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The Effects of Implementing Green Roof Scenario on NO_2 and Urban Hear Island Distribution in Yogyakarta City

Wahyuni Sukanti, Tri Mulyani Sunarharum

Magister Perencanaan Wilayah dan Kota, Universitas Gadjah Mada, Yogyakarta, INDONESIA

E-mail: wahyuni.sukanti@mail.ugm.ac.id

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ABSTRACT

The development of urban areas requires a city to meet residential space needs which can have an impact on reducing green open space and causing derivative impacts in the form of decreasing air quality. The problem faced by the City of Yogyakarta in developing green open space is limited land, therefore innovation in green open space development is needed, one of which is developing green infrastructure by implementing a green roof scenario. So this research aims to analyze the application of the green roof scenario to air quality, especially in the distribution of Urban Heat Island (UHI) and Nitrogen Dioxide (NO_2) in Yogyakarta City. The method used in this research are Landsat 8 images in 2021 with field observations and delineation of the potential area for green roofs at hotels and malls that have rooftops and the potential to implement green roofs. The research results show that implementing the green roof scenario in Yogyakarta can affect air quality. There are changes in the area that decrease the area in UHI class 4 (>3) from 4.74 Ha to 3.78 Ha and an increase in the Non-UHI area from 1,449.68 Ha to 1,731.57 Ha. Based on the NO_2 parameter there has also been a change that increases in the area on a very good air quality scale from 406.80 Ha to 560.96 Ha, and a decrease in the area on a very poor scale from 23.71 Ha to 16.24 Ha. The results of the delineation of the UHI map, NO_2 distribution, and spatial plans for Yogyakarta City show that locations with high UHI levels and poor NO_2 quality are most widely distributed in Kemantren Gondokusuman, Umbulharjo, and Kotagede

Keywords: green infrastructure; air quality; urban heat island.

INTRODUCTION

The development of an area can increase population growth in an area and has implications for increasing consumption of energy, water and land resources and waste. The development of transportation, industrial, trade and residential facilities is the main factor causing the increasing density of areas such as urban areas. This development has resulted in the impact of land conversion leading to gray infrastructure and the lack of widespread implementation of green infrastructure.

One type of green infrastructure is Green Open Space (RTH) which is one of the solutions that has emerged to improve the quality of the urban environment because RTH is a combination of natural and human systems in the urban environment and is part of the spatial planning of an urban area filled with plants and vegetation to support ecological, social, cultural, economic, and aesthetic benefits, and functions as a protected area (Fandeli et al. 2004).

Law Number 26 of 2007 concerning Spatial Planning is understood to aim to organize safe, comfortable, productive and sustainable green open spaces. Green open space (RTH) has many functions, including helping to absorb emissions produced by residents of Yogyakarta City, improving the city's microclimate and beautifying the beauty of the city (aesthetic function). Law Number 26 of 2007 clearly mandates that RTH must be regulated in the spatial planning of an area with a proportion of 20% public RTH and 10% private RTH. However, the problem faced by urban areas in developing this RTH is limited land, including in Yogyakarta City. In 2017, the use of existing land in Yogyakarta City was dominated by settlements covering an area of 2,112.50 Ha or 65% of the total area of Yogyakarta City; meanwhile, land use for RTH was only 23.53% consisting of public RTH covering an area of 263.90 Ha (8.12%) and private RTH covering an area of 500.90

ha (15.41%) (DLH Yogyakarta City, 2022). Furthermore, in terms of air quality, there was a decline in air quality from 2017 to 2019, but in 2021 and 2021 there was an increase due to the reduction in the pollutant load in the form of NO_2 and SO2 in 2020 and 2021. In 2020 and 2021, the results of air quality measurements held by the Yogyakarta City Environmental Service (DLH) NO_2 and SO_2 parameters decreased which was influenced by the reduced mobility of the people of Yogyakarta City due to the Covid-19 pandemic.

Green open space has an important function in reducing emissions and improving the microclimate. So it is necessary to increase the number of green open spaces in an effort to improve air quality and microclimate, but based on the Yogyakarta City Environmental Management Information Document, it is stated that the obstacle in developing green open spaces in Yogyakarta City is limited land. Therefore, innovation is needed in the development of green open spaces. So in this study, the innovation studied is the optimization of green infrastructure through the scenario of implementing green roofs in buildings that have rooftops, namely hotels and malls in the administrative area of Yogyakarta City.

Based on the formulation of the problem, the purpose of this study is to identify conditions and analyze the effect of green roof implementation on air quality in urban areas of Yogyakarta.

An environmentally friendly house integrates green open space as a vital element to promote sustainability and enhance well-being. This concept involves incorporating gardens, lawns, and natural vegetation into the design to reduce carbon footprints and improve air quality. The open spaces serve as natural insulation, cooling the house passively by minimizing heat absorption and promoting airflow. Strategically placed trees and shrubs provide shade, lowering the need for artificial cooling systems. Additionally, green roofs and vertical gardens contribute to biodiversity, creating habitats for birds and insects while reducing stormwater runoff. These areas act as a buffer, filtering pollutants and noise, fostering a serene environment. Beyond environmental benefits, green open spaces encourage outdoor activities, supporting physical and mental health. They create a connection to nature, fostering mindfulness and relaxation. By utilizing native plants and drought-resistant species, maintenance is minimized, conserving water resources. Composting and rainwater harvesting can be integrated into these spaces, further enhancing sustainability. The seamless blend of architecture and nature exemplifies a harmonious living space, promoting eco-conscious living without compromising aesthetics. Ultimately, green open spaces in environmentally friendly homes represent a commitment to sustainable living, creating healthier environments for both residents and the planet (Rumiki E et.al, 2024; Barri A, 2024; Detty KB et.al, 2024).

RESEARCH METHODS

This research was conducted using a quantitative-qualitative deductive method. The research location is in the urban area of Yogyakarta City which administratively consists of 14 sub-districts and 45 villages with an area of 3,250Ha using 2021 data.

Normalized Difference Vegetation Index (NDVI)

The first data processing carried out was Landsat image processing using the Normalized Difference Vegetation Index (NDVI) method using ArcMap 10.4. The Normalized Difference Vegetation Index (NDVI) is a method that utilizes bands 4 and 5 on Landsat 8 images to compare the level of greenery of vegetation (chlorophyll content) in plants. The NDVI value ranges from -1 to +1.

The output of NDVI is a new image file/layer. The value of NDVI can range from -1 to 1. The following is the formula used in this study.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

Description:

NDVI : Normalized Difference Vegetation Index or the value/index of the condition of vegetation/plants in an area
NIR : Near Infrared Reflectance or reflection of near infrared rays

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RED : Red Reflectance or reflection of red light

Urban Heat Island (UHI)

Processing UHI processing begins by looking at the surface temperature or Land Surface Temperature (LST). LST is a condition controlled by the balance of surface energy, atmosphere, thermal properties of the surface, and subsurface media (Delarizka dik., 2016). LST itself is one of the indicators of UHI. The surface temperature of an area can be identified from Landsat satellite imagery extracted from the thermal band. The extracted surface brightness temperature data is considered as ToA (Top of Atmosphere) brightness temperature. This is because temperature extraction is based on the radiance value received by the sensor. The stages for obtaining an estimate of surface temperature are as follows.

The basic equation used to convert pixel values to spectral radiance values (U.S.Geological Survey, 2017). The formulas included in it are:

$L\lambda$ = ML. Qcal + AL
Description:

$L\lambda$ = spectral radian on the sensor ($W/m^2/sr.\mu m$)
Qcal = pixel value (DN)
ML = rescaling constant, obtained in image metadata
AL = enhancement constant, obtained in
image metadata
a. Emissivity Correction

The acquisition of radiant temperature cannot be separated from the emissivity values of the soil and vegetation. This study refers to (Valor & Caselles, 1996), namely:

$$\varepsilon v = 0{,}985 \pm 0{,}007$$

b. Atmospheric Correction – Top of Atmosphere (ToA)

This correction is based on the radiative transfer equation to correct atmospheric factors that affect the radiation emitted by the object.
b) Corrected Surface Temperature
This study uses emissivity-corrected values to obtain surface temperature estimates. The equations used are as follows:

$$T_{rad} = \frac{K_2}{\ln\left(\frac{K_1}{L_{\lambda-e}} + 1\right)}$$

Where:
Trad = radiant temperature in Kelvin
$L\lambda$-e = corrected spectral radiant value
Emissivity
K1 = spectral radiant calibration constant
($W/m^2/sr.\mu m$), obtained in

Metadata for band 10

K2 = absolute temperature calibration constant (K), obtained in metadata
for band 10 or 11.

c. Calculation of Urban Heat Island Value

Can be obtained using the following equation.

$$\Delta T\mu\text{-}r = T\mu - Tr$$

Where:
$\Delta T\mu$-r = effect of UHI caused

Tμ = surface temperature in the city or form of land use that is warmer than the surrounding temperature
Tr = surface temperature around the area measured Tμ

The equation above shows the threshold temperature for areas where UHI occurs. While for areas where UHI does not occur, it is obtained through the equation:

$$T > \mu + 0,5\ \alpha$$
$$0 < T \leq \mu + 0,5\ \alpha$$

Where:

T = surface temperature (LST)

μ = average value of surface temperature

α = standard deviation value of surface temperature

Normalized Difference Built-Up Index (NDBI)

NDBI (Normalized Difference Building Index) is one of the indices used to extract information on the condition of built-up areas. The NDBI method uses the reflection method on Shortwave Infrared (SWIR) waves and Near infrared (NIR) waves. There is a higher reflection in the SWIR area of urban areas or built-up areas compared to the NIR wave area. In Landsat 8 itself, SWIR waves can use band 6 while NIR waves can use Band 5.

$$\mathrm{NDBI} = \frac{\mathrm{MIR} - \mathrm{NIR}}{\mathrm{MIR} + \mathrm{NIR}}$$

Where:

NDBI : Normalized Difference Built-Up Index or Value/index of Building density

MIR : middle infrared channel

NIR : near infrared band

RESULTS AND DISCUSSION

The results and discussion of this study are the identification and influence of the application of green roof scenarios on the distribution of UHI and NO_2. The results and discussion of this study are as follows:

Potential for Application of Green Roof

The toponymy data of hotels and malls included in the administrative area of Yogyakarta City are then delineated to obtain the roof area of hotels and malls that can be applied with green roofs. Overall, the upper area that can be applied with green roofs is 13.11 Ha which is spread across several sub-districts. The sub-district with the most hotels is in Gedongtengen Sub-district, which is 20 hotels. In addition, this green roof scenario is also applied to malls, namely Malioboro Mall which is administratively located in Danurejan Sub-district, as well as Lippo Plaza and Galeria Mall which are located in Gondokusuman Sub-district.

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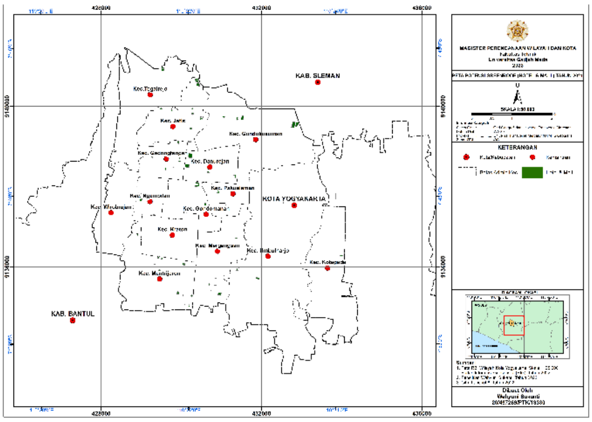

Figure 1. Green Roof Potential Map

Urban Heat Island (UHI)

Based on the results of the analysis of Landsat 8 image data for Yogyakarta City in 2021 using ArcGIS 10.4 software, the NDVI value was obtained with a range of vegetation index values from -0.12 to +0.45. The results of the vegetation index value range were then classified by vegetation density. The classification range is presented in the following table**.**

Table 1. Vegetation Index Value Range

Vegetation Index Value Range	**Area (Ha)**	**Percentage (%)**
Non-vegetation	600,79	18,49
Very low vegetation	1.679,90	51,69
Low vegetation	603,49	18,57
Medium vegetation	260,92	8,03
High vegetation	104,89	3,23

Source: Author's Analysis, 2023

Based on this, it can be seen that the city of Yogyakarta is dominated by very low vegetation, which is 1,699.9 Ha or 51.69% of the total urban land area. When viewed from its type, very low vegetation is land covered with asphalt or paving. This is in line with the land use of the city of Yogyakarta which is also dominated by settlements. Low vegetation and non-vegetation are also the second and third largest percentages after very low vegetation, and are spread across all sub-districts. Meanwhile, medium and high vegetation have a fairly small percentage, namely 8.03% and 3.23% which are spread across several sub-districts, including Kemantren, Kotagede, Umbulharjo, Mantrijeron, Tegalrejo, and some in Gondokusuman, Mergangsan, and Gondomanan.

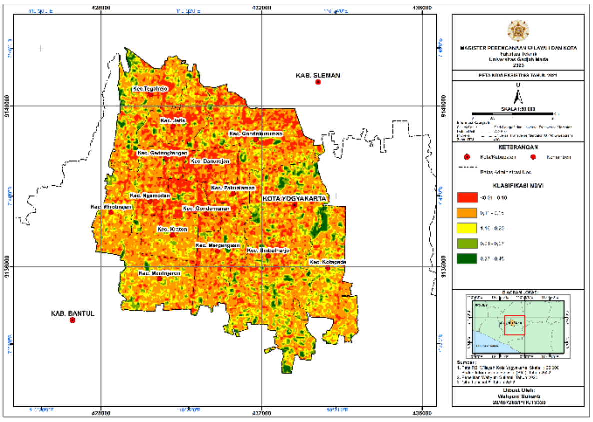

Figure 2. NDVI Map of Yogyakarta City

Furthermore, the UHI calculation is analyzed based on the Land Surface Temperature (LST) calculation. Based on the LST distribution data in Yogyakarta City, it is known that the sub-district with the highest LST value, namely a range of 32.1°C to 25.8°C is the Gondokusuman Sub-district. This can be caused by the high NDBI and high mobilization flow in the sub-district, considering that the location is one of the dense and traffic-prone locations and there are several service, trade and education activities. Based on equations (1) and (2), the UHI threshold value in 2021 is 31.27°C with a value of μ = 31.31°C and α = 0.82. This explains that the area above the UHI threshold value of 31.27°C is an area where the UHI phenomenon occurs. The results of the UHI threshold are then entered into the following equation:

UHI Map = Tmean (μ + 0.5 α)

However, before entering the equation, a filtering process is carried out on the LST map that has been obtained. The filtering process is the process of smoothing the value of a pixel. This result is caused because the influence of heat in a pixel is not only influenced by one pixel but also by the values of other pixels. The results of the Tmean filtering are then used in the process of making the UHI map. UHI values are classified into 5 classes. The division of UHI value classifications in this study is Non UHI (<0) ° C, UHI 1 (0.01 - 1) ° C, UHI 2 (1.01 - 2) ° C, UHI 3 (2.01 - 3) ° C and UHI 4 (> 3) ° C.

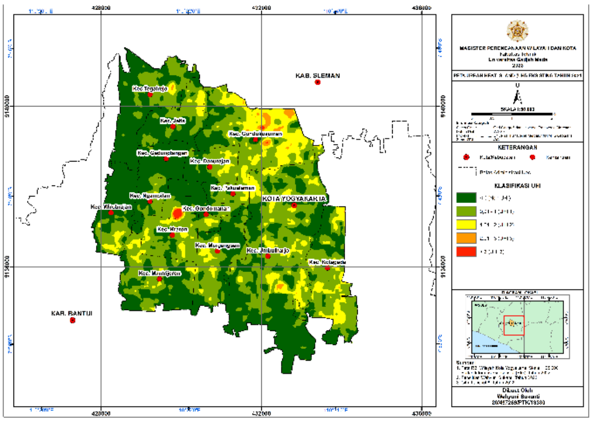

Figure 3. UHI Distribution Map

Nitrogen Dioxide (NO_2)

Air quality based on NO_2 is seen based on distribution data from air quality monitoring results in Yogyakarta City which is then mapped based on monitoring location points using ArcGis 10.4. The air quality value of the NO_2 parameter is classified into 5 classes, namely very good (2.5 - 4.5), good (4.6 - 6.5), moderate (6.6 - 9.0), bad (9.1 - 11.0) and very bad (11.1 - 13.5).

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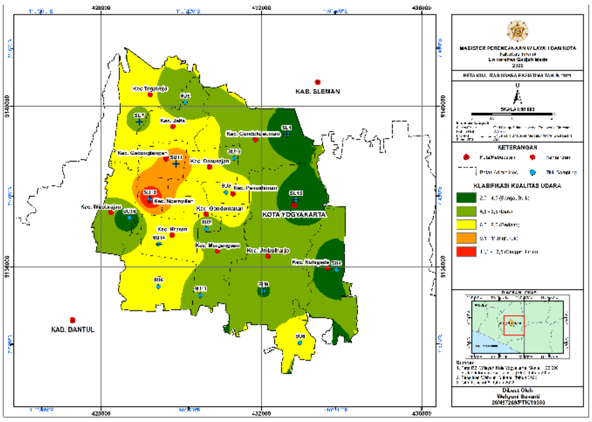

Figure 4. NO_2 Distribution Map

The Effect of Green Roof Scenario Implementation on UHI and NO_2

The analysis of green roof implementation was carried out by applying the roofs of hotels and malls that have been identified as being able to apply green roofs to buildings covered by vegetation. so that the calculation process is carried out using ArcGIS 10.4 software to delineate the addition of green space which is then carried out by the process of determining the UHI scale as in equations (1) and (2). Furthermore, the process of making a UHI map is carried out according to equation (3) to see how much influence the addition of green space on the roof of the building has in its role in reducing the UHI level and NO_2 distribution. This process is also carried out using the help of ArcGIS 10.4 software in the delineation process and map overlay to determine its effect on air quality.

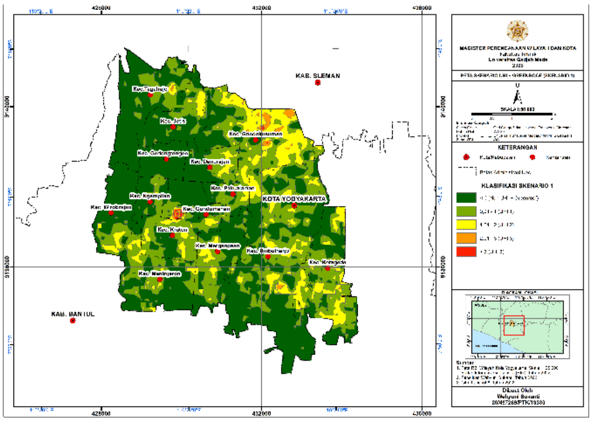

Figure 5. Map of Green Roof Implementation Against UHI

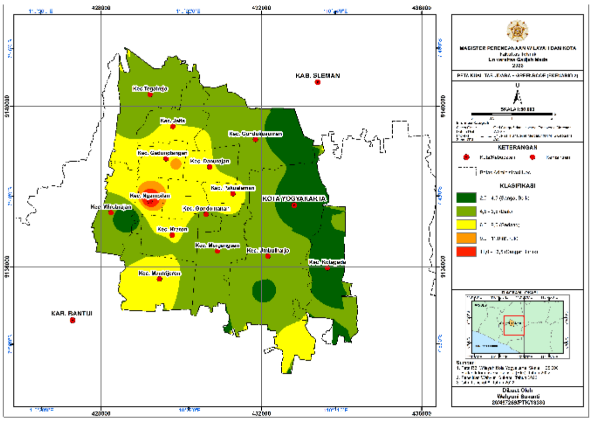

Figure 6. Map of Green Roof Application to NO_2

Table 2. Differences in Existing Area and Scenario Based on UHI Class

Class UHI	Value Range	Existing		Scenario	
		Area (Ha)	Percentage (%)	Area (Ha)	Percentage (%)
Non UHI	<0	1449.68	44.61	1731,57	53,28
UHI 1	0.01 - 1	1369.69	42.14	1088,28	33,49
UHI 2	1.01 - 2	402.52	12.39	400,41	12,32
UHI 3	2.01 - 3	23.37	0.72	25,96	0,80
UHI 4	>3	4.73	0.15	3,78	0,12
Total		**3250.00**	**100**	**3250.00**	**100**

Source: Author's Analysis, 2023

Table 3. Differences in Existing and Scenario Areas Based on NO_2 Quality Class

Class NO_2	Value Range	Existing		Scenario	
		Area (Ha)	Percentage (%)	Area (Ha)	Percentage (%)
Very Good	2.5-4.5	406.80	12.52	560,96	17,26
Good	4.6-6.5	1522.82	46.86	1806,60	55,59
Average	6.6-9.0	1165.62	35.87	833,04	25,63
Bad	9.1-11.0	131.06	4.03	33,16	1,02
Very Bad	11.1-13.5	23.71	0.73	16,24	0,50
Total		**3250.00**	**100**	**3250.00**	**100**

Source: Author's Analysis, 2023

The application of the green roof scenario has an impact on environmental changes, especially in air quality, especially on the NO_2 and UHI variables. However, urban development that requires an increase in the number of buildings will certainly affect the number of green open spaces if the right strategies and innovations are not implemented in managing green open spaces. Based on the overlay map of the green roof application scenario, the distribution of NO_2 and UHI on green open space planning in the Yogyakarta City Regional Spatial Plan (RTRW), it can be seen that green open space locations are quite spread throughout the sub-districts, but when viewed from the environmental scaling classification, the locations that should receive more attention are the Gondokusuman, Umbulharjo and Kotagede sub-districts which have more locations with a poor scale (1.7 - 3.0).

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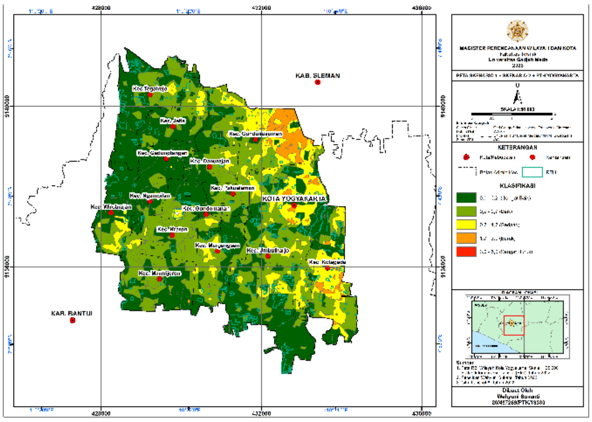

Figure 7. Overlay Map of the Impact of Green Roof Implementation on Green Open Space Planning in the Yogyakarta City RTRW

Godokusuman and Umbulharjo Sub-districts are areas that have many shopping, tourism and housing areas which result in high mobility and surface temperatures in the area, while Kotagede Sub-district is dominated by settlements which result in high surface temperatures. Based on the Yogyakarta City RTRW, Kotagede and Umbulharjo Sub-districts have quite a lot of green open space planning, but Gondokusuman Sub-district does not have enough green open space planning locations. So in this case, the sub-district that is the "warning" area is Gondokusuman Sub-district.

Based on its location, Gondokusuman, Umbulharjo and Kotagede Sub-districts do not have many locations where green roofs can be applied so that the application of scenarios in these locations does not have a significant effect on the classification value. Therefore, in this case, the Yogyakarta City government needs to manage and develop green open space in locations that have moderate and poor classifications, especially in Gondokusuman Sub-district which does not have many green open space planning locations in the RTRW.

CONCLUSION

The results of the study indicate that the application of the green roof scenario in the city of Yogyakarta can affect the phenomenon of Pulau Bahang or Urban Heat Island (UHI) and the distribution of Nitrogen Dioxide (NO_2) emissions in several locations, especially in locations with high community mobilization intensity. Based on the results of the application of the green roof scenario at the mall and hotel locations, it is known that there is a change in area, namely a decrease in the area in UHI class 4 (> 3) from 4.74 Ha to 3.78 Ha and an increase in the Non UHI area, namely from 1,449.68 Ha to 1,731.57 Ha. In addition, based on the distribution of NO¬2, there is an increase in the area that has a very good NO_2 quality scale, namely from 406.80 Ha to 560.96 Ha, and a decrease in the area on a very poor scale, namely from 23.71 Ha to 16.24 Ha. Gedongtengen Sub-district is a sub-district that has the highest potential for implementing green roofs compared to other sub-districts in the city of Yogyakarta. The results of the overlay and classification of the impact of UHI and NO_2 distribution in Yogyakarta City based on the green open space planning in the RTRW, locations that require special attention because they have more locations with poor scales are Kemantren Gondokusuman, Umbulharjo and Kotagede. Therefore, the application of green roofs or a combination of other green infrastructure strategies can be applied to these areas to reduce the impact of the distribution of UHI and NO_2.

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