the road or jogging track, whereas shrubs and bushes function as guides and barriers. In addition, vegetation is produced in MoI Park. Production vegetation is a group of plants that residents deliberately plant to take advantage of in agricultural production activities, such as cowpea trees (*Vigna unguiculata*), water spinach (*Ipomoea aquatica*), soybeans (*Glycine max*), and shallots (*Allium cepa*). Low plants dominate shrubs and horticultural plants, and the spacing is not close enough, so there is still empty land between the plants. In addition, the arrangement pattern and selection of vegetation at the four sites consider the level of user safety and park aesthetics, which influence the NDVI value. Apart from the urban forest, which functions as a city park, there are office locations, namely, the South Sulawesi governor's office, and a campus, namely Hasanuddin University. Both locations are dominated by annual vegetation that functions as shade, such as rain trees (*Samanea saman*) and sandalwood (*Santalum album*). The characteristics of these two trees are that they are large and tall, having a wide crown growth. These trees are planted on the entire site, influencing the vegetation density value.

Air temperature

The results of the air temperature analysis for the six urban forest sites in Makassar are arranged in a row from highest to lowest values: Pakui Sayang Park at 31.8 °C, Hasanuddin Park at 31.4 °C, Macan Park at 31.2 °C, Hasanuddin University at 31.1 °C, and MoI Park and South Sulawesi Governor's Office at 30.9 °C (Table 8). The surrounding environmental conditions influence the varying temperatures at the research location. Apart from measurements in the research of the urban forest area, measurements were carried out outside the urban forest to determine the level of vegetation modification in the urban forest area based on the surrounding air temperature. Green open spaces provide tangible benefits for environmental quality [Finlay et al., 2015; Cheesebrough et al., 2019]. The measurement results revealed that the temperature in the urban forest area was lower than outside the urban forest area. The air temperature inside and outside the urban forest has decreased by up to 1.2 °C (Table 8). Thus, decreasing temperature can make the people inside urban forest areas feel more comfortable than those outside urban forests. The increase in temperature outside urban forests is caused by solar radiation increasing the heat of objects. Urban elements are dominated by buildings, which cause an increase in temperature. The smoother and brighter the surface of a material is, the more solar radiation will be reflected. Moreover, in urban forests, many trees have canopies and produce shadows to prevent them from absorbing up to 90% of solar radiation. It aligns with the research by Safitri et al. [2022], which revealed that low air temperatures tend to occur in areas with vegetation cover. In contrast, built-up areas dominate the trend of increasing temperatures. It shows the effectiveness of the function of vegetation in modifying air temperature [Jannah and Bioresita, 2023]

Relationships between urban forest vegetation density levels and surrounding air temperature

The smaller the NDVI value is, the greater the air temperature; conversely, if the NDVI value is better, the air temperature will be lower. The results

Table 8. The air temperature inside and outside the urban forest

Urban forest location	Average daily temperature (°C)						
	Inside urban forest	Location control I	Deviation	Location control II	Deviation	Lokasi control III	Deviation
Hasanuddin University	31.1	31.3	0.2	31.4	0.3	31.2	0.1
Governor of South Sulawesi office	30.9	31.5	0.6	31.4	0.5		
Pakui Sayang Park	31.8	32.1	0.3	32.7	0.9	32.1	0.3
Macan Park	31.2	31.9	0.7	32.1	0.2		
Hasanuddin Park	31.4	32	0.6	31.6	0.9		
MoI Park	30.9	31.9	1	32.1	1.2		

Note: The location of the control (I, II, and III) is the location of the sampling data outside the urban forest or an area without tree shade.

of the calculation of the highest NDVI values in the six urban forests are from Hasanuddin University and the South Sulawesi Governor's Office. In contrast, the locations with the lowest NDVI values were Pakui Sayang Park, Hasanuddin Park, and MoI Park. The temperature at Hasanuddin University is higher than at MoI Park even though Hasanuddin University has a higher NDVI value than MoI Park (Table 9). The surrounding environmental conditions can cause this. The level of activity and percentage of dense buildings caused the air temperature in the Hasanuddin University area to increase. Moreover, MoI Park is located in the western corner of Makassar, far from urban areas. There are only residential areas, several offices, and schools at this location, so there is not much activity there. Human structures and activities influence the changes in the local microclimate, including humidity, temperature, and groundwater availability. It is a factor in the lower air temperature at MoI Park than at the other locations.

Relative humidity

The results of the humidity analysis at the six research locations reveal that the urban forest locations with the lowest humidity are in Pakui Sayang Park, and those with the highest humidity are MoI Park and the Governor's Office. The humidity values ranged from 65.9% to 77.4% at Hasanuddin University, 61% to 78.9% at the governor's office, 60.5% to 74.5% at Pakui Sayang Park, 67% to 76% at Tiger Park, 67.3% to 76.6% at Hasanuddin Park, and 69.2% to 78.7% at MoI Park (Table 10). The air humidity in MoI Park is more significant than that in other locations, because the location of MoI Park is far from urban areas, which usually have dense activities and buildings, and the vegetated land around the park is still relatively large; the locations with more vegetation have higher air humidity than the locations with less vegetation [Gill et al., 2007]. The air humidity at all locations is still included in the comfortable category. The ideal air humidity for human comfort is 40–75%.

Table 10. Relative humidity of urban forests

Urban forest location	Relative humidity
Hasanuddin University	71.3
Governor of South Sulawesi office	73.2
Pakui Sayang Park	67.5
Hasanuddin Park	71.9
Macan Park	71.3
MoI Park	74.4

Wind speeds

The results of the wind speed measurements at the six research locations reveal differences in the wind speed in the morning, afternoon, and evening. The morning has wind speeds in the range of 0–0.8 m/s. The afternoon has wind speeds in the range of 0–1.6 m/s. The afternoon has a wind speed ranging from 0–0.8 m/s in the shaded category. In the morning, the average wind speed has a value below 0.3 m/s or is in the calm category. In contrast, in the afternoon, the average wind speed has a value above 0.3 m/s to below two m/s or is in the shaded category. The wind speed in the morning is lower than in the afternoon, because the temperatures in the morning, afternoon, and evening significantly influence the wind speed. The temperature at 2.00 pm is relatively higher than at 09.00 am or 7.00 pm. The difference in heat causes the molecules in the air to stretch, thus increasing the wind speed. Conversely, colder temperatures cause the molecules in the air to become tighter, resulting in lower wind speeds [Adjam and Renoat, 2017].

Thermal comfort

The analysis of air temperature and air humidity at the six urban forest locations yielded a thermal

Table 9. Relationship between the NDVI values and temperature

Urban forest location	NDVI	Temperature (°C)
Hasanuddin University	0.38	31.1
Governor of South Sulawesi office	0.38	30.9
Pakui Sayang Park	0.34	31.8
Hasanuddin Park	0.34	31.4
Macan Park	0.36	31.2
MoI Park	0.34	30.9

Table 11. THI of urban forest

Urban Forest location	THI	Category
Hasanuddin University	25.1	Quite convenient
Governor of South Sulawesi office	24.9	Quite convenient
Pakui Sayang Park	25.6	Quite convenient
Hasanuddin Park	25.3	Quite convenient
Macan Park	25.2	Quite convenient
MoI Park	24.9	Quite convenient

comfort value with a THI at the six locations of the urban forest included in the quite comfortable category, which ranged from 24.9 to 25.6. The lower the THI value is, the more comfortable it is compared with high values. The lowest THI value is at the Governor's Office and MoI Park, whereas the highest is at Pakui Sayang Park (Table 11). The THI values of the six research locations are classified as quite comfortable, and there is a difference in the THI values inside and outside the urban forest. It shows that the six urban forests can modify the air temperature and control the air humidity.

CONCLUSIONS

This research revealed that until now the distribution of urban forests in Makassar has not been evenly distributed in each sub-district, only four sub-districts have urban forests that meet the criteria of urban forests according to Government Regulation No. 63 of 2002, including Hasanuddin University Urban Forest, South Sulawesi Governor's Office Urban Forest, Pakui Sayang Park, Macan Park, Hasanuddin Park, and Maccini Sombala of Indonesia Park, and the total area of the urban forest area is only 2.3% of the 10% of the required urban forest area. These urban forests were identified as parks, offices and campuses. This research showed that urban forests with medium vegetation density criteria have an effect on reducing temperature and increasing humidity in the area around the urban forest, as well as wind speeds that are still in the comfortable category. Thus, the urban forest can provide a comfortable feeling for the people around it compared to outside the urban forest or the areas where there is no green open space. This research contributes to a broader understanding of the importance of the existence of urban forest green open space in suppressing environmental problems, especially in increasing temperatures in urban areas, as well as the importance of managing urban forests that are already owned by a city.

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