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Analysis of Environmental Quality in Green Open Space (RTH) for Sustainable Urban Planning in Makassar, Indonesia

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Abstract This study aims to assess the environmental quality of Green Open Spaces (RTH) in Makassar City, Indonesia, and evaluate their contribution to sustainable urban spatial planning. A mixed-methods approach was adopted, combining quantitative and qualitative techniques, and supported by Geographic Information System (GIS)-based spatial analysis to examine the distribution, area, and quality of RTH using spatial data and satellite imagery. An urban ecological perspective was also applied to explore the role of RTH in enhancing urban ecological balance, including climate change mitigation, biodiversity conservation, and the provision of natural habitats. The results indicate that several RTH areas—such as Pakui Park, Macan Park, Hasanuddin Park, and the private forest of Bukit Baruga—demonstrate good environmental quality, characterized by high vegetation cover, excellent air and surface water quality, and minimal environmental disturbance. However, from a quantitative standpoint, the total RTH coverage in Makassar reached only 11.47% of the city's area in 2023, falling significantly short of the 30% target set by Law No. 26/2007. Oxygen demand analysis and national standards suggest that the optimal RTH coverage should range between 13.37% and 30.93% of the total urban area. These findings highlight the critical need for integrating spatial data and ecological approaches into urban spatial planning to reinforce both the ecological and social functions of RTH. Expanding the coverage and improving the quality of green spaces are essential strategies for fostering a sustainable, climate-resilient, and livable urban environment in Makassar.

Keywords Green Open Space, Environmental Quality, GIS, Urban Ecology, Sustainable Spatial Planning, Makassar

1. Introduction

Green Open Spaces (RTH) play a critical role in sustainable urban spatial planning [1]. They serve as the city's lungs, water absorption areas, and public spaces, offering significant ecological, economic, and social benefits, such as improving air quality, mitigating urban heat island effects, supporting flood control, and enhancing the overall quality of life for urban dwellers [2]. In the face of rapid urbanization and population growth in major cities, including Makassar, the planning and management of RTH have become pressing challenges. The environmental quality of RTH directly impacts sustainable urban spatial planning. Poorly maintained RTH, characterized by insufficient vegetation and minimal upkeep, can substantially hinder effective urban planning [3]. Sustainable urban development requires synergy between RTH management and architectural planning. At its core, sustainable development aims to improve the quality of life for both present and future generations [4]. Widati & Amiany [5] asserted that sustainable spatial planning relies heavily on the integration of quality RTH to mitigate the adverse effects of urbanization.

Moreover, Widati & Amiany [5] emphasized the importance of integrating RTH into urban design to improve the quality of life in urban areas. Well-designed and high-quality RTH contribute significantly to urban residents' well-being by fostering social interaction, providing recreational spaces, and mitigating negative urbanization effects, such as pollution and elevated temperatures. The RTH issue has garnered increasing attention from stakeholders, underscoring the need for continuous public awareness and the development of sustainable initiatives that prioritize the the availability of green space [6]. Sustainable development presents a significant global challenge, particularly for developing nations such as Indonesia [7]. Therefore, sustainable city design—based on efficiency and the optimal use of materials, energy, and space—greatly depends on the quality and availability of RTH. Makassar, as one of Indonesia's major metropolitan areas, is facing immense urbanization pressures. The increasing demand for land for housing, infrastructure, and economic activities often comes at the expense of RTH [8], leading to environmental degradation such as deteriorating air quality, rising urban temperatures, and a reduction in communal spaces. The critical functions of RTH in water absorption, air pollution control, and public recreation are increasingly threatened by land-use changes [9]. Many existing RTH in Makassar suffer from inadequate maintenance and limited vegetation diversity [10]. This issue is further exacerbated by the lack of integration between RTH and sustainable urban planning in Makassar [11]. Moreover, urban infrastructure projects, such as elevated toll roads and the construction of high-rise buildings in park areas, have further jeopardized urban green spaces.

Lestari & Nur [12] revealed that the distribution and quality of RTH in Makassar are insufficient to support the city's ecological balance. Current RTH coverage in Makassar stands at only 11%, far below the minimum required 30%, as stipulated by the Ministry of Public Works Regulation No. 5 of 2008 [13]. Environmental and Spatial Planning Agency of Makassar City [14] also showed that the city still falls short of this target. Furthermore, the regulation specifies that each sub-district must provide at least 0.2 m^2 of green space per capita, with a minimum total area of 24,000 m^2.

Based on the Makassar Spatial Plan (RTRW), high-density residential areas, resulting from urbanization, are concentrated in the sub-districts of Tamalate, Makassar, Panakkukang, Ujung Pandang, and Manggala. This study focuses on Panakkukang, Ujung Pandang, and Manggala. In Panakkukang, RTH covers 1,912,064 m^2 or 12.316% of the total area, while in Ujung Pandang, it covers 332,638 m^2 or 11.439% [15]. In Manggala, private green spaces are located in the Bukit Baruga residential complex. The existence of RTH in these areas significantly influences environmental sustainability, particularly in high-density residential zones [8].

Recent field surveys and secondary reports indicate that ecological imbalance in Makassar's RTH is reflected in several pressing issues. First, vegetation composition is dominated by only a few ornamental species, resulting in low biodiversity (with fewer than 10 dominant plant species in most parks). Second, poor maintenance practices—such as irregular pruning, insufficient watering, and unmanaged waste—have reduced the ecological performance of many public parks. Third, inadequate protection of soil and vegetation has led to a decline in water infiltration capacity, contributing to increased local flooding risks. Finally, microclimate measurements in several dense residential areas showed that Thermal Humidity Index (THI) values exceeded comfort standards, highlighting the limited role of existing RTH in mitigating the urban heat island effect [16].

Figures 1-3 illustrate notable differences among the three sub-districts studied. Panakkukang exhibits dense residential development with fragmented RTH patches, most of which are small parks scattered between commercial and housing areas. Manggala contains larger private green areas within residential complexes, particularly in Bukit Baruga, but accessibility for the wider community is limited. Ujung Pandang features smaller but well-maintained public parks integrated into the historic urban fabric, which provide social and recreational benefits despite their limited ecological capacity. These variations in land use and social structure strongly influence the accessibility, biodiversity, and ecological performance of each RTH [16].

Thus, understanding the impact of RTH environmental quality on sustainable architectural planning in Panakkukang, Ujung Pandang, and Manggala is essential not only for improving urban living standards but also for ensuring that urban development aligns with sustainability and environmental conservation principles [17]. This study aims to evaluate the environmental quality of RTH in Makassar and assess its role in contributing to sustainable urban spatial planning.

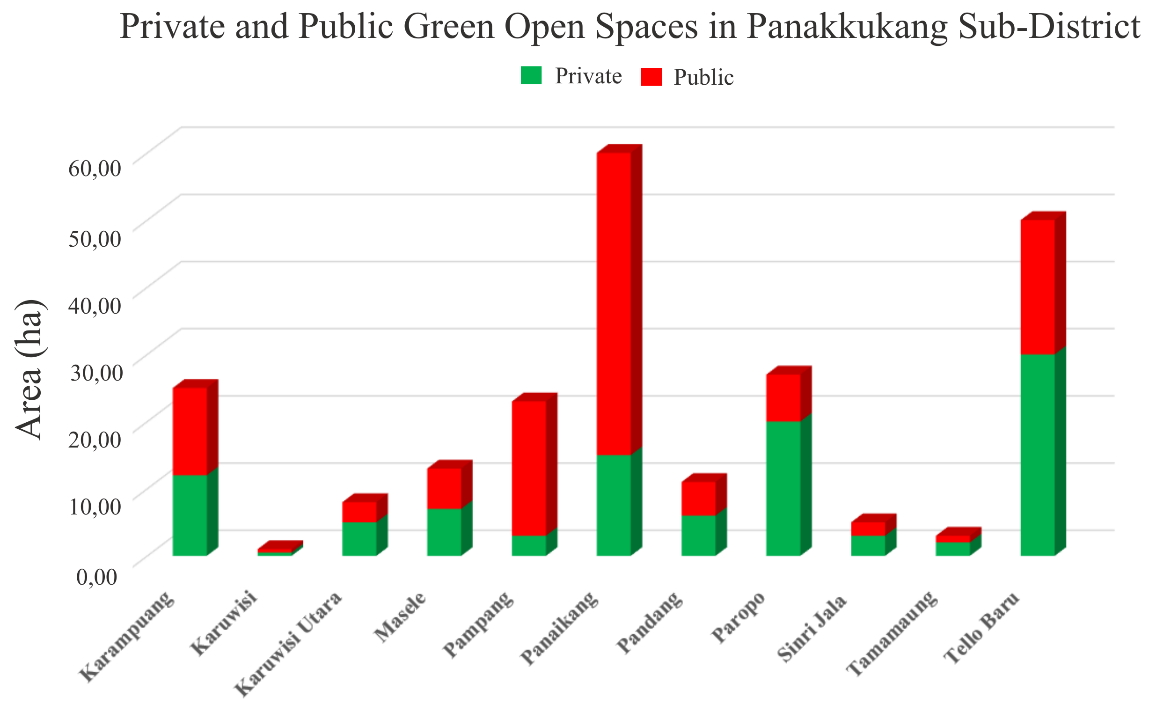

Figure 1. Comparison of the Areas of Private and Public Green Open Spaces in Panakkukang Sub-District

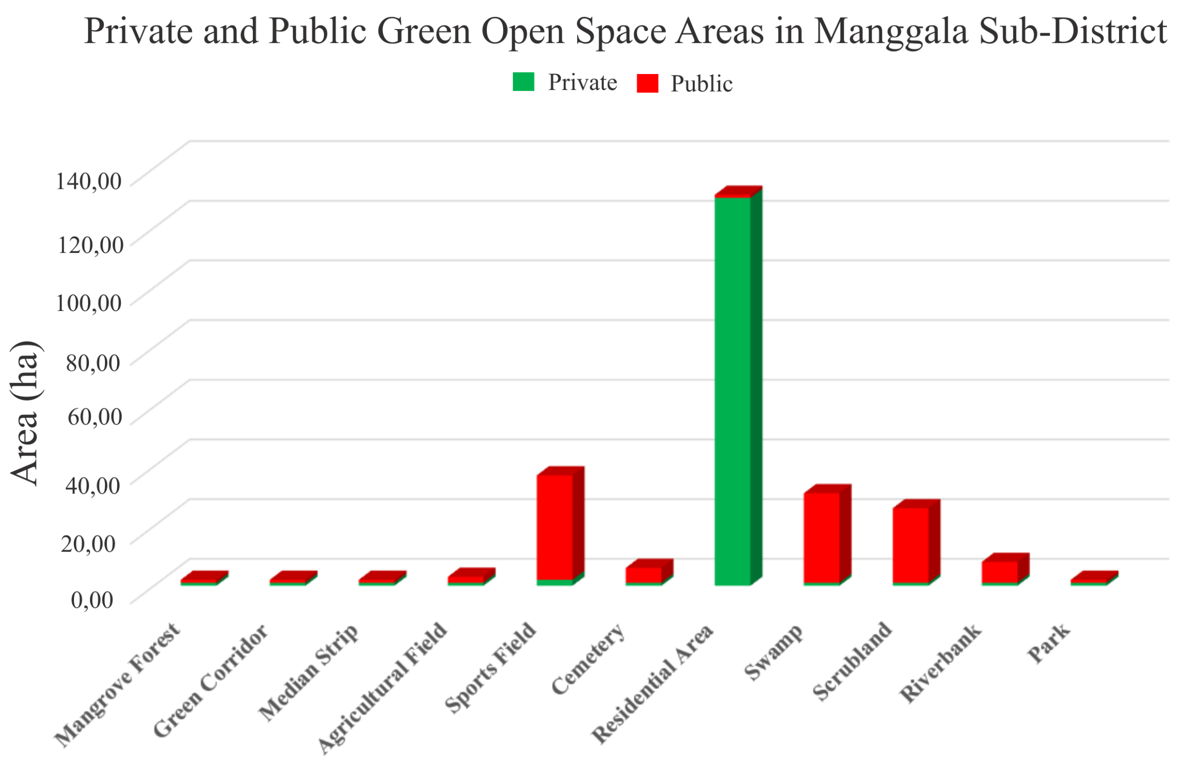

Figure 2. Comparison of Private and Public Green Open Space Areas in Manggala Sub-District

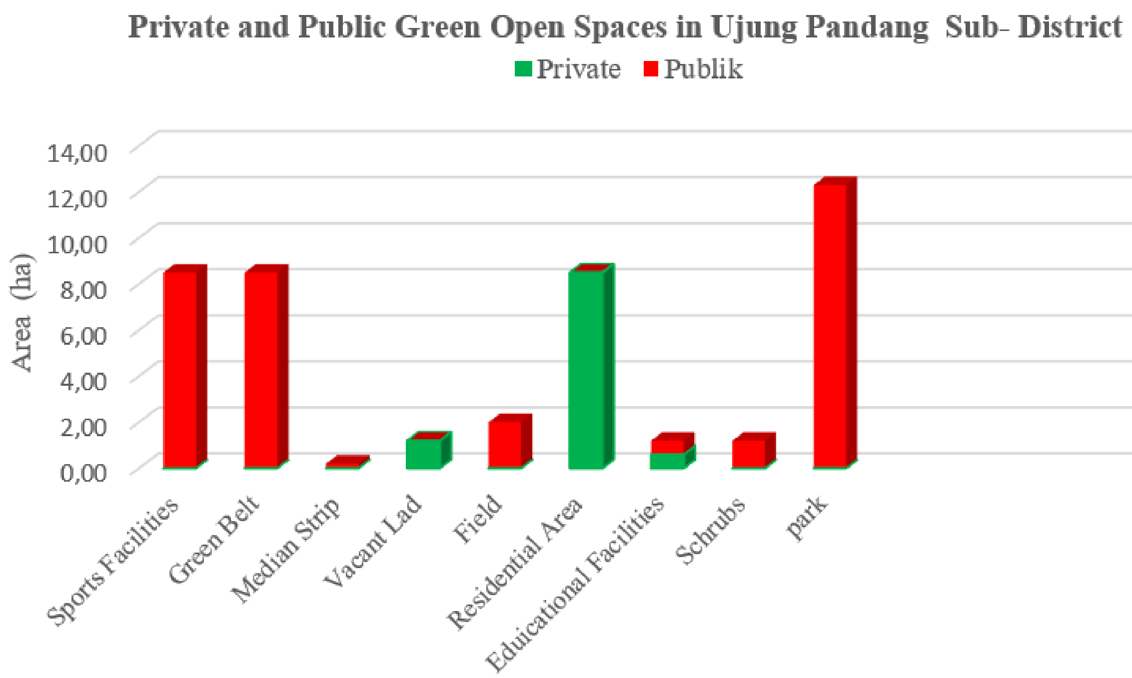

Figure 3. Comparison of Private and Public Green Open Space Areas in Ujung Pandang Sub-District

2. Methods

The methodology employed in this study adopts a mixed-methods approach, integrating both quantitative and qualitative techniques. The quantitative aspect involves the use of numerical data to assess environmental quality, including vegetation index, air quality, surface temperature, noise levels, and pollution. Statistical analysis is then conducted to examine the relationships between Green Open Spaces (RTH) and various environmental parameters. The qualitative component consists of interviews with key stakeholders (government officials, local communities, urban planners) to understand their perceptions and policies regarding RTH. Additionally, direct observations are made to assess both the physical and social aspects of RTH.

This study also incorporates a spatial approach utilizing Geographic Information Systems (GIS) to analyze the distribution, area, and quality of RTH based on spatial data and satellite imagery. Furthermore, an urban ecology perspective is adopted to examine the role of RTH in supporting the ecological balance of the city, including climate change mitigation, biodiversity conservation, and the provision of natural habitats.

The research was conducted over a six-month period, from April to September 2023, in three sub-districts of Makassar City, South Sulawesi Province: Panakkukang, Ujung Pandang, and Manggala. RTH locations in Panakkukang Sub-district include Taman Pakui; in Ujung Pandang Sub-district, Taman Macan and Taman Hasanuddin; and in Manggala Sub-district, private RTH is located within the Bukit Baruga Complex (Figure 4).

Primary data were collected directly from field observations conducted at the study sites. These included measurements of tree diameters, species identification, tree and fauna counts, temperature readings, and environmental quality assessments such as airborne particulate matter (dust) and noise levels. Vegetation cover percentage was determined through spatial delineation of Green Open Space (RTH) areas using polygon mapping techniques within a Geographic Information System (GIS) framework. Secondary data were obtained from relevant government agencies, previous research reports, scientific literature, and other supporting documents. This included information related to soil erosion, water quality, and historical temperature records. The assessment of environmental quality was carried out using a scoring system based on averaged criteria, as detailed in Table 1 and Table 2.

In the vegetation analysis, several indices were applied to better quantify biodiversity: Ni (number of individuals for each species), Ni/N (proportion of individuals relative to the total), Ln (Ni/N) (the natural logarithm of that proportion), and H' (the Shannon–Wiener Diversity Index). These indices are widely used in ecological studies to measure species diversity and evenness [18], [19].

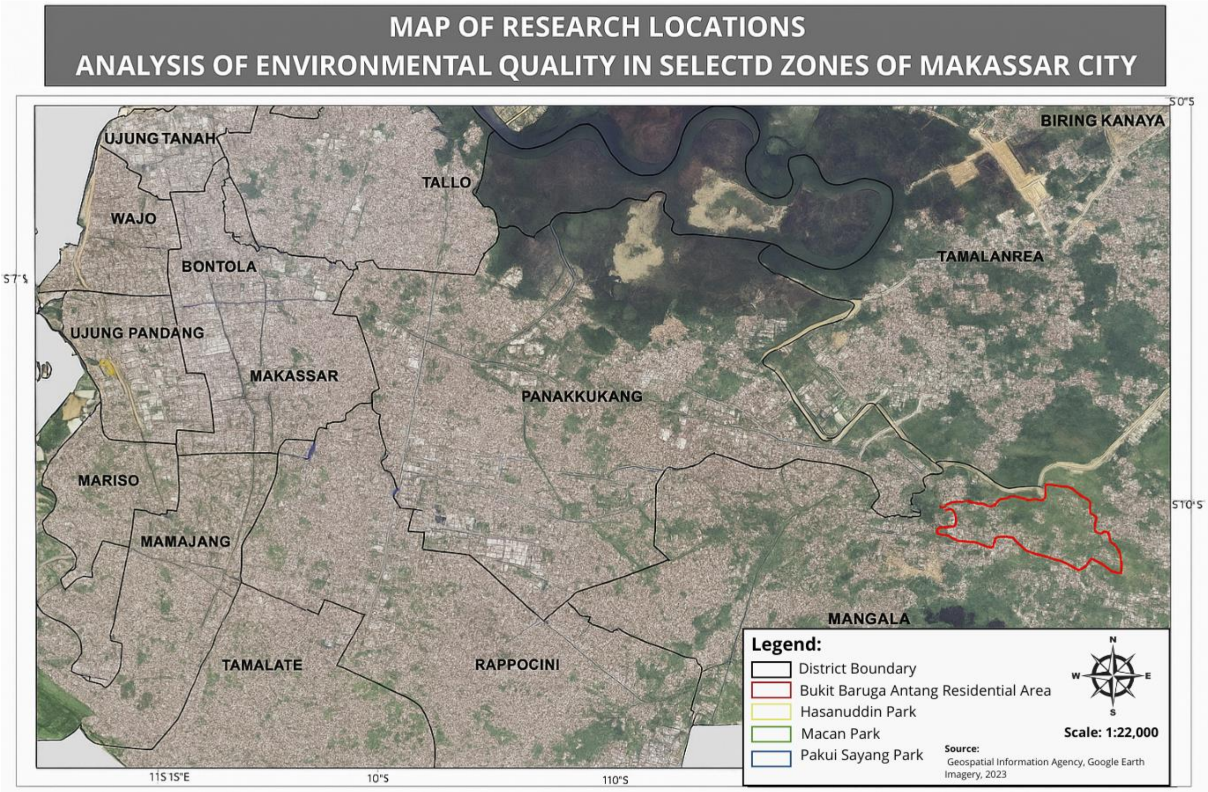

Figure 4. Map of Research Locations

Table 1. Specific data of Column/Row

No.	Environmental Parameter	Unit	Value and Environment Quality Scale Range				
			Very Good (Scale 5)	Good (Scale 4)	Moderate (Scale 3)	Poor (Scale 2)	Very Poor (Scale 1)
1	Vegetation	-	Diversity Index ≥ 3	2.0–2.9	1.0–1.9	0.1–0.9	0
2	Canopy Cover Percentage	%	≥ 90%	80–89	70–79	50–69	< 50
3	Terrestrial Wildlife / Fauna	-	> 8 species	6	4	2	None
4	Temperature Humidity Index (THI)	-	< 21	21–24	25–28	29	> 29
5	Ambient Airborne Dust	μg/m³	< 115	115–172	173–229	230	> 230
6	Noise Level	dB(A)	< 43	43–63	64–84	85	> 85
7	Soil Erosion	-	Very Mild	Mild	Moderate	Severe	Very Severe
8	Surface Water Quality (pH)	-	6.0–9.0	5.0–<6.0 or > 9.0–10.0	4.0–<5.0 or > 10.0–11.0	3.0–<4.0 or > 11.0–12.0	< 3.0 or > 12.0

Table 2. Environmental Quality Assessment

No.	Average Score	Environmental Quality
1	1.0–1.8	Very Poor
2	1.9–2.6	Poor
3	2.7–3.4	Moderate
4	3.5–4.2	Good
5	4.3–5.0	Very Good

3. Result and Discussion

3.1. Biophysical Environmental Characteristics of Green Open Spaces (RTH)

3.1.1. Vegetation

A. Taman Pakui

Based on field observations, several terrestrial plant species were identified within the study area. In general, the vegetation cultivated in the green open space (RTH) areas is predominantly composed of Ketapang Cendana (*Terminalia mantaly*), Tanjung (*Mimusops elengi*), and Angsana (*Pterocarpus indicus*). A total of 11 tree and palm species were recorded (Table 3). The vegetation diversity analysis indicated a diversity index (H') of 1.42, which is categorized as moderate.

The calculated tree diversity index (H' = 1.42) demonstrates a moderate level of species diversity, as the value falls within the range of 1–1.9. In contrast, the understory vegetation diversity index of 2.58 is considered high, indicating greater ecological stability at the shrub and ground cover levels. According to Dollah [8], species diversity is closely linked to ecosystem productivity and resilience. A higher diversity index reflects richer species composition, enhanced ecological balance, and greater adaptive capacity to urban environmental pressures. The CO_2 absorption and O_2 production capacity of the tree species are presented in Table 4.

Table 3. Terrestrial Flora (Vegetation) of Tree Habitus at Taman Pakui, Panakukang Subdistrict

No.	Species Name	Scientific Name	Ni	Ni/N	Ln Ni/N	Ni*Ln Ni/N	Diversity Index (H')
1	Angsana	*Pterocarpus indicus*	13	0.08	-2.49	0.21	1.42
2	Asam	*Tamarindus indica*	1	0.01	-5.06	0.03	
3	Beringin	*Ficus benjamina*	4	0.03	-3.67	0.09	
4	Bitti	*Vitex cofassus*	5	0.03	-3.45	0.11	
5	Cemara	*Casuarina equisetifolia*	6	0.04	-3.26	0.12	
6	Ketapang	*Terminalia catappa*	1	0.01	-5.06	0.03	
7	Ketapang cendana	*Terminalia mantaly*	95	0.61	-0.50	0.30	
8	Ki Hujan	*Samanea saman*	6	0.04	-3.26	0.12	
9	Mahoni	*Swietenia mahagoni*	4	0.03	-3.67	0.09	
10	Mangga	*Mangifera indica*	1	0.01	-5.06	0.03	
11	Tanjung	*Mimusops elengi*	21	0.13	-2.01	0.27	
			157	1.00	-37.49		

Table 4. CO_2 Absorption and Oxygen Production at Taman Pakui, Panakukang Subdistrict

No.	Species Name	Scientific Name	Number of Individuals	CO_2 Absorption (Ton/ha/Years)	O_2 Production (Ton/ha/Years)
1	Angsana	*Pterocarpus indicus*	13	1.45	1.06
2	Asam	*Tamarindus indica*	1	0.40	0.29
3	Beringin	*Ficus benjamina*	4	0.56	0.41
4	Bitti	*Vitex cofassus*	5	0.16	0.11
5	Cemara	*Casuarina equisetifolia*	6	0.67	0.48
6	Ketapang	*Terminalia catappa*	1	0.11	0.08
7	Ketapang cendana	*Terminalia mantaly*	95	3.35	2.43
8	Ki Hujan	*Samanea saman*	6	3.42	2.48
9	Mahoni	*Swietenia mahagoni*	4	1.83	1.33
10	Mangga	*Mangifera indica*	1	0.55	0.40
11	Tanjung	*Mimusops elengi*	21	0.80	0.58
Total			**157**	**13.30**	**9.67**

The ecological services provided by Taman Pakui's RTH are significant, particularly in mitigating greenhouse gas emissions. The results show that vegetation in this park absorbs 13.30 tons of CO_2eq per hectare annually and produces 9.67 tons of O_2eq per hectare annually. Species such as Rain Tree (*Samanea saman*) and Ketapang Cendana (*Terminalia mantaly*) are the most significant contributors due to their broad canopies and high biomass.

From the perspective of sustainable urban planning, these findings highlight that even a moderately diverse park can play a vital role in improving air quality, regulating microclimate, and enhancing urban livability. Increasing vegetation diversity and canopy cover in parks like Taman Pakui will further strengthen their ecological function as urban carbon sinks and oxygen producers, which are essential for building climate-resilient cities.

B. Taman Macan

An inventory and direct field measurements conducted at Taman Macan identified 16 species of tree and palm vegetation. The dominant species recorded were Angsana (*Pterocarpus indicus*), Red Palm (*Ptychosperma coccinea*), and Saga (*Adenanthera pavonina*), which together formed the structural backbone of the park's vegetation. The findings of the vegetation inventory are presented in Table 5.

The diversity analysis produced a Shannon–Wiener index (H') of 2.24, which is categorized as good. This value is notably higher than that of Taman Pakui (H' = 1.42), suggesting that Taman Macan possesses a more balanced distribution of tree species and a richer ecological structure. The diversity index for understory vegetation (H' = 2.61) is classified as high, further strengthening the ecological resilience of this urban green space. According to Dollah [8], higher diversity values correlate with greater species richness, ecosystem productivity, and resilience to ecological disturbances. The CO_2 absorption and O_2 production capacity of the tree species at Taman Macan are presented in Table 6.

The calculation results demonstrate that vegetation in Taman Macan absorbs 20.05 tons of CO_2eq per hectare annually and produces 14.58 tons of O_2eq per hectare annually. Species with high biomass potential, particularly *Pterocarpus indicus* (Angsana) and *Adenanthera pavonina* (Saga), are the primary contributors to these ecosystem services.

In the context of sustainable urban planning, Taman Macan plays a crucial role as an ecological buffer within the dense urban core of Makassar. Its higher species diversity and substantial carbon sequestration capacity strengthen its function as a "green lung" that improves air quality, moderates the urban microclimate, and supports urban biodiversity. However, maintaining this ecological performance requires continuous monitoring, enrichment planting of native species, and integration of vegetation management into city-scale climate adaptation strategies.

Table 5. Terrestrial Flora (Vegetation) at Taman Macan, Ujung Pandang Subdistrict

No.	Species Name	Scientific Name	Ni	Ni/N	Ln Ni/N	Ni*Ln Ni/N	Diversity Index (H')
1	Angsana	*Pterocarpus indicus*	25	0.27	-1.31	0.35	2.24
2	Aren	*Arenga pinnata*	1	0.01	-4.53	0.05	
3	Beringin	*Ficus benjamina*	2	0.02	-3.84	0.08	
4	Bungur	*Lagerstroemis speciosa*	1	0.01	-4.53	0.05	
5	Glodokan Tiang	*Polyalthia longifolia*	6	0.06	-2.74	0.18	
6	Kerai Payung	*Filicium decipiens*	12	0.13	-2.05	0.26	
7	Ketapang	*Terminalia catappa*	1	0.01	-4.53	0.05	
8	Ketapang cendana	*Terminalia mantaly*	2	0.02	-3.84	0.08	
9	Ki Hujan	*Samanea saman*	2	0.02	-3.84	0.08	
10	Mahoni	*Swietenia mahagoni*	2	0.02	-3.84	0.08	
11	Mangga	*Mangifera indica*	2	0.02	-3.84	0.08	
12	Nangka	Artocarpus heterophyllus	3	0.03	-3.43	0.11	
13	Palem merah	*Ptychosperma coccinea*	18	0.19	-1.64	0.32	
14	Palem raja	*Roystonea regia*	2	0.02	-3.84	0.08	
15	Saga	*Adenanthera pavonina*	10	0.11	-2.23	0.24	
16	Tanjung	*Mimusops elengi*	4	0.04	-3.15	0.14	
			93	1.00	-53.19		

Table 6. CO_2 Absorption and Oxygen Production at Taman Macan, Ujung Pandang Subdistrict

No.	Species Name	Scientific Name	Number of Individuals	CO_2 Absorption (Ton/ha/Years)	O_2 Production (Ton/ha/Years)
1	Angsana	*Pterocarpus indicus*	25	7.18	5.22
2	Aren	*Arenga pinnata*	1	0.27	0.20
3	Beringin	*Ficus benjamina*	2	0.06	0.04
4	Bungur	*Lagerstroemis speciosa*	1	0.39	0.28
5	Glodokan Tiang	*Polyalthia longifolia*	6	0.81	0.59
6	Kerai Payung	*Filicium decipiens*	12	1.17	0.85
7	Ketapang	*Terminalia catappa*	1	0.14	0.10
8	Ketapang cendana	*Terminalia mantaly*	2	0.13	0.10
9	Ki Hujan	*Samanea saman*	2	0.94	0.69
10	Mahoni	*Swietenia mahagoni*	2	0.22	0.16
11	Mangga	*Mangifera indica*	2	0.02	0.01
12	Nangka	*Artocarpus heterophyllus*	3	0.10	0.07
13	Palem merah	*Ptychosperma coccinea*	18	0.63	0.45
14	Palem raja	*Roystonea regia*	2	0.46	0.33
15	Saga	*Adenanthera pavonina*	10	7.06	5.14
16	Tanjung	*Mimusops elengi*	4	0.45	0.33
Total			**93**	**20.05**	**14.58**

C. Taman Hasanuddin

Based on inventory and direct field measurements at Taman Hasanuddin, 16 species of tree and palm vegetation were identified. The dominant species included Ketapang Cendana (*Terminalia mantaly*), Tanjung (*Mimusops elengi*), Red Palm (*Ptychosperma coccinea*), and Angsana (*Pterocarpus indicus*). The results of the vegetation inventory are presented in Table 7.

The Shannon–Wiener diversity index (H') for tree vegetation was calculated at 2.05, which is classified as good and higher than that of Taman Pakui (H' = 1.42). This indicates that Taman Hasanuddin possesses a relatively balanced distribution of species and contributes to the ecological stability of the surrounding urban area. The diversity index for understory vegetation was 2.08, also classified as high, suggesting that ecological resilience is further supported at the shrub and ground cover levels. These findings highlight the park's potential role in sustaining biodiversity within a densely urbanized district. The CO_2 absorption and O_2 production capacity of the tree species at Taman Hasanuddin are presented in Table 8.

The ecological function of Taman Hasanuddin is further reflected in its carbon sequestration capacity. Vegetation in this park absorbs 22.72 tons of CO_2eq per hectare annually and produces 16.52 tons of O_2eq per hectare annually. Species such as *Vitex cofassus* (Bitti), *Pterocarpus indicus* (Angsana), and *Mimusops elengi* (Tanjung) make the most significant contributions due to their canopy structure and biomass. From a sustainable urban planning perspective, Taman Hasanuddin is strategically vital as it is located in the heart of Ujung Pandang, an area characterized by high-density land use, commercial activities, and traffic congestion. The presence of this park provides essential ecosystem services: improving air quality, reducing surface temperature, facilitating water infiltration, and offering a cooling atmosphere for surrounding communities. To maintain and enhance these benefits, management strategies should focus on increasing vegetation diversity with native species, strengthening routine maintenance, and ensuring that future urban development projects integrate and protect the ecological functions of this park.

D. Private Bukit Baruga Green Open Space, Manggala District

Based on inventory and direct measurements at the Private Bukit Baruga Green Open Space (RTH), 15 species of tree and palm vegetation were identified. The dominant species included *Swietenia mahagoni* (Mahogany) and *Samanea saman* (Rain Tree), which contributed the largest proportion of individuals. The results of the vegetation inventory are presented in Table 9.

Table 7. Terrestrial Flora (Vegetation) at Taman Hasanuddin, Ujung Pandang Subdistrict

No.	Species Name	Scientific Name	Ni	Ni/N	Ln Ni/N	Ni*Ln Ni/N	Diversity Index (H')
1	Angsana	*Pterocarpus indicus*	18	0.12	-2.15	0.25	2.05
2	Bitti	*Vitex cofassus*	17	0.11	-2.20	0.24	
3	Bungur	*Lagerstroemis speciosa*	4	0.03	-3.65	0.09	
4	Glodokan tiang	*Polyalthia longifolia*	3	0.02	-3.94	0.08	
5	Kelapa	*Cocos nucifera*	1	0.01	-5.04	0.03	
6	Kembang merak	*Caesalpinia pulcherrima*	1	0.01	-5.04	0.03	
7	Kerai Payung	*Filicium decipiens*	2	0.01	-4.34	0.06	
8	Ketapang cendana	*Terminalia mantaly*	45	0.29	-1.23	0.36	
9	Ki hujan	*Samanea saman*	4	0.03	-3.65	0.09	
10	Mahoni	*Swietenia mahagoni*	1	0.01	-5.04	0.03	
11	Mangga	*Mangifera indica*	1	0.01	-5.04	0.03	
12	Mengkudu	*Morinda citrifolia*	1	0.01	-5.04	0.03	
13	Nangka	*Artocarpus heterophyllus*	3	0.02	-3.94	0.08	
14	Palem merah	*Ptychosperma coccinea*	23	0.15	-1.90	0.28	
15	Saga	*Adenanthera pavonina*	1	0.01	-5.04	0.03	
16	Tanjung	*Mimusops elengi*	29	0.19	-1.67	0.31	
			154	1.00	-58.90		

Table 8. CO_2 Absorption and Oxygen Production at Taman Hasanuddin, Ujung Pandang Subdistrict

No.	Species Name	Scientific Name	Number of Individuals	CO_2 Absorption (Ton/ha/Years)	O_2 Production (Ton/ha/Years)
1	Angsana	*Pterocarpus indicus*	18	6.61	4.81
2	Bitti	*Vitex cofassus*	17	7.91	5.75
3	Bungur	*Lagerstroemis speciosa*	4	0.76	0.56
4	Glodokan tiang	*Polyalthia longifolia*	3	0.51	0.37
5	Kelapa	*Cocos nucifera*	1	0.07	0.05
6	Kembang merak	*Caesalpinia pulcherrima*	1	0.32	0.23
7	Kerai Payung	*Filicium decipiens*	2	1.47	1.07
8	Ketapang cendana	*Terminalia mantaly*	45	0.37	0.27
9	Ki hujan	*Samanea saman*	4	1.30	0.95
10	Mahoni	*Swietenia mahagoni*	1	0.28	0.20
11	Mangga	*Mangifera indica*	1	0.03	0.02
12	Mengkudu	*Morinda citrifolia*	1	0.01	0.01
13	Nangka	*Artocarpus heterophyllus*	3	0.17	0.12
14	Palem merah	*Ptychosperma coccinea*	23	0.61	0.44
15	Saga	*Adenanthera pavonina*	1	0.62	0.45
16	Tanjung	*Mimusops elengi*	29	1.68	1.23
Total			154	22.72	16.52

Table 9. Terrestrial Flora (Vegetation) at the Private Bukit Baruga Green Open Space

No.	Species Name	Ni	Ni/N	Ln Ni/N	Diversity Index (H')
1	*Durio zibethinus*	1	0.00	-5.74	0.02
2	*Anthocephalus macrophyllus*	1	0.00	-5.74	0.02
3	*Artocarpus heterophyllus*	4	0.01	-4.35	0.06
4	*Bauhinia purpurea*	1	0.00	-5.74	0.02
5	*Elaeis guineensis*	14	0.05	-3.10	0.14
6	*Mangifera indica*	39	0.13	-2.08	0.26
7	*Mimusops elengi*	28	0.09	-2.41	0.22
8	*Polyalthia longifolia*	13	0.04	-3.17	0.13
9	*Pterocarpus indicus*	2	0.01	-5.05	0.03
10	*Samanea saman*	65	0.21	-1.57	0.33
11	*Swietenia macrophylla*	8	0.03	-3.66	0.09
12	*Swietenia mahagoni*	91	0.29	-1.23	0.36
13	*Tabebuia aurea*	5	0.02	-4.13	0.07
14	*Terminalia catappa*	28	0.09	-2.41	0.22
15	*Terminalia mantaly*	11	0.04	-3.34	0.12
		311	1	-53.713453	2.08

The vegetation types cultivated in the Private Bukit Baruga Green Open Space (RTH) are predominantly Swietenia mahagoni (Mahogany) and Samanea saman (Rain Tree), which contributed the largest proportion of individuals. A total of 15 species of tree and palm vegetation were identified. The results of the vegetation diversity analysis show a tree species diversity index of 2.08, which is considered moderate and higher than that of Taman Pakui. In addition, the diversity index for understory plants was recorded at 3.63, which is categorized as high, indicating good ecosystem stability.

Based on spatial analysis through delineation of tree canopy coverage, the vegetation coverage percentages for the four study locations were obtained. Taman Pakui and Bukit Baruga RTH had coverage levels of 70% and 77%, respectively, while Taman Macan and Taman Hasanuddin demonstrated higher coverage of 90% and 97%, respectively, influenced by the larger sizes of these areas.

The CO_2 absorption and O_2 production analysis (Table 10) further demonstrates the ecological contribution of this RTH. The total absorption capacity of Bukit Baruga reached 45.99 tons of CO_2/ha/year with oxygen production of 32.49 tons O_2/ha/year, dominated by Mahogany and Rain Tree species. This highlights the important role of private green open spaces as urban carbon sinks. Vegetation in these areas also contributes to regulating the carbon and oxygen balance, improving soil properties, enhancing water absorption, and providing essential environmental services for urban ecosystems.

3.1.2. Terrestrial Fauna

The presence of fauna is an important indicator in assessing the environmental quality of Green Open Spaces (RTH), particularly in the context of sustainable urban planning. Fauna not only reflects the health of ecosystems but also plays a role in maintaining environmental balance, such as natural pest control, plant pollination, and seed dispersal. The diversity of fauna species, especially birds, insects (such as butterflies and bees), and small mammals (such as squirrels or bats), can serve as indicators of ecosystem quality in RTH. Urban fauna diversity has also been recognized globally as an ecological indicator of ecosystem health [19].

The fauna species found in Taman Pakui, Taman Macan, Taman Hasanuddin, and Private Bukit Baruga RTH consist of several groups, including mammals, reptiles, amphibians, birds (Aves), and insects (Insecta). Observations of terrestrial fauna indicate that insects are the most dominant class encountered in the study area. Several species of honeybirds and butterflies were found on flowering plants, feeding on nectar. Domesticated fauna, such as the cat (*Felis catus*), were also observed. According to the Ministry of Environment and Forestry Regulation No. P.106/MENLHK/SETJEN/KUM.1/12/ 2018, no protected terrestrial fauna species were found in the study area. A decline in fauna populations can be an early warning signal for the degradation of an area's ecological quality. Therefore, the integration of ecological functions and spatial planning needs to be designed with consideration of fauna habitat needs as part of the vision for a sustainable Makassar city.

Table 10. CO_2 Absorption and Oxygen Production at Bukit Baruga Private Green Open Space, Manggala Subdistrict

No.	Species Name	Scientific Name	Number of Individuals	CO_2 Absorption (Ton/ha/Years)	O_2 Production (Ton/ha/Years)
1	Durian	Durio zibethinus	1	0.42	0.31
2	Jabon	Anthocephalus macrophyllus	1	0.58	0.42
3	Jackfruit	Artocarpus heterophyllus	4	1.33	0.96
4	Bauhinia	Bauhinia purpurea	1	0.39	0.28
5	Oil Palm	Elaeis guineensis	14	2.74	1.99
6	Mango	Mangifera indica	39	4.11	2.98
7	Tanjung	Mimusops elengi	28	2.63	1.91
8	Glodokan Tiang	Polyalthia longifolia	13	1.25	0.90
9	Angsana	Pterocarpus indicus	2	1.25	0.91
10	Rain Tree	Samanea saman	65	11.45	8.33
11	Big-leaf Mahogany	Swietenia macrophylla	8	2.13	1.55
12	Mahogany	Swietenia mahagoni	91	14.33	10.41
13	Tabebuia	Tabebuia aurea	5	0.73	0.53
14	Ketapang	Terminalia catappa	28	1.90	1.38
Total			311	45.99	32.49

3.1.3. Thermal Humidity Index (THI)

The Thermal Humidity Index (THI) is a key indicator of microclimate conditions in urban green open spaces. The concept of thermal comfort has long been studied through the Predicted Mean Vote (PMV) model [18], which was later adapted for outdoor tropical settings [18]. In this study, THI is used as a parameter to evaluate the effectiveness of RTH in providing thermal comfort and regulating the urban microclimate.

A. Taman Pakui

The average Thermal Humidity Index (THI) in the Green Open Space of Taman Pakui Sayang, as presented in the diagram above, falls within the moderate comfort category, with an average THI value of 27.9. This is due to the very high air temperature, which results in relatively high THI values. THI serves as an important parameter for evaluating the effectiveness of the park as a microclimate cooler and a provider of comfortable spaces amidst urbanization. In the context of sustainable urban planning, THI helps ensure that the Taman Pakui RTH not only beautifies the city of Makassar but also functions optimally in enhancing the quality of life for urban residents. Figure 5 shows the recorded temperature variations during the morning, afternoon, and evening, while Figure 6 illustrates the corresponding THI values that reflect thermal comfort conditions in the park.

B. Taman Macan

The average Thermal Humidity Index (THI) in the Green Open Space of Taman Macan varies significantly. As the THI value increases, the comfort category decreases, indicating reduced comfort. From the diagram above, it can be observed that the average THI over five days of measurement was 28.1, which falls within the moderate category. Figure 7 presents the daily temperature variations recorded in the morning, afternoon, and evening, while Figure 8 shows the corresponding THI values throughout the observation period. The finding of a moderate THI category in Taman Macan suggests that Green Open Spaces in Makassar have not yet fully optimized thermal comfort. To support sustainable urban planning, there is a need for ecological and microclimate-based design interventions, as well as the utilization of THI data in planning and managing Green Open Spaces that are more adaptive to climate change and the needs of the community.

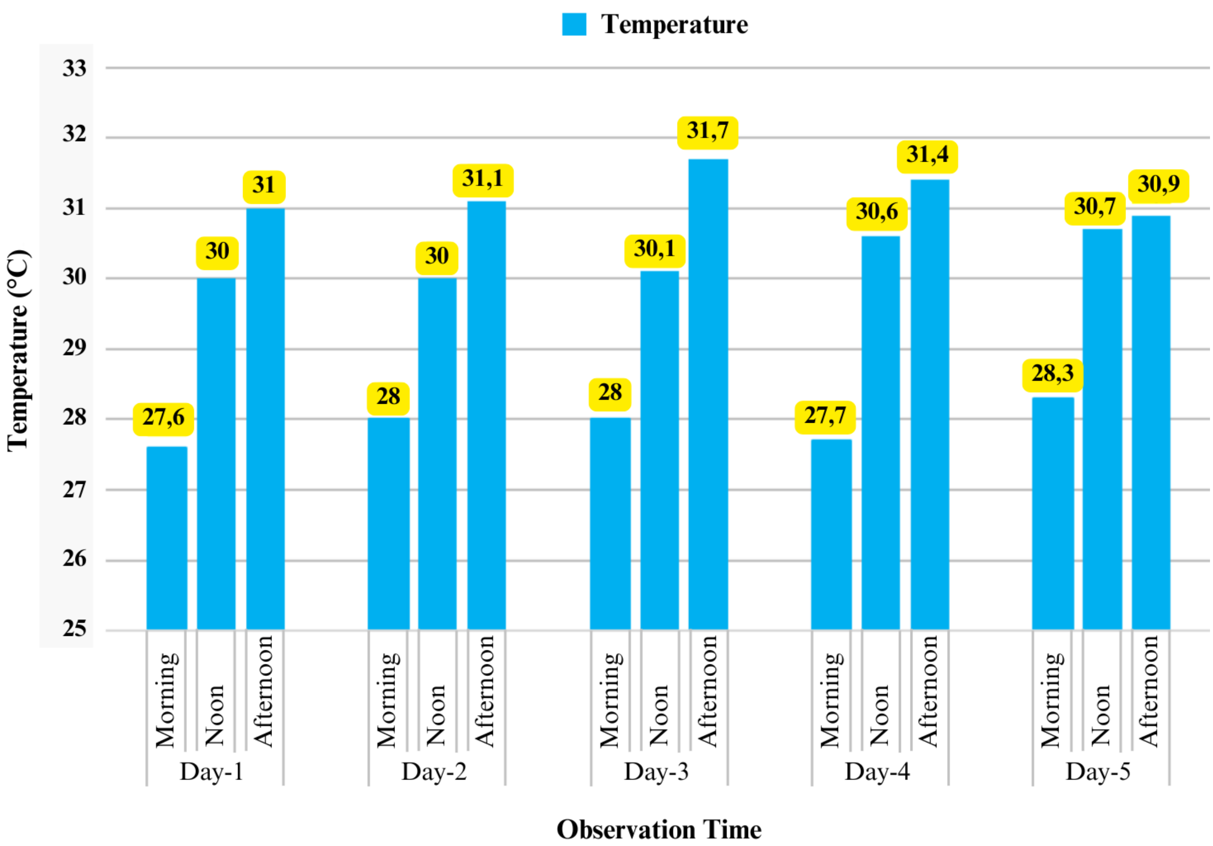

Figure 5. Comparison of Daily Temperature Measurements in the Morning, Afternoon, and Evening at Taman Pakui Sayang

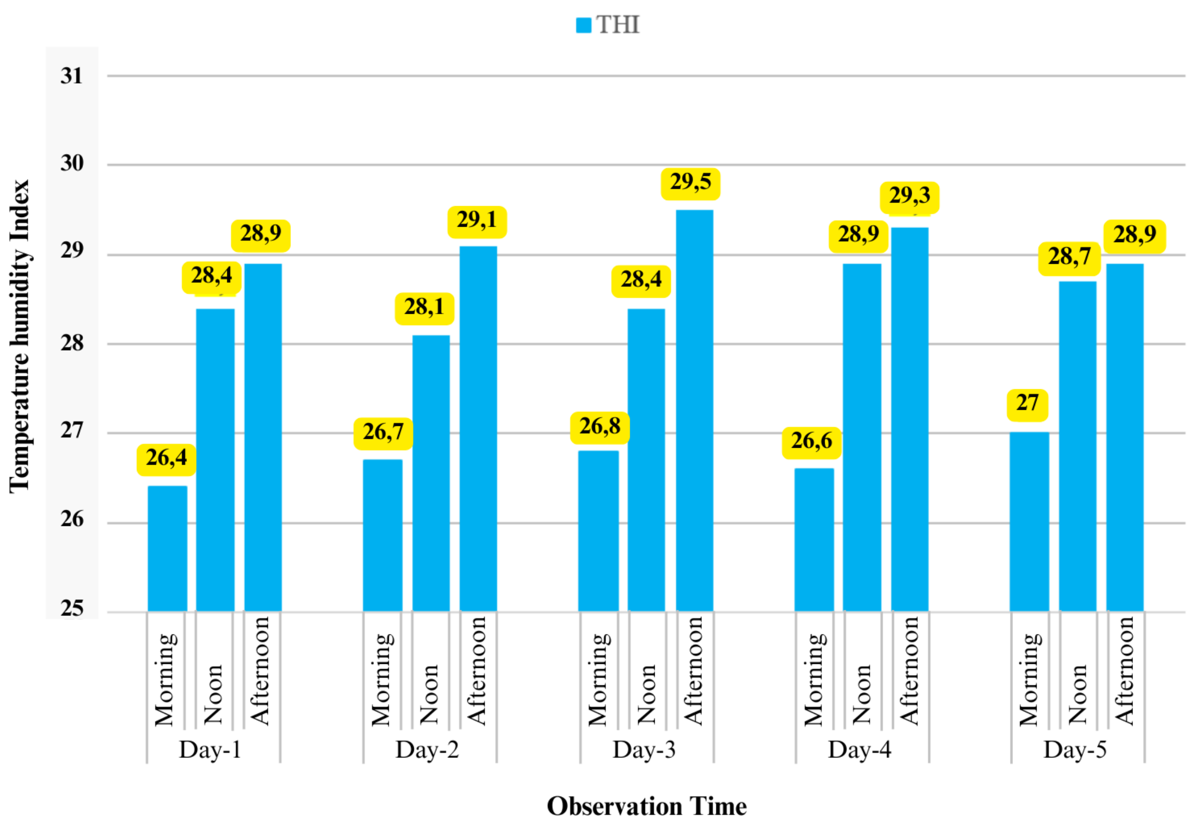

Figure 6. Comparison of Daily THI Values Measured in the Morning, Afternoon, and Evening at Taman Pakui Sayang

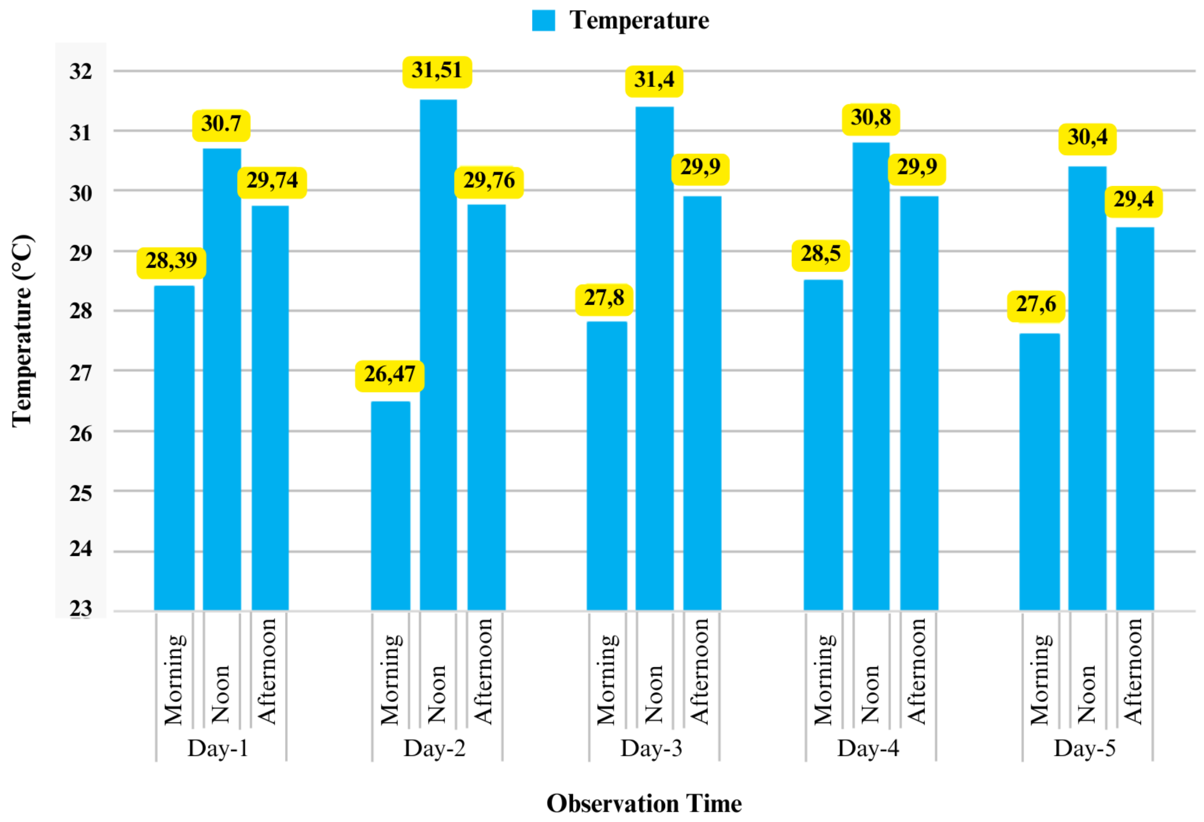

Figure 7. Comparison of Daily Temperature Measurements in the Morning, Afternoon, and Evening at Taman Macan

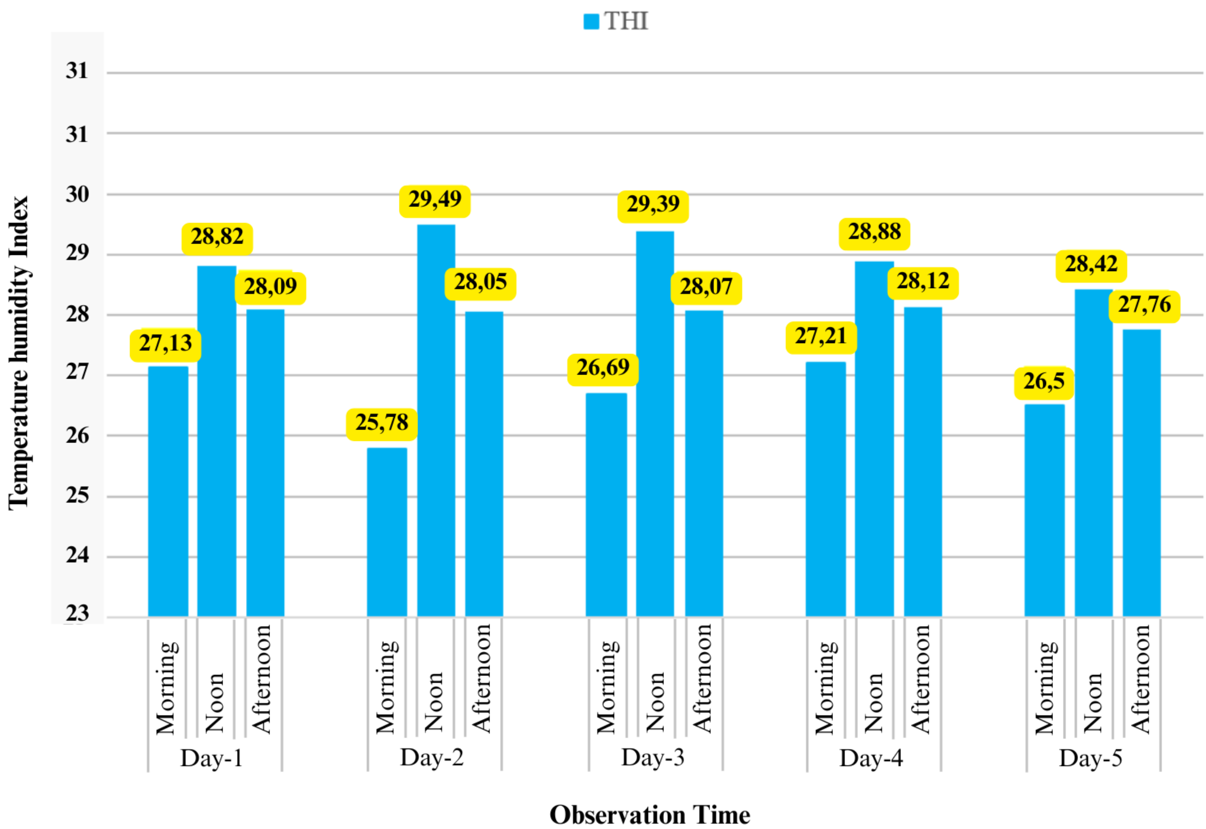

Figure 8. Comparison of Daily THI Values Measured in the Morning, Afternoon, and Evening at Taman Macan

C. Taman Hasanuddin

The average Thermal Humidity Index (THI) at Taman Hasanuddin varies significantly. The highest THI value occurred during the afternoon on the fourth day of measurement, with a value of 28.35. As the THI value increases, the comfort category decreases, indicating reduced comfort. From the diagram above, it can be seen that the average THI over five days of measurement falls within the comfortable category. Figure 9 presents the daily temperature patterns recorded in the morning, afternoon, and evening, while Figure 10 shows the corresponding THI values across the same time intervals. The comfortable average THI over five days of measurement at Taman Hasanuddin indicates that this park has made a positive contribution to thermal comfort in the city. Taman Hasanuddin has effectively performed its role as a green open space supporting a comfortable microclimate, although fluctuations during the afternoon should be monitored. In the framework of sustainable urban planning in Makassar, this park serves as a concrete example of the importance of integrating Green Open Spaces into city planning, both in terms of ecological and social functions.

D. Hutan Private Bukit Baruga

The thermal neutrality data of the Bukit Baruga Private Forest are presented in Table 11.

The THI results for the Bukit Baruga Private Forest show that the air temperature in residential houses without shading plants from 06:00 to 18:00 WITA averaged 30.39 ℃, with a maximum value of 31.27 ℃ and a minimum value of 29.72 ℃. In contrast, residential houses with shading plants showed an average of 29.72 ℃, with a maximum of 30.15 ℃ and a minimum of 28.96 ℃. The results indicate that the temperatures in these residential houses are well above the comfort zone, and it can be concluded that the thermal comfort condition for residences in the Bukit Baruga Antang Housing area is above the comfort zone (> 27.1 ℃), compared to the thermal comfort standard of SNI T-14-1993-03, which specifies a nearly comfortable range of 25.8 ℃–27.1 ℃.

The measurements in Bukit Baruga Housing show that without vegetation intervention, the residential area becomes significantly hotter and thermally uncomfortable. This emphasizes that shading vegetation is a crucial component in creating thermal comfort and supporting urban sustainability.

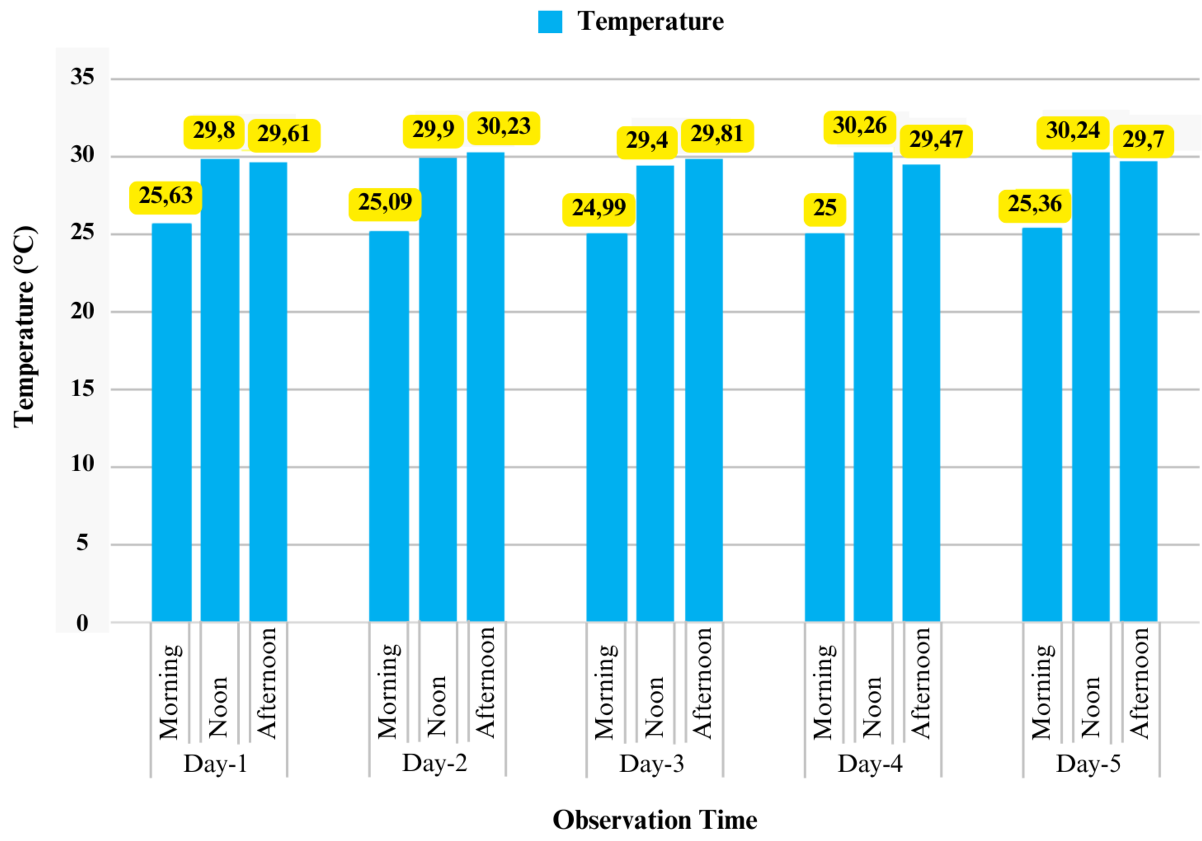

Figure 9. Comparison of Daily Temperature Measurements in the Morning, Afternoon, and Evening at Taman Hasanuddin

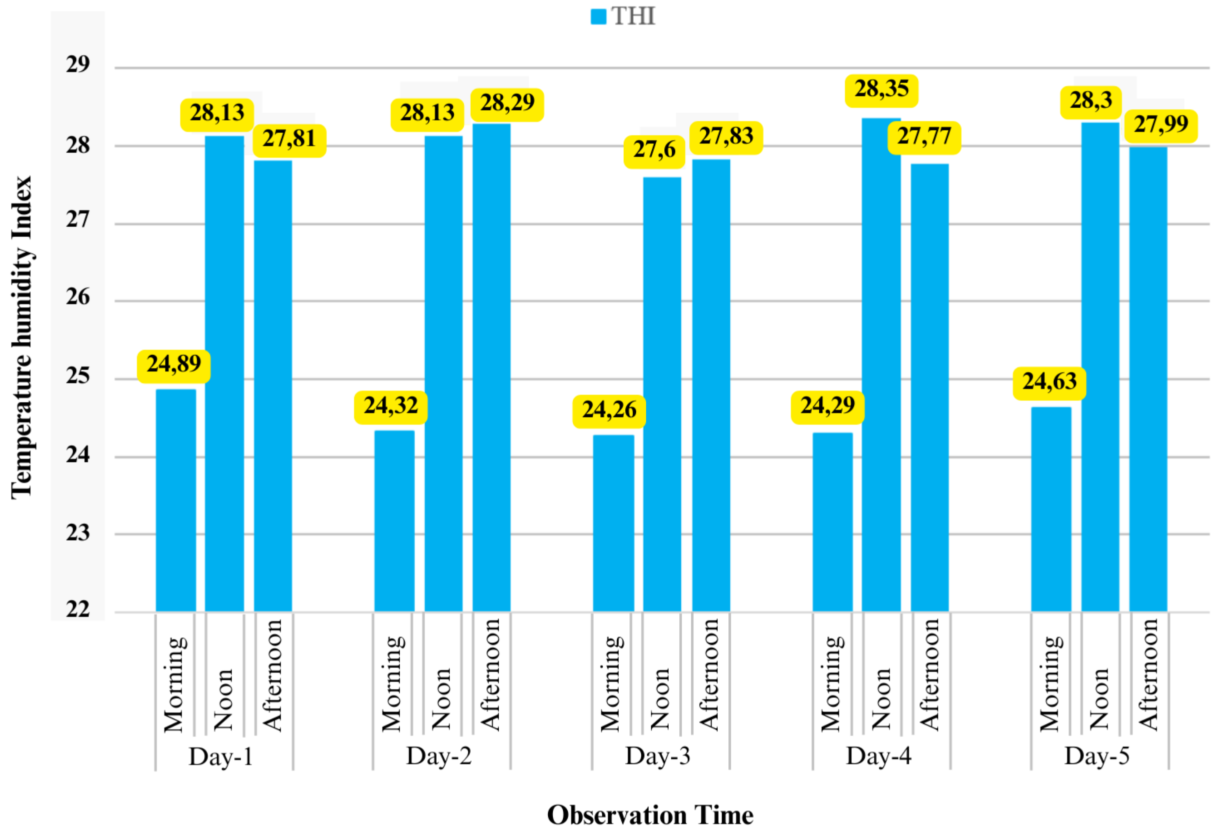

Figure 10. Comparison of Daily THI Values Measured in the Morning, Afternoon, and Evening at Taman Hasanuddin

Table 11. Data Kenetralan Termal Hutan Privat Bukit Baruga

Criteria	Score	No Shade Tress (%)	With Shade Tree (%)
Cold	-3	0	0
Cool	-2	0	0
Slightly Cool	-1	0	1,8
Thermally Neutral	0	25	91,1
Slightly Warm	1	75	7,1
Warm	2	0	0
Hot	3	0	0

Source: SNI T-14-1993-03 on Building Thermal Comfort Standards.

4. Conclusions

The environmental quality of Green Open Spaces (RTH) in Makassar City, such as Taman Pakui, Taman Macan, Taman Hasanuddin, and Bukit Baruga Private Forest, is considered good based on ecological indicators, including vegetation cover, air and water quality, and low environmental disturbances. However, in terms of quantity, the presence of RTH is still inadequate, covering only 11.47% of the city's total area in 2023, far below the national target of 30%.

This condition underscores the importance of expanding both the area and distribution of RTH as part of a sustainable urban planning strategy. RTH should be viewed not only as an aesthetic or recreational element but also as an ecological infrastructure that plays a crucial role in maintaining environmental balance, supporting climate resilience, and improving the quality of life for urban residents.

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