Evaluation of Green Open Space Needs Based on Oxygen Requirements: Implementation of the 13th Goal of The SDGs 2030

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ABSTRACT

Kendari City is an area experiencing rapid population growth and urbanization. Over the past two decades, the population growth rate in this area has been 1.70%/year. This condition has resulted in the conversion of green land into residential, commercial, and industrial land, which has an impact on the decline in the availability of Green Open Space and has an effect on the phenomenon of climate change. This study utilizes Sentinel 2A satellite imagery and the Normalized Difference Vegetation Index (NDVI) transformation to map the distribution of Green Open Space in Kendari City. Identification of the need for Green Open Space is carried out based on oxygen needs using the modified Gerakis (1974) formula. The results of the study show that: 1) Kendari City has a total area of Green Open Space based on NDVI analysis of 19,458.94 hectares; 2) based on the analysis of oxygen needs for residents, animals, and motorized vehicles, the total area of Green Open Space needed in Kendari City is 1,927.79 hectares; and 3) the implementation of the results of this study can support the achievement of Goal 13 of the SDGs 2030 through strengthening environmental policies, increasing public awareness, and involving local communities in environmental conservation efforts. This shows that the green open space available in Kendari City is sufficient to accommodate oxygen needs so that additional green open space is not needed. Therefore, the focus of Kendari City's future policies can be shifted to the management and optimization of existing green open spaces to support broader sustainable development goals.

Keywords: *green open space; oxygen requirements; SDGs 2030; Kendari City*.

ABSTRAK

Kota Kendari adalah wilayah yang mengalami pertumbuhan penduduk dan urbanisasi yang pesat. Selama dua decade terakhir, laju pertumbuhan penduduk di wilayah ini sebesar 1,70%/tahun. Kondisi ini mengakibatkan terjadinya alih fungsi lahan hijau menjadi lahan permukiman, komersial, dan industri sehingga berdampak pada penurunan ketersediaan Ruang Terbuka Hijau dan berefek pada fenomena perubahan iklim. Penelitian ini memanfaatkan citra satelit Sentinel 2A dan transformasi Normalized Difference Vegetation Index (NDVI) untuk memetakan sebaran Ruang Terbuka Hijau di Kota Kendari. Identifikasi kebutuhan luasan Ruang Terbuka Hijau (RTH) dilakukan berdasarkan kebutuhan oksigen dengan rumus Gerakis (1974) yang telah dimodifikasi. Hasil penelitian menunjukkan bahwa: 1) Kota Kendari memiliki luas total RTH berdasarkan analisis NDVI sebesar 19.458,94 hektare; 2) berdasarkan analisis kebutuhan oksigen bagi penduduk, hewan, dan kendaraan bermotor, total luas RTH yang dibutuhkan di Kota Kendari adalah 1.927,79 hektare; dan 3) implementasi hasil penelitian ini dapat mendukung pencapaian Tujuan ke-13 SDGs 2030 melalui penguatan kebijakan lingkungan, peningkatan kepedulian masyarakat, dan pelibatan masyarakat setempat dalam upaya pelestarian lingkungan. Hal ini menunjukkan bahwa RTH yang tersedia di Kota Kendari sudah cukup untuk menampung kebutuhan oksigen, sehingga belum diperlukan penambahan RTH. Oleh karena itu, fokus kebijakan Kota Kendari ke depan dapat dialihkan pada pengelolaan dan optimalisasi RTH yang ada untuk mendukung tujuan pembangunan berkelanjutan yang lebih luas.

Kata Kunci: *ruang terbuka hijau; kebutuhan oksigen; SDGs 2030; Kota Kendari.*

INTRODUCTION

Green Open Space is a general term that refers to various types of green facilities accessible to the public, such as urban forests, city parks, green lanes, gardens or agricultural land, public cemeteries, sports fields, railway embankments, and riverbanks (Cole et al., 2019). In Undang-Undang Republik Indonesia No. 26 of 2007 on Spatial Planning, it is explained that the proportion of green open space in urban areas should be at least 30% of the total city area. This proportion consists of 20% public green open space and 10% private green open space (Adillasintani, 2013; Santi et al., 2017). The determination of the size of green open space aims to create a balance and harmony between the natural environment and the built environment.

In general, the availability of green open spaces in cities across Indonesia does not yet comply with the established regulations. The available green open spaces in most Indonesian cities range only from 6% to 8% (Arsyad, 2017). This is a consequence of the rapid innovation in urban development and expansion in recent times, which does not take environmental aspects into account and tends to reduce green open areas (Kusumandari, 2014), leading to a decrease in the amount of previously sufficient available vacant land (Rijal, 2008). A 50% reduction in green open spaces causes an increase in temperature by 0.4-1.8°C, whereas a 50% increase in green open spaces can reduce the temperature by 0.2-0.5°C (Effendi, 2007).

The city of Kendari, located in Southeast Sulawesi Province, is experiencing rapid population growth and urbanization. Between 2010 and 2020, the population growth rate in Kendari was recorded at 1.70% per year (Purwanto, 2022). This situation has led to the conversion of green spaces into residential, commercial, and industrial areas, which has inevitably reduced the availability of green open spaces in Kendari.

According to data from the Kendari City Central Bureau of Statistics, the average air temperature in Kendari City in 2021 reached 32.67°C (BPS Kota Kendari, 2022), which falls into the high-temperature category for surface land temperature classification. With such high temperatures, Kendari City requires green open spaces to help mitigate climate change. Green open spaces play a role in absorbing CO_2 and regulating the microclimate, thereby reducing the impacts of extreme temperatures and the risk of flooding, which frequently occurs in Kendari City.

With the increasingly evident effects of climate change, it is crucial to access detailed and up-to-date data on green open spaces. Evaluating green open spaces as a database using Sentinel 2A imagery technology is not merely a measurement tool but a fundamental pillar in sustainable urban planning. Furthermore, by understanding the oxygen needs fulfilled by green open spaces, we can ensure that the ecosystem balance is maintained, helping to preserve air quality and improve the quality of life for the community. Thus, the evaluation of green open spaces becomes not only an efficient urban management instrument but also a proactive step in addressing climate change challenges more holistically. Based on the above description, the objectives of this study are: 1) to analyze the distribution of green open spaces in Kendari City using Sentinel 2A imagery; 2) to analyze the need for green open spaces based on oxygen requirements in Kendari City; and 3) to describe the implementation of the 13th goal of the sdgs 2030 based on the need for green open spaces in Kendari City.

METHOD

This research was conducted from August 2022 to October 2022 in Kendari City, Southeast Sulawesi Province, located at 3°54'40" S - 4°5'05" S and 122°26'33" E - 122°39'14" E. The type of research conducted was a case study, involving in-depth analysis of data and facts related to the research object.

The method used combined field research and desk research. In this study, Sentinel 2A imagery was first corrected radiometrically and geometrically. The Sentinel 2A imagery is used in this study due to its advantages in having good spatial resolution (up to 10 meters), a wide spectral coverage with 13 bands, and the ability to capture data in the Near-Infrared (NIR) and Shortwave Infrared (SWIR) regions, which are highly useful for vegetation analysis. Additionally, Sentinel 2A has a high revisit frequency of every 5 days, enabling more accurate land change monitoring compared to satellites like Landsat, which only captures data every 16 days. Another advantage is its free and open-access data. With these features, Sentinel 2A is an efficient and accurate

choice for mapping and monitoring green open space in Kendari City. Subsequently, the normalized difference vegetation index (NDVI) value was obtained as a parameter to distinguish between vegetation and non-vegetation. The classification of NDVI is shown in Table 1.

Table 1. NDVI Classification

NDVI Value	Density Level
-1 – 0.12	Non-vegetated land
0.12 – 0.22	Very low greenness
0.22 – 0.42	Low greenness
0.42 – 0.72	Moderate greenness
.0,72 - 1	High greenness

Then, to determine the area of green open space based on oxygen requirements, the modified Gerakis formula was used as follows.

$$.Lt \frac{(At+Bt+Ct)(\frac{gram}{day})}{54\left(\frac{dry\ weight\ gram}{m^2}\right)\times 0.9375\left(\frac{gram\ O2}{dry\ weight\ gram}\right)\times 2}$$

Explanation:
- Lt : The area of green open space in year t (m²).
- At : The amount of oxygen required by the population in year t.
- Bt : The amount of oxygen required by motor vehicles in year t.
- Ct : The amount of oxygen required by livestock in year t.
- 54 : The constant value indicating that 1 m² of land produces 54 grams of dry plant weight/day.
- 0,9375 : The constant value indicating that 1 gram of dry plant weight is equivalent to the production of 0.9375 grams of oxygen.
- 2 : The number of seasons in Indonesia.

Table 2. The Oxygen Requirement of Each Oxygen Consumer

Consumer	Category	Oxygen Requirement (kg/day)	Description
Humans		0.864	
Motor Vehicles	Passenger car	11.63	3 hours/day
	Bus	45.76	2 hours/day
	Truck	22.88	2 hours/day
	Motorcycle	0.58	1 hour/day
Livestock	Cow	1.702	
	Goat	0.314	
	Chicken	0.167	
	Pig	1.24	
	Buffalo	1.702	
	Duck	1.702	

The assumptions used in this study are as follows: 1) each person consumes the same amount of oxygen every day, which is 600 liters or 0.864 kg/day; 2) the oxygen requirements for motor vehicles are as follows: 11.63 kg/hour for passenger cars with an operating time of 3 hours/day, 22.88 kg/hour for trucks, 45.76 kg/hour for buses, and 0.58 kg/hour for motorcycles; 3) the active time for motor vehicles is 3 hours/day for passenger vehicles, 2 hours/day for buses and trucks, and 1 hour/day for motorcycles; 4) motor vehicles operate only in the city of Kendari; 5) the oxygen requirements for livestock are 1.702 kg/day for buffalo and cattle, 0.314 kg/day for goats, and 0.167 kg/day for chickens; 6) the oxygen requirements for industries are not considered; and 7) the oxygen supply is provided only by plants.

RESULT
Land Cover Classification in Kendari City

The land cover classification results were obtained from the NDVI values on Sentinel 2A imagery. NDVI is an index derived from the ratio of NIR and Red spectrum and is widely used in vegetation phenology, including for land cover type classification (Adole et al., 2016;

Julien and Sobrino, 2009; Pastor-Guzman et al., 2018).

The NDVI values are generated from a mathematical equation combining several bands in satellite image data. These bands are band 4 (Red) and band 5 (NIR) (As-Syakur and Adnyana, 2009; Kasmin et al., 2016), selected because their measurements are most influenced by leaf chlorophyll absorption (Prahasta, 2008; Kasmin et al., 2016). The NDVI values range from -1 (typically water) to +1 (strongest vegetative growth) (Waas and Nababan, 2010).

The analysis of NDVI values on Sentinel 2A imagery reveals five land cover type classifications in Kendari City: water bodies, built-up land, open land, grassland vegetation, and forest vegetation. The extent of forest vegetation and grassland vegetation influences the availability of oxygen in Kendari City. The area of each land cover class can be seen in Table 3 below.

Table 3. Land Cover Classification in Kendari City Based on Sentinel 2A Imagery

No.	Land Cover Type	Area (ha)	Percentage (%)
1	Water body	74.53	0.28
2	Built-up land	1,887.27	7.03
3	Open land	5,410.77	20.17
4	Grassland vegetation	7,360.43	27.43
5	Forest vegetation	12,098.5	45.09
	Total	**26,831.50**	**100**

Source: Primary Data Analysis Results, 2022.

Based on Table 3 above shows that the dominant land cover type in Kendari City is forest vegetation covering an area of 12,098.5 hectares (45.09%), while the least dominant is water bodies covering an area of 74.53 hectares (0.28%). Furthermore, the distribution of land cover in Kendari city can be seen in the following Figure 1.
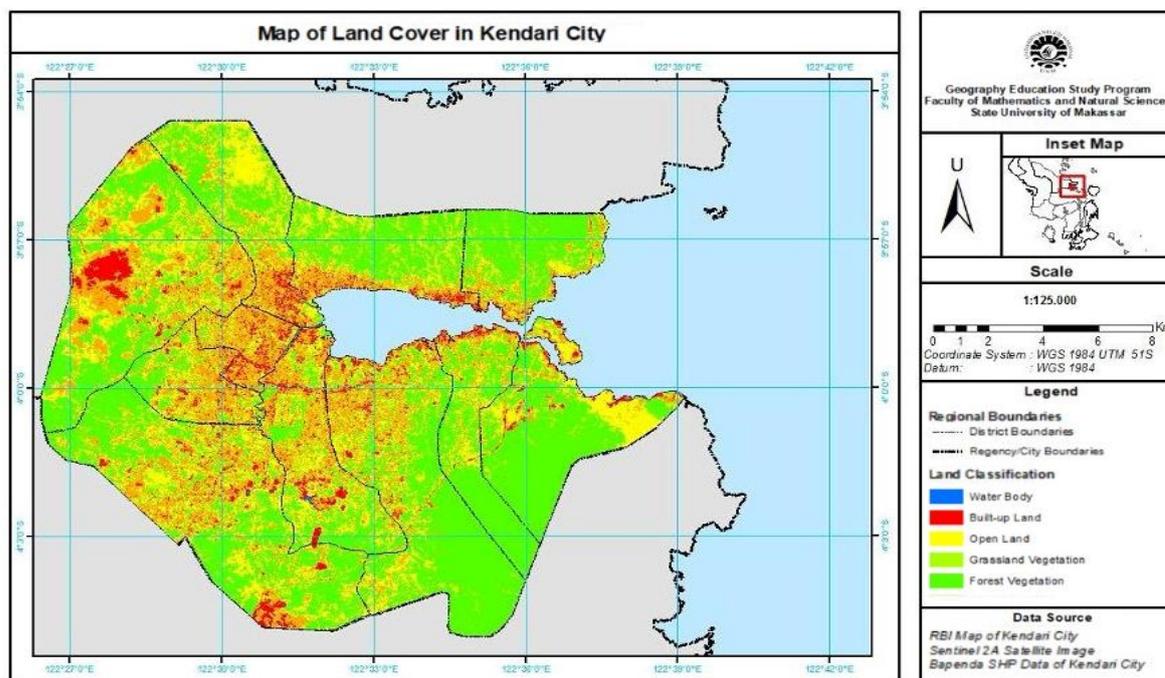
Figure 1. Map of Land Cover in Kendari City (Result of Sentinel 2A Image Analysis, 2022)

Distribution of Green Open Spaces in Kendari City Based on Sentinel 2A Imagery

In this study, the green open space referred to is the entire range of land covers consisting of open land, grassland vegetation, and forest vegetation that are used openly. Green open space encompasses plants that grow naturally as well as those intentionally planted.

To determine the distribution and extent of green open space areas that can produce oxygen, the NDVI values are used in Sentinel

2A images. The NDVI values range from -1 to 1. The area of green open space and non-green open space in Kendari City can be seen in the following Table 4.

Table 4. Green Open Space and Non-Green Open Space Areas in Kendari City Based on Sentinel 2A Imagery.

No.	District	Green Open Space	Non-Green Open Space
1.	Abeli	1,313.56	245.10
2.	Nambo	2,240.09	307.03
3.	Poasia	3,206.93	913.04
4.	Kambu	1,324.35	828.59
5.	Baruga	3,472.53	1,254.81
6.	Wua-Wua	267.67	861.52
7.	Kadia	227.41	488.09
8.	Puuwatu	2,893.74	1,386.99
9.	Mandonga	1,554.63	467.26
10.	Kendari Barat	1,593.71	389.27
11.	Kendari	1,364.32	230.86
	Total	**19,458.94**	**7,372.56**
	Total Area of Kendari City	**26.831,50**	

Source: Primary Data Analysis Results, 2022.

Based on Table 4 above shows that based on the Sentinel 2A image analysis results, the area of Kendari City is 26,831.5 hectares, with green open spaces covering 19,458.94 hectares (72.52%) and non-green open spaces covering 7,372.56 hectares (27.48%). Furthermore, the largest green open space is located in the Baruga District, covering 3,472.53 hectares, while the Kadia District is the area with the least green open space, covering 227.41 hectares. For a clearer understanding, the distribution of green open spaces in Kendari City based on the Sentinel 2A image can be seen in the following Figure 2.
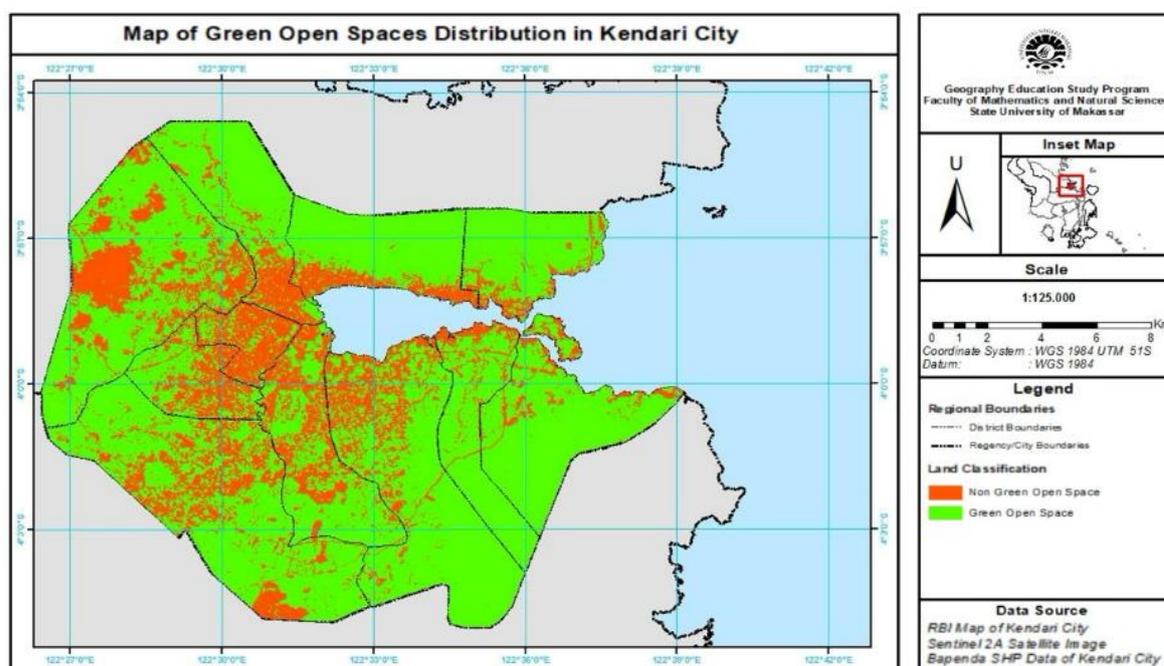
Figure 2. Map of Green Open Spaces Distribution in Kendari City

Figure 3. Condition of Green Open Spaces in Kendari City (Survey Results, 2022)

The Need for Green Open Spaces Based on Oxygen Requirements in Kendari City

Each hectare of green open space is estimated to produce 0.6 tons of O_2 for consumption by 1,500 people per day, allowing them to breathe comfortably (Wisesa, 1988). Furthermore, 1 hectare of green open space is capable of absorbing CO_2 emitted by 2000 humans or 5m^2 per person (Mangunsong and Sihite, 1994). The oxygen requirement referred to in this study is the oxygen used by humans, livestock, and motor vehicles.

Oxygen Requirement for Population

Humans oxidize 3000 calories/day from their food, using 600 liters of O_2 and producing 450 liters of CO_2. Typically, humans require 600 liters of O_2, equivalent to 864 grams (0.864 kg) of O_2/day. The oxygen (O_2) requirement based on the population of Kendari City can be seen in the following Table 5.

Table 5. Oxygen Requirement Based on the Population in Kendari City

No.	District	Total Population	Oxygen Requirement (kg/day)	∑ Oxygen Requirement (kg/day)
1	Mandonga	38,509		33,271.78
2	Baruga	31,099		26,869.54
3	Puuwatu	38,502		33,265.73
4	Kadia	38,062		32,885.57
5	Wua-Wua	31,912		27,571.97
6	Poasia	37,158	0.864	32,104.51
7	Abeli	17,003		14,690.59
8	Kambu	23,219		20,061.25
9	Nambo	11,138		9,623.23
10	Kendari	29,510		25,496.64
11	Kendari Barat	44,684		38,606.98
	Total	**340,796**	**0.864**	**294,447.74**

Source: Data Analysis Results, 2022.

Based on Table 5 above shows that the overall O_2 requirements of the population in Kendari city amount to 294,447.74 kg/day. Kendari Barat district is the area with the highest O_2 demand, namely 38,606.98 kg/day, while the Nambo district is the area with the lowest O_2 demand, which is 9,623.23 kg/day.

Oxygen Requirements for Livestock

Animals are living beings that require oxygen for various activities, and the amount of oxygen needed varies for each type of animal and its activities. The oxygen requirement based on the number of livestock in Kendari City can be seen in Table 6 below.

Tabel 6. Oxygen Requirements Based on the Number of Livestock in Kendari City

No.	Livestock Type	Quantity	Oxygen Requirement (kg/day)	∑ Oxygen Requirement (kg/day)
1	Cow	3,699	1,702	6,295.70
2	Buffalo	39	1,702	66.38
3	Goat	4,518	0,314	1,418.65
4	Duck	2,480	1,702	4,220.96
5	Chicken	1,783,485	0,167	297,842
6	Pig	19	1,24	23.56
	Total	**1,794,240**		**309,867.24**

Source: Primary Data Analysis Results, 2022.

Based Table 6 above shows that the overall oxygen equirement for livestock in Kendari City is 309,867.24 kg/day. Among the livestock types, chickens require the highest amount of O_2, specifically 297,842 kg/day, while pigs have the lowest O_2 requirement at 23.56 kg/day.

Oxygen Requirements for Motor Vehicles

Every motorized vehicle requires a combustion process requires oxygen. The amount of oxygen needed depends on the type of fuel used. Oxygen requirements based on the number of motorized vehicles can be seen in the following Table 7.

Table 7. Oxygen Requirements for Motor Vehicles in Kendari City

No.	Motor Vehicles Type	Quantity	Oxygen Requirement (kg/day)	∑ Oxygen Requirement (kg/day)
1	Passenger car	50,478	11.63	587,059.14
2	Bus	143	45.76	6,543.68
3	Truck	23,819	22.88	544,978.72
4	Motorcycle	360,336	0.58	208,994.88
	Total	**434,776**		**1,347,576.42**

Source: Primary Data Analysis Results, 2022.

Based on Table 7 above shows that, in general, the oxygen requirement for motor vehicles in the Kendari City is 1,347,576.42 kg/day. Passenger cars are the type of motor vehicle that requires the highest amount of O_2, which is 587,059.14 kg/day, while buses are the motor vehicles with the lowest O_2 requirement, which is 6,543.68 kg/day. So, the green open space area in Kendari City based on oxygen requirements is 1.927,79 ha.

Table 8. The Need for Green Open Spaces Based on Oxygen Requirements in Kendari City

No.	Consumer	∑ Oxygen Requirement (kg/day)	The Need for Green Open Spaces Based on Oxygen Requirements (ha)	Green Open Spaces Existing NDVI (ha)
1	Populations	294,447.74		
2	Motor Vehicles	1,347,576.42	1,927.79	19,458.94
3	Livestock	309,867,243		

Source: Primary Data Analysis Results, 2022.

Based Table 8 above shows that based on the oxygen demand analysis, the total area of green open space needed in the city of Kendari is 1,927.79 hectares. Furthermore, based on the three consumer classifications, it is evident that motor vehicles are the most dominant oxygen consumers, requiring 1,347,576.42 kg/day, whereas the oxygen demand for humans is the smallest, at 298,175.04 kg/day. Currently, the green open space in Kendari City, based on the NDVI analysis, covers an area of 19,458.94 hectares. This indicates that the available green open space in Kendari City is sufficient to accommodate the oxygen required, and thus, there is no need for additional green open space at this time.

Implementation of the 13th Goal of the SDGs 2030 Based on the Need for Green Open Spaces in Kendari City

The implementation of the 13th of the SDGs 2030, which focuses on Climate Action, in Kendari City can be seen through efforts to utilize green open spaces to support a healthy

and sustainable environment. The implementation of the 13th Goal of the SDGs 2030 in Kendari City, based on data on available green open spaces and oxygen requirements, can be seen in the following Table 9.

Table 9. Implementation of the 13th Goal of the SDGs 2030 Based on the Need for Green Open Spaces in Kendari City

Target Goal 13 of SDGs	Description of Target	Implementation of Green Open Space Analysis Results in Kendari City
13.1	To strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.	This study shows that the extent of green open spaces in Kendari City is sufficient for oxygen needs, contributing to improved air quality and resilience to climate change.
13.2	Integrating climate change measures into national policies, strategies, and planning.	Can be used by local governments to formulate policies that support the preservation of green open spaces as part of climate change mitigation strategies, such as: 1) zoning regulations for example, green open space areas, water catchment areas, no-build zones, and others; 2) incentives for green open space development; 3) green building regulations; 4) utilization of vacant land; and 5) park adoption programs.
13.3	Enhancing education, raising awareness, and building human and institutional capacities related to mitigation, adaptation, impact reduction, and early warning of climate change.	To serve as a foundation for public education programs on the importance of green open spaces in mitigating climate change and providing oxygen, such as: 1) mass media campaigns; 2) workshops and seminars; 3) integrating topics on green open spaces and environmental conservation into school curricula; 4) tree planting; 5) educational tours; 6) organizing environmental-related competitions; 7) community group outreach; 8) developing applications or websites providing information on green open spaces; 9) using AR/VR technology to provide interactive experiences about green open spaces and the importance of environmental conservation; and 10) engaging companies in Corporate Social Responsibility (CSR) programs that support the preservation of green open spaces.
13. a	Implementing the commitments of developed countries under the United Nations Framework Convention on Climate Change to mobilize jointly $100 billion per year by 2020 from all sources to address the needs of developing countries in the context of beneficial mitigation actions and transparency in implementation, and fully operationalizing the Green Climate Fund through capitalization of the fund as soon as possible.	To assist in identifying local needs that support mitigation actions at national and international levels.

Target Goal 13 of SDGs	Description of Target	Implementation of Green Open Space Analysis Results in Kendari City
13.b	Promoting mechanisms to enhance effective planning and management capacities related to climate change in least developed countries, small island developing states, including a focus on women, youth, and local marginalized communities.	To serve as a basis for engaging local communities through active participation, education, and collaboration with various stakeholders in programs for the protection and preservation of green open spaces, with a focus on inclusivity and sustainability.

Overall, research on the need for green open spaces in Kendari City shows that Kendari has sufficient capacity to meet oxygen requirements and significantly contributes to climate change mitigation. Implementing these research findings can support the achievement of SDG 13 targets by strengthening environmental policies, increasing public awareness, and engaging local communities in environmental conservation efforts.

DISCUSSION

This research has evaluated the need for green open spaces based on oxygen requirements in Kendari City. The results of the data analysis indicate that Kendari City has good environmental support capacity ecologically, with a green open space area reaching 19,458.94 hectares or 72.52% of the total city area, illustrating its strong position in environmental conservation. This aligns with the guidelines of Republic of Indonesia Law Number 26 of 2007 on Spatial Planning, stating that the proportion of green open spaces in urban areas should be at least 30% of the city's total area. This proportion of green open spaces in urban areas consists of 20% public green open spaces and 10% private green open spaces (Adillasintani, 2013; Santi et al., 2017). Furthermore, in Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 05/PRT/M/2008 concerning Guidelines for the Provision and Utilization of Green Open Spaces in Urban Areas, it is explained that for comfortable activities, each resident requires a green open space of 20 m^2. In district-scale green open spaces, which constitute an environment with a population of 120,000 people, it is recommended to have a district park with a minimum area of 24,000 m^2 or 0,2 m^2 per person. In larger types of green open spaces, such as urban areas with a minimum population of 480,000, it is recommended to have green open spaces with a minimum area of 4,0 m^2 per resident in the form of city forests and 0.3m^2 per resident in the form of city parks.

The minimum green open space area of 30% is the minimum measure of vegetated area to ensure ecosystem balance in the region (Baharuddin, 2011). The green open spaces not only play a role in improving air quality and providing oxygen but also have a positive impact on the mental and physical health of urban residents (Kabisch and Van Den Bosch, 2017). This finding is consistent with the fact that the green open space requirement in Kendari City, based on oxygen demand analysis, is only 1.951.891.407m^2 or 1,927.79 hectares, indicating that the current area of green open spaces far exceeds the minimum requirement and is capable of accommodating the oxygen needs of Kendari City residents adequately

The significant presence of green open spaces in Kendari City plays a role in reducing the city's air temperature and enhancing resilience to climate change, thereby supporting the 13th goal of the SDGs for 2030, which is climate action. Green open spaces contribute to reducing the impacts of climate change through carbon sequestration and mitigating the urban heat island effect (Gómez-Baggethun and Barton, 2013). Furthermore, green open spaces also contribute to rainwater management and reduce the risk of floods, which becomes increasingly relevant in dealing with unpredictable climate changes (Madureira et al., 2018).

Further, the implications of the extensive green open spaces in Kendari City also extend to social aspects and the well-being of its residents. Access to green open spaces correlates with increased social welfare and environmental justice (Wolch et al., 2014). In Kendari city, expansive green open spaces not only provide areas for recreation and physical activities for residents but also support the sustainability of the local ecosystem by

preserving natural habitats and biodiversity. This reinforces studies showing that cities with sufficient green open spaces tend to be more socially and ecologically inclusive (Haase et al., 2017).

In the context of policy, research findings suggest that Kendari City does not need to increase its green open spaces. Instead, efforts can be directed towards the management and maintenance of existing green open spaces. The management of green open spaces should involve sustainable and participatory strategies, engaging the local community in the planning and upkeep of these areas. Implementing this policy will ensure that the ecological and social benefits of green open spaces are maintained and even enhanced, aligning with global and local goals to create greener, healthier, and more sustainable cities (Byrne et al., 2010). Further explained, the development of green open spaces can be achieved by utilizing offices, residential areas, places of worship, schools, universities, sports fields, roads, riverbanks, and large irrigation canals as vegetated areas. The recommended vegetation type for green open spaces should primarily be tree species. Trees have the ability to absorb carbon dioxide at a rate of 19.92 kg/ha/hour, which is significantly higher compared to shrubs (12.56 kg/ha/hour) and grasslands or rice fields (2.74 kg/ha/hour) for the same area (Ardani, et al., 2013; Baharuddin, 2011). Trees have different abilities to absorb carbon dioxide; for example, the angsana tree absorbs 720 kg per year, the acacia tree absorbs 720 kg per year, the ketapang tree absorbs 71 kg per year, and the broad-leaved mahogany tree absorbs 61 kg per year, among others (Prasetia et al., 2018).

Based on the Regulation of the Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 05/PRT/M/2008 on Guidelines for the Provision and Utilization of Green Open Spaces in Urban Areas, criteria of recommended tree and shrub species for urban green spaces are based on their silvicultural characteristics, ensuring that each type of vegetation differs according to the function and form of the green open space. In areas where there is insufficient space for expanding green open spaces, diversifying plant structures can be achieved by introducing several types of plants that occupy specific strata, thereby increasing

the vegetation stratification (Rijal, 2008). The intensification of empowering green open spaces can also be achieved by increasing tree density per hectare (Nowak and Crane, 2002; Nowak et al., 2007).

Overall, this research emphasizes that Kendari City possesses strong ecological assets through extensive green open spaces, which not only fulfill oxygen requirements but also contribute to climate change mitigation, enhance residents' quality of life, and sustain ecosystem health. Therefore, future policy focus can shift towards managing and optimizing the benefits of existing green open spaces to support broader sustainable development goals.

CONCLUSION

Based on the findings of the research, it can be concluded that: 1) Kendari City has a total area of green open space measuring 19,458.94 hectares based on NDVI analysis using Sentinel 2A imagery; 2) according to the analysis of oxygen requirements for residents, animals, and motor vehicles, the total area of green open space needed in Kendari City is 1,927.79 hectares; and 3) implementing these research findings can support the achievement of 13th Goal of the SDGs 2030 targets by strengthening environmental policies, increasing public awareness, and engaging local communities in environmental conservation efforts. This indicates that the available green open spaces in Kendari are sufficient to accommodate oxygen requirements, thus, additional green open space is not currently required. Therefore, the focus of Kendari City's future policy can be shifted towards the management and optimization of existing green open spaces to support broader sustainable development goals.

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