JPPIPA 11(11) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Analysis of Changes in Green Open Space and Their Influencing Factors in Surakarta City

Septita Dwi Listanti[1*], Rachmad Hermawan[2], Yudi Setiawan[2]

[1] Tropical Biodiversity Conservation Study Program, Graduate School, Bogor Agricultural University, Bogor, Indonesia.
[2] Department of Forest Resources Conservations and Ecotourism, Faculty of Forestry and Environment, Bogor Agricultural University, Bogor, Indonesia.

Received: July 15, 2025
Revised: October 04, 2025
Accepted: November 25, 2025
Published: November 30, 2025

Corresponding Author:
Septita Dwi Listanti
septitadwilistanti@outlook.com

DOI: 10.29303/jppipa.v11i11.12153

© 2025 The Authors. This open access article is distributed under a (CC-BY License)

Abstract: Green Open Space (GOS) is a critical urban element, but the legally mandated minimum 30% area is often unmet. This study aims to analyze the changes in the GOS area from 2002, 2013, and 2024 and the factors influencing it. GOS area change was analyzed using the delineation method on high-resolution satellite imagery from Google Earth Pro, and the results showed that the area of GOS in Surakarta City in 2002 was 360.95 ha, in 2013 was 341.18 ha, and in 2024 was 328.76 ha. Logistic regression analysis was applied to model the influence of explanatory variables, resulting in findings that distance to the road, distance to settlements, distance to transportation facilities, and population density are significant variables influencing GOS decline. Although these variables only explained 9.1% of the change, this suggests that there could be other external factors affecting GOS that have not been analyzed in this study. The local government needs to strengthen policies, tighten building permit supervision, and ensure consistency with Regional Spatial Planning to optimize existing GOS and develop new GOS in potential locations to address the deficit of approximately 1,072.84 ha.

Keywords: Delineation; Green open space; Logistic regression

Introduction

Population increase is a challenge experienced by many large cities in Indonesia, including Surakarta City, which experienced population growth threefold from 1980 to 2010 (Mardiansjah et al., 2018). Urban areas continue to experience changes that cause land use dynamics. The ongoing development to accommodate the community's needs generally causes changes in urban areas. Without proper planning, the implementation of urban development often causes negative impacts. These can happen because ecological values are less prioritized than economic values in urban development. If not balanced with the management of Green Open Space (GOS), land use transformation can cause environmental problems such as changes in ecosystem function, the hydrological cycle, loss of biodiversity, and increased environmental pollution (Yu et al., 2024).

Green open spaces are regulators of urban microclimate, beauty enhancers, places for urban communities to socialize, and agents of groundwater conservation in urban areas (Rawung, 2015; Schuch et al., 2017). The Urban Heat Island (UHI) phenomenon is a condition in which an urban area has a higher surface temperature than the surrounding rural areas. Increasing the amount of vegetation can effectively reduce surface temperature and reduce the impact of UHI (Arifah & Susetyo, 2018). The provision of GOS in a city has been regulated in Law Number 26 of 2007 concerning Spatial Planning; it is stated that a city/district should provide at least 30% of the total area of the city for GOS.

The massive urban development that occurs threatens the existence of green open spaces. Research

How to Cite:
Listanti, S. D., Hermawan, R., & Setiawan, Y. (2025). Analysis of Changes in Green Open Space and Their Influencing Factors in Surakarta City. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 1057–1066. https://doi.org/10.29303/jppipa.v11i11.12153

conducted by Matsuda et al. (2018) proved that with an increase in the built-up land area, the area of green spaces in Depok City decreased. Meanwhile, one of the main issues in Surakarta City is the increase in built-up land cover, which causes climate change in the form of a maximum land surface temperature rise of 4.24°C from 2000 to 2021, resulting in the phenomenon of the UHI (Handayani et al., 2017; Putra & Rudiarto, 2018; Wibisono et al., 2023). Zahrotunisa et al. (2020) stated that the built-up land condition in Surakarta caused the city to experience UHI.

Previous research on determining priority locations for GOS in Surakarta, which was limited to the Serengan Subdistrict, was conducted by Setiawan et al. (2014), and another study using parameters such as residential areas, building density, distance from roads, and distance from rivers was conducted by Wicaksono et al. (2017). There has been no comprehensive analysis linking GOS transformation across three decades with factors influencing it in Surakarta. This study is important as its findings will provide an evidence-based foundation for the local government's evaluation of existing Regional Spatial Planning (RTRW) effectiveness and the strategic formulation of targeted GOS conservation and urban climate mitigation policies.

Method

Location and Time

The research was conducted in November-December 2024 in Surakarta City, Central Java Province. The total area studied was 46.73 km² (Figure 1).

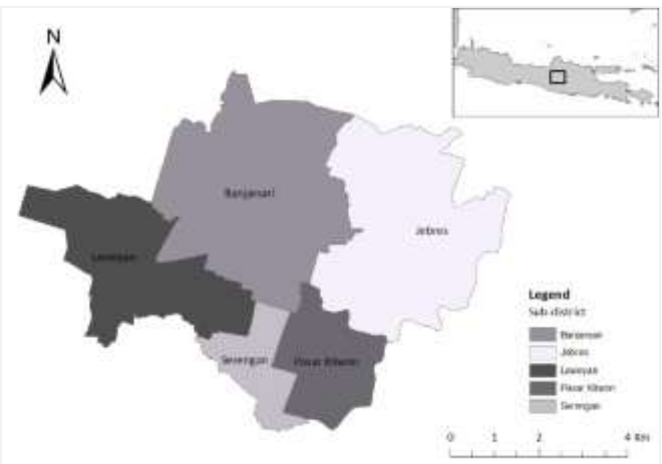

Figure 1. Map of research location

Types and Sources of Data

The data used in this study include high-resolution satellite images from 2002, 2013, and 2024 from Google Earth Pro, the Regional Spatial Planning map of Surakarta City, coordinate points for ground checks, and data on GOS change factors such as the road network, settlements, the distribution of economic facilities, rivers, slopes, industrial distribution, the distribution of transportation facilities, the distribution of government offices, tourist sites, educational facilities, and population density.

Analysis of GOS Changes

The delineation method was used on high-resolution images in Google Earth Pro. Delineation was carried out by identifying the appearance of GOS using photo maps and drawing measuring lines for clear GOS boundaries. The type of boundary category used as a reference in the delineation method is general boundaries. General boundaries are lines that appear to exist in reality but have not been determined by the authorities, usually in the form of physical appearances, either natural or artificial (Wardani et al., 2016). The image data used were from 2002, 2013, and 2024, representing each decade. Based on the analysis results, the percentage of GOS changes from year to year and their locations were determined.

Analysis of the Factors Driving GOS Changes

The analysis stage began with converting all driving factor data into vector form using ArcGIS 10.8 software, which was then processed using a logistic regression algorithm with SPSS Statistics 22 software. Logistic regression analysis was used to test whether the probability of occurrence of the GOS change variable could be predicted by its explanatory variables. The variable used is a binary value of 0 and 1, where 0 means no GOS change and 1 means a change in GOS. The assumption that must be met in logistic regression is the absence of multicollinearity (Broto, 2019). Multicollinearity testing is based on the linear correlation between explanatory variables. The multicollinearity test can be seen from the Variance Inflation Factor (VIF). If the VIF value is smaller than 10, then multicollinearity is not indicated. The VIF equation is written as follows (Kutner et al., 2005):

$$VIF_i = \frac{1}{1 - R_i^2} \quad (1)$$

The logistic regression equation is used as follows:

$$\log\left[\frac{Pi}{1 - Pi}\right] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots \beta_n X_n \quad (2)$$

Where:
Pi : Probability value of the i-th fixed variable
β_0 : Constant

β_{1-n} : Coefficient of independent variable 1 to n
n : number of variables
$X_1, X_2, \ldots, X_n$: Factors that are believed to influence the GOS changes

Table 1. Variables in Estimating the Factors of GOS Changes

Dependent variable (Y)	Independent variables (X)
Y = GOS changes into other land functions	X_1 = Distance to river
	X_2 = Distance to government offices
	X_3 = Distance to educational facilities
	X_4 = Distance to economic facilities
	X_5 = Distance to road
	X_6 = Distance to tourist attractions
	X_7 = Distance to industries
	X_8 = Distance to settlement
	X_9 = Distance to transportation facilities
	X_{10} = Population density (number of people/Km^2)
	X_{11} = Slope

The polygon distance for each variable was calculated before performing logistic regression analysis in SPSS. The analysis results were then tested using the coefficient of determination (R^2 test); the higher the R^2 of the regression model, the better the regression results (Sapriyadi et al., 2024). The coefficient of determination test is a test to determine the fit of the independent variables with the dependent variable and the ability of the independent variables to explain the dependent variable.

Hypothesis testing was conducted to test the influence of independent variables (X) on the declining GOS area in Surakarta City. The regression coefficient of each tested variable shows the relationship between variables using the regression test results shown in the significance column. The test criteria used a confidence level of 95% or a significance level of 5% ($\alpha = 0.05$) with the following hypotheses:
Ha = if the significance level ≤ 0.05, which means that the independent variable significantly affects the decline of GOS area in Surakarta City.
H0 = if the significance level > 0.05, which means that the independent variable does not significantly affect the decline of GOS area in Surakarta City.

Results and Discussion

General Conditions

Surakarta City is located in Central Java Province. Boyolali Regency and Karanganyar Regency surround it on the northern side, Karanganyar and Sukoharjo Regency on the eastern side, Sukoharjo Regency on the southern side, and Sukoharjo Regency on the western side. Geographically, Surakarta City is located at 110º45'15"–110º45'35" East Longitude and 7º36'00"–7º56'00" South Latitude, with a total area of 46.73 km². Surakarta City consists of five sub-districts, namely Laweyan Sub-district with 11 villages, Banjarsari with 13 villages, Serengan with seven villages, Pasar Kliwon with nine villages, and Jebres with 11 villages. The largest sub-district in Surakarta is Banjarsari, with an area of 15.26 km², while the smallest sub-district is Serengan, with only 3.08 km². The topography of Surakarta City lies in the lowlands, with an altitude of 95–105 meters above sea level and a land slope ranging from 0–15%. Surakarta City is a water basin area because it is located between two volcanoes, namely Mount Lawu (2,806 m) and Mount Merapi and Merbabu (3,115 m). Surakarta's low topography makes the city vulnerable to floods; hence, city management needs to be well organized.

Green Open Space Changes in 2002, 2013, and 2024

The results of the delineation analysis of Maxar Technologies' high-resolution imagery in Google Earth Pro show that in 2002, Surakarta City had approximately 360.95 ha of GOS spread across the city (Figure 2). This area is only about 7.72% of the total area of Surakarta City. The most significant contributor is from Jebres Sub-district, with an area of 157.15 ha.

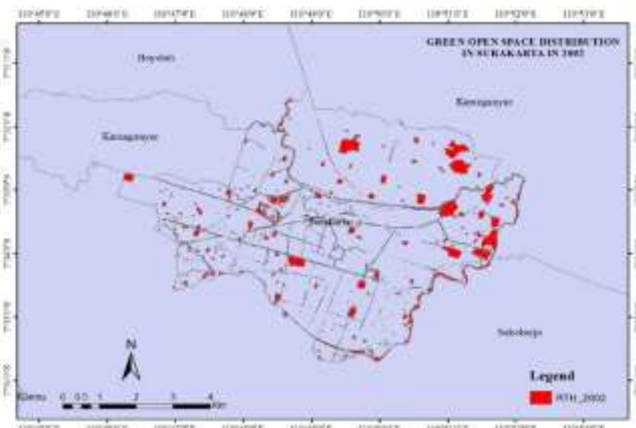

Figure 2. Green open space (GOS) distribution in 2002

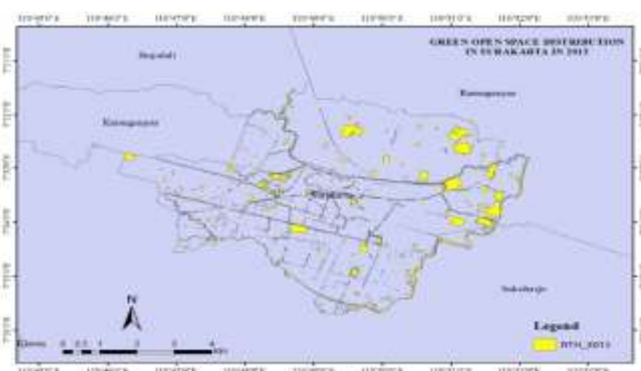

Figure 3. Green Open Space (GOS) distribution in 2013

As for the results of the Copernicus image analysis in 2013, during the period 2002–2013, the area of GOS decreased by 19.78 ha. The Surakarta GOS area in 2013 was 341.18 ha or 7.30% of the total area of Surakarta City (Figure 3). Laweyan Sub-district experienced the most significant decrease by 7.68 ha. The transformation of the GOS land function was mainly converted into built-up land. Since 2002, Surakarta's land use has changed significantly in terms of business, service, industry, and residential functions. The development of these supporting facilities occurred due to the recovery of economic conditions after the monetary crisis that hit Indonesia (Arifia et al., 2017).

Then, the GOS area in Surakarta City in 2024 decreased further to 328.76 ha or 7.04% of the total area. There was a decrease in the area of green space in the period 2013–2024 by 12.41 ha. Jebres Sub-district experienced the most significant decrease of 6.24 ha. Based on an interview with the environmental department staff, the decline in GOS occurred due to the diversion of GOS functions into other public facilities such as road expansion, construction of overpasses/flyovers, construction of health centers, construction of offices, and others. The distribution of GOS in 2024 can be seen in Figure 4.

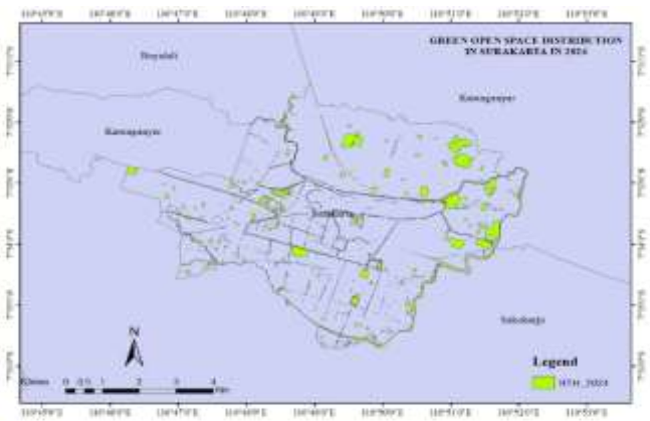

Figure 4. Green Open Space (GOS) distribution in 2024

Further information related to the area of GOS in each sub-district can be seen in the following table:

Table 2. GOS area in 2002, 2013, and 2024

Sub-district	GOS area (ha)		
	2002	2013	2024
Laweyan	58.02	50.34	48.78
Banjarsari	96.37	90.15	85.57
Serengan	13.97	11.89	11.87
Pasar Kliwon	35.44	35.42	35.41
Jebres	157.15	153.38	147.13
Total	360.95	341.18	328.76

Based on the results of the study, it can be seen that the area of green space in Surakarta City continues to decline from year to year. In 2002, Jebres Sub-district had the largest green space area of 157.15 ha, followed by Banjarsari Sub-district with 96.37 ha, Laweyan Sub-district with 58.02 ha, Pasar Kliwon Sub-district with 35.44 ha, and Serengan Sub-district with 13.97 ha. However, as can be seen in the table above, in 2013 all sub-districts experienced a simultaneous decline in green space area. Jebres Sub-district decreased to 153.38 ha, Banjarsari Sub-district to 90.15 ha, Laweyan Sub-district to 50.34 ha, Pasar Kliwon Sub-district to 35.42 ha, and Serengan Sub-district to 11.89 ha. The decline in green space area continued until 2024, with Jebres Sub-district decreasing to 147.13 ha, Banjarsari Sub-district to 85.57 ha, Laweyan Sub-district to 48.78 ha, Pasar Kliwon Sub-district to 35.41 ha, and Serengan Sub-district to 11.87 ha. The most significant decrease occurred in Laweyan Sub-district in the 2002–2013 period, amounting to 7.68 ha. It can also be seen that there was a decrease of 6.22 ha in Banjarsari Sub-district in the same period. This was followed by a decrease of 6.25 ha in Jebres Sub-district in the 2013–2024 period.

Surakarta City has not fulfilled the minimum requirement of 30% green space as required in Law No. 26 of 2007, so Surakarta still needs to fulfil about 1,072.84 ha. According to the land use distribution, the location with potential for GOS development is the Jebres Sub-district. This is because in the sub-district, there are still many riparian locations and unutilized areas that have the potential to be optimized as functional GOS. In addition, the Serengan Sub-district faces the biggest challenge. Besides being the sub-district with the smallest area, according to Rahman, Awaluddin, and Hani'ah (2016), Serengan is the sub-district with the least area of GOS, with the dominating form of GOS being the road border. The density of built-up land in Serengan Sub-district is an inhibiting factor in the development of GOS.

When looking at the distribution of GOS changes, the majority of changes cover an area of less than 0.35 ha. This statement is in line with the research by Zhou et al. (2018), which explains that small GOS areas are more vulnerable to change. Fragmented GOS tend to be more susceptible to land use changes, because small GOS usually do not receive as much supervision as large GOS. Large GOS usually have clear legal protection and are stipulated in the Regional Spatial Planning (RTRW), so conversion activities are more complicated.

Options for developing GOS in densely populated areas that can still be pursued include developing building spaces that function as GOS, optimizing existing GOS, and constructing environmentally friendly buildings in accordance with the Indonesian Green Blue Index (IHBI). Combining the calculation of blue open space and non-vegetated open space that have

GOS functions can benefit cities that are already densely built up, such as Surakarta. At the very least, with the IHBI approach, the city of Surakarta can still strive to achieve its 30% GOS target.

Analysis of Driving Factors on GOS Changes

Factors that allegedly affect the changes of GOS were analyzed using the logistic regression analysis method. Before being processed in SPSS, all variable data were converted into vectors so that distances could be calculated and classified. Logistic regression analysis could be performed when the data were ready to be entered into SPSS. The establishment of a logistic regression model of factors influencing the changes of GOS in Surakarta City for the 2003–2024 period was conducted using eleven independent variables consisting of population density, distance from road, distance from settlement, distance from river, slope, distance from government offices, distance from industry, distance from transportation facilities, distance from economic facilities, distance from tourist attractions, and distance from educational facilities.

The binary logistic regression method was performed using the forward stepwise conditional method. Regression modelling was performed by entering independent variables one by one. If the variable was significant, it was retained in the model, but if it was not significant, it was removed from the model. The significance level used was 5% (α = 0.05). The results of the logistic regression model contained only variables that were significant for GOS changes in Surakarta City.

Before analyzing the independent variables, a multicollinearity test was conducted. This test aimed to ensure that the regression model used did not experience distortion due to dependence between independent variables. The results of the multicollinearity test can be seen in Table 3. The VIF value of all independent variables showed values below 10. This indicated that there was no multicollinearity among the independent variables, so these variables can be used for logistic regression modelling.

Table 3. VIF Value of the Independent Variable

Variable	VIF
Distance to river	1.002
Distance to government offices	1.001
Distance to educational facilities	1.005
Distance to economic facilities	1.001
Distance to road	1.117
Distance to tourist attractions	1.459
Distance to industries	1.044
Distance to settlement	1.615
Distance to transportation facilities	1.118
Population density	1.601
Slope	1.363

Next, to determine the suitability and ability of the independent variables in explaining the dependent variable, the value of the coefficient of determination test results (Nagelkerke's R Square) varies from 0 (zero) to 1 (one). A lesser value means that the ability of the independent variables to explain the variation in the dependent variable is minimal. A value close to one means that the independent variables provide almost all the information needed to predict variations in the dependent variable. Model summary information can be seen in Table 4.

Table 4. Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	979.947[a]	.023	.053
2	972.066[a]	.027	.063
3	956.407[a]	.036	.082
4	949.831a	.039	.091

Based on Table 4, it can be observed how the gradual addition of independent variables affects the model's ability to explain the variability of the dependent variable. With the addition of variables from Step 1 to Step 4, there is an increase in the Nagelkerke R Square value. The magnitude of the coefficient of determination in the logistic regression model can be seen in the Nagelkerke R Square value. Based on Table 4 above, the Nagelkerke R Square value in Step 4, which is the final model after all variables have been included, is 0.091 or 9.1%. This means that the dependent variable, namely the GOS changes, can be explained by 9.1% of the independent variability, while the remaining 90.9% is explained or influenced by other factors outside the research model.

Research conducted by Naufal et al. (2020) on the development of a mathematical model of land change in 2016-2018 in Pandaan District showed a Nagelkerke R Square value below 0.5, namely 0.453. Meanwhile, Gunadi's (2024) research on factors affecting GOS changes in Depok City produced a Nagelkerke R square value of 0.703 or equivalent to 70.3%. This could be because even though most of the predictor variables were the same, different cities had different characteristics of factors driving land use change. The Nagelkerke R Square value of 9.1% explains that the complexity of the phenomenon of GOS changes in Surakarta City cannot be explained just by the physical-environmental variables used in this study, so it is necessary to consider additional factors beyond the scope of the current model.

Simultaneous testing was used to check all coefficients in the model simultaneously or as a whole. Testing using the Omnibus Test of Model Coefficients is divided into three parts: Step, Block, and Model. The following are the results of simultaneous parameter testing obtained through the Omnibus Test of Model Coefficients table. The results of simultaneous parameter testing can be seen in Table 5.

Table 5. Omnibus Test of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	41.839	1	.000
	Block	41.839	1	.000
	Model	41.839	1	.000
Step 2	Step	7.881	1	.005
	Block	49.719	2	.000
	Model	49.719	2	.000
Step 3	Step	15.659	1	.000
	Block	65.378	3	.000
	Model	65.378	3	.000
Step 4	Step	6.576	1	.010
	Block	71.954	4	.000
	Model	71.954	4	.000

The results show that the overall Sig. value is < 0.05. Since this value is < 0.05, the model is statistically significant, or there is at least one independent variable that simultaneously affects the variable of GOS reduction in Surakarta City.

The regression coefficient of each independent variable tested provides information on the relationship between variables using the regression test results shown in the Sig. column. The testing criteria used a confidence level of 95% or a significance level of 5% ($\alpha = 0.05$).

Hypothesis testing was conducted to examine the effect of independent variables (X), consisting of distance to roads, distance to settlements, distance to transportation facilities, population density, and slope, on the decline in GOS area in Surakarta City. Table 6 shows column B, which indicates the coefficient values for each variable. The results of logistic regression analysis explain that distance to roads, distance to settlements, distance to transportation facilities, and population density have a significant effect on GOS area changes in Surakarta. These coefficient values were used to formulate the logistic regression equation, resulting in the following mathematical model of GOS changes in Surakarta City: $Y = -0.601 + 0.026X5 - 0.024X8 - 0.002X9 - 0.005X10$.

Table 6. Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 4	X5	.026	.009	7.962	1	.005	1.027
	X8	-.024	.006	17.120	1	.000	.976
	X9	-.002	.000	26.976	1	.000	.998
	X10	-.005	.001	15.232	1	.000	.995
	Constant	-.601	.301	3.994	1	.046	.548

Note: B: Unstandardized Coefficient, S.E.: Standard Error, Wald: $[B/S.E.]^2$, df: Degrees of Freedom, Sig.: Significance, Exp(B): Odds Ratio

The measurement of the probability of the dependent variable for each unit change in the independent variable can be seen from the OR = odds ratio or Exp(B) value, assuming that other variables in the model remain constant. If the value of Exp(B) > 1, it can be interpreted that as the independent variable increases, the likelihood of event Y occurring also increases. However, if the value of Exp(B) < 1, then as the independent variable increases, the likelihood of event Y occurring decreases. If the value of Exp(B) = 1, the independent variable does not affect the likelihood of event Y occurring.

For significant level α of 5%, of the 11 independent variables tested, there are four variables namely distance to the road (X5), distance to settlements (X8), distance to transportation facilities (X9), and population density (X10) that affect the decline of GOS in Surakarta City. The results in table 6 show that the distance to the road (X5), distance to settlements (X8), distance to transportation facilities (X9), and population density (X10) have significant values of 0.005, 0.000, 0.000, and 0.000 respectively (smaller than $\alpha = 0.05$) therfore H5, H8, H9, and H10 are accepted. Thus it can be interpreted that the results of statistical calculations show that the distance to the road (X5), distance to settlements (X8), distance to transportation facilities (X9), and population density (X10) partially have a significant effect on the decline of GOS area (Y).

The distance to the road (X5) has a coefficient (B) of 0.026. It shows a significant effect on GOS changes in Surakarta City, with a significance value of 0.005, which is smaller than the specified significance level ($\alpha = 0.05$). A positive coefficient indicates that the direction of the variable's influence is also positive. This indicates that the greater the distance of an area from the road, the greater the likelihood of GOS change. This may contradict the assumption that the closer the GOS is to the road, the easier it is for the GOS to undergo land use change (Martins, 2022). However, there are several possibilities that cause the likelihood of GOS change to increase the further away it is from the road. The distance of GOS to the road has an Exp(B) value of 1.027, which means that for every one-unit increase in distance to the road, the likelihood of GOS change increases by 1.027 times or 2.7%. In other words, the farther the distance of GOS from the road, the higher the likelihood of a decrease in GOS area. This may occur due to the redistribution of urbanisation pressure, where GOS in areas further away from primary road infrastructure becomes a target for development expansion. This phenomenon may occur because of the lower potential land prices in suburban areas, supported by the potential for leniency in regulatory enforcement compared to GOS in the city centre. The crowded conditions in downtown Surakarta have caused development pressure to shift away from the city centre and spread to surrounding areas, particularly the border areas between Surakarta and its satellite regions. The availability and lower prices of land outside the city, combined with easier road access than in the city centre, have attracted developers to build housing and other types of buildings. In addition, GOS located close to roads are likely to have already been designated as GOS by the local government and are strictly monitored, unlike GOS far from roads, which may have looser regulations and less strict monitoring. Nevertheless, this assumption does not rule out the possibility that GOS near roads may have already changed function long before 2002, considering that Surakarta was once the capital of the Mataram Kingdom, which since then has dense human activity. However, the approximate location of GOS relative to the road needs to be taken into account to determine whether it will operate effectively (Caesarina & Rahmani, 2019).

The distance to settlements (X8) has a coefficient (B) of -0.024. It shows a significant effect on GOS changes area in Surakarta City, with a significance value of 0.000, that is smaller than the specified significance level (α = 0.05). A negative coefficient indicates that the direction of the variable's effect is also negative. This indicates that the greater the distance between GOS and settlement areas, the lower the likelihood of GOS change. It can be concluded that proximity to settlement areas is a driving factor for GOS changes in Surakarta City. This may be because GOS located close to settlement areas are small in size and therefore vulnerable to land use change. The distance to settlement areas has an Exp(B) value of 0.976, which means that for every one unit increase in distance to settlement areas, the probability of GOS changing area decreases by 0.976 times or 2.4%. The further the distance of GOS from settlement areas, the lower the probability of GOS changing area. GOS located near settlement areas tend to be more vulnerable to infrastructure expansion or commercial development. Although the influence is relatively small, this can occur because the closer to settlement areas, the higher the demand for land conversion. This finding is supported by research by Li et al. (2015), which states that in urban areas in Shanghai, China, old settlement areas that have been built for a long time have the smallest GOS coverage compared to other types of land use, such as new housing or villa housing.

The distance to transportation facilities (X9) has a coefficient (B) of -0.002. It shows a significant effect on GOS changes area in Surakarta City, with a significance value of 0.000, that is smaller than the specified significance level (α = 0.05). A negative coefficient indicates that the direction of the variable's effect is also negative. This indicates that the greater the distance of GOS is to transportation facilities, the lower the likelihood of GOS decline. Conversely, the closer to transportation facilities, the greater the likelihood of GOS decline. This result is in line with the discussion on GOS changes based on typology, where rail boundaries have undergone significant changes. The expansion of the Tirtonadi Terminal in Surakarta is known to have used part of the Tirtonadi Park land. The Exp(B) value of X9 or the distance to transportation facilities is 0.998, which means that for every one unit increase in the distance to transportation facilities, the possibility of changes in GOS area decreases by 0.998 or 0.2%. This result shows that the further the distance of GOS from transportation facilities, the lower the probability of GOS changing area, although it is relatively small. In line with the research by Nurjanah et al. (2012), which shows that the construction of the Kertawangunan terminal in Kuningan caused land use changes, particularly for the improvement of bus roads. Another study supporting this finding was conducted by Li et al. (2019), which states that land use around train stations in the city of Qingdao is dominated by housing and shows a phenomenon of agglomeration. Meanwhile, in Semarang, there has been a change in the use of undeveloped land around stations or railroad tracks; the land is being converted into illegal buildings that have the potential to become slums around railroad tracks and train stations (Aspin & Nafsi, 2021).

Population density (X10) has a coefficient (B) of -0.005. It shows a significant effect on GOS change area in Surakarta City, with a significance value of 0.000, that is smaller than the specified significance level (α = 0.05). A negative coefficient indicates that the direction of the effect of the population density variable is also negative. This result indicates that the higher the population density, the lower the probability of GOS change. In fact, this finding contradicts the general assumption that the more densely populated an area is, the higher the probability of land change (Fajarida, 2024). The results of this study are in line with the research conducted by Kusrini et al. (2011), which found that the greater the land change, the smaller the population. This is assumed because in densely populated locations, there is no remaining GOS that can be converted anymore. Furthermore, variable X10, or population densit,y has an Exp(B) value of 0.995, which means that for every one unit increase in population density, the probability of GOS change decreases by 0.995 times or 0.5%. This shows that the higher the population density, the lower the probability of GOS changing area. It should be noted that there is a negative correlation between the population density variable and GOS are change. Instead of increasing GOS conversion, based on the statistical results of this study, high density is actually associated with a lower probability of GOS change. This can be interpreted as an indicator of urban saturation, where in areas that have reached a saturation point of development, the remaining GOS is minimal, so that the pressure for horizontal conversion shifts to other areas that have land reserves or development expands vertically.

However, it should be noted that this regression model has a Nagelkerke R Square value of 9.1%, while the remaining 90.9% is explained by or influenced by other factors outside the research model. Other factors that can affect the decline of GOS area in Surakarta City include changes in spatial planning policies, inadequate supervision of building construction permits, land prices, natural disasters, and changes in socio-economic conditions (Li et al., 2025).

Besides the driving factors of the declining GOS area mentioned above, the local government needs to consider other factors and conditions before formulating the newest regional spatial planning especially, regarding GOS regulation. Priority areas for public GOS provision are determined based on the public GOS fulfillment level. Areas with a higher percentage of fulfillment have a lower priority. The least amount of land available in each sub-district is also a benchmark for determining priority areas for public green space (Juanda, 2025).

Conclusion

The area of GOS in Surakarta City has continued to decline from 2002 to 2024. In 2002, the green space area was 360.95 ha (7.72% of the total area), then decreased to 341.18 ha (7.30%) in 2013, and decreased again to 328.76 ha (7.04%) in 2024. Surakarta City has not met the minimum requirement of 30% GOS area and needs to allocate approximately 1,072.84 ha or 22.96% of the total area for GOS. The results of the logistic regression analysis show a Nagelkerke R Square value of 9.1%, meaning that 90.9% of the GOS changes in Surakarta City are explained by factors outside the research variables. The factors that significantly influence the decline in GOS area in Surakarta City are distance to roads, distance to settlements, distance to transportation facilities, and population density. Further research is needed on the external factors that were not explained in this study. The Surakarta City government needs to strengthen policies and tighten supervision of building permits, ensure consistency between the RTRW and its implementation in the field, optimize existing GOS, and design a GOS development plan in potential locations.

Acknowledgments
The authors extend our gratitude to Regional Development Planning Agency of Surakarta City, Environmental Service of Surakarta City, Public Works and Housing Agency of Surakarta City, and Tropical Biodiversity Conservation Study Program.

Author Contributions
S.D.L.: Writing & Editing; R.H.: Conceptualization & Review; Y.S.: Analysis & Review. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

References

Arifah, N., & Susetyo, C. (2018). Penentuan Prioritas Ruang Terbuka Hijau berdasarkan Efek Urban Heat Island di Wilayah Surabaya Timur. *Jurnal Teknik ITS*, *7*(2), 143-148. https://doi.org/10.12962/j23373539.v7i2.32454

Aspin, A., & Nafsi, N. (2021). Pola Sebaran permukiman kumuh (studi kasus: Kecamatan Semarang Utara Kota Semarang). *Nature: National Academic Journal of Architecture*, *8*(1), 39-52. https://doi.org/10.24252/nature.v8i1a4.

Broto, B. E. (2019). Pengaruh disiplin kerja dan pengalaman kerja terhadap kinerja pegawai di kantor badan pusat statistik Kabupaten Labuhan Batu. *Informatika: Jurnal Ilmiah Fakultas Sains dan Teknologi, Universitas Labuhanbatu*, *7*(2), 50-67. https://doi.org/10.36987/informatika.v7i2.1336

Caesarina, H. M., & Rahmani, D. R. (2019). Penyediaan ruang terbuka hijau dengan pendekatan kota hijau di Perkotaan Martapura. *Jurnal Planoearth*, *4*(1), 11-17. https://doi.org/10.31764/jpe.v4i1.712

Fajarida, D. R. (2024). Permasalahan tata ruang kota di Tangerang: analisis konflik antara kepadatan penduduk dan ruang hijau. *Filosofi*, *1*(4), 301-308.https://doi.org/10.62383/filosofi.v1i4.443

Gunadi, S. P. (2024). *Permodelan spasial prediksi perubahan ruang terbuka hijau di Kota Depok*. Retrieved from https://repository.ipb.ac.id/handle/123456789/160100

Handayani, M. N., Sasmito, B., & Wijaya, A. P. (2017). Analisis Hubungan antara Perubahan Suhu dengan Indeks Kawasan Terbangun Menggunakan Citra Landsat (Studi Kasus : Kota Surakarta). *Jurnal Geodesi Undip*, *6*(4), 208–2018. https://doi.org/10.14710/jgundip.2017.18145

Juanda, T., Sugiarto, A., Nuraini, C., & University of Pembangunan Panca Budi. (2025). Land utilization as green open space and city park as public space in Lima Puluh District, Batu Bara Regency, North Sumatra Province. *Journal of Information Technology, Computer Science and Electrical Engineering (JITCSE), 2*(1), 161–168. https://doi.org/10.61306/jitcse.v2i1.184

Kusrini, Suharyadi, & Su R. H., (2011). Perubahan penggunaan lahan dan faktor yang mempengaruhinya di Kecamatan Gunungpati Kota Semarang. *Majalah Geografi Indonesia*, *25*(1), 25-40. https://doi.org/10.22146/mgi.13358

Kutner, M.H., Nachtsheim, C.J., Neter, J. & Li, W. (2005). *Applied Linear Statistical Models.* New York: Mc Graw Hill.

Li, W., Bai, Y., Zhou, W., Han, C., & Han, L. (2015). Land use significantly affects the distribution of urban green space: case study of Shanghai, China. *Journal of Urban Planning and Development*, *141*(3), 1-9. https://doi.org/10.1061/(ASCE)UP.19435444.00002

Li, T., Chen, Y., Wang, Z., Liu, Z., Ding, R., IEEE Member, & Xue, S. (2019). Analysis of jobs-housing relationship and commuting characteristics around urban rail transit stations. *IEEE Access*, 7, 175083-175092. https://doi.org/10.1109/ACCESS.2019.295746

Li, J., Lin, F., & Chen, Y. (2025). Spatio-temporal patterns of the construction and development of urban open spaces in Macau from 1889–2020. *Journal of Asian Architecture and Building Engineering*, 1–23. https://doi.org/10.1080/13467581.2025.2458807

Mardiansjah, F. H., Handayani, W., & Setyono, J. S. (2018). Pertumbuhan Penduduk Perkotaan dan Perkembangan Pola Distribusinya pada Kawasan Metropolitan Surakarta. *Jurnal Wilayah Dan Lingkungan*, *6*(3), 215. https://doi.org/10.14710/jwl.6.3.215-233

Martins, B. 2022. Where to construct new urban green spaces to be at the recommended distance from users and to complement existing ones? A study in five cities of northern Portugal. *Urban Forestry & Urban Greening*, *72*, 1-10. https://doi.org/10.1016/j.ufug.2022.127571

Matsuda, M., Nasrullah, N., & Sulistyantara, B. (2018). Study about factors influencing transition of green open spaces based on analysis of land use in Depok City, West Java, Indonesia. *IOP Conference Series Earth and Environmental Science*, *179*, 012035. https://doi.org/10.1088/1755-1315/179/1/012035

Naufal, M., & Susetyo, C. (2020). Prediksi perubahan penutupan lahan pasca beroperasinya gerbang TOL (interchange) Pandaan di Kecamatan Pandaan Kabupaten Pasuruan menggunakan metode regresi logistik biner. *Jurnal Teknik ITS, 9*(1), 53-59. https://doi.org/10.12962/j23373539.v9i1.48278

Nurjanah, E. N., & Purwandari, H. (2012). Alih fungsi lahan: potensi pemicu transformasi desa - kota (studi kasus pembangunan terminal tipe A "Kertawangunan"). *JSEP (Journal of Social and Agricultural Economics)*, *6*(3), 53-68. Retrieved from https://sl1nk.com/9brKS

Putra, M. R. R., & Rudiarto, I. (2018). Simulasi perubahan penggunaan lahan dengan konsep celluler automata di Kota Mataram. *Jurnal Pengembangan Kota*, *6*(2), 174-185. https://doi.org/10.14710/jpk.6.2.174-185

Rahman, M. D., Awaluddin, M., & Hani'ah, H. (2016). Analisis Spasial Ketersediaan Ruang Terbuka Hijau Terhadap Jumlah Penduduk di Kota Solo. *Jurnal Geodesi Undip*, *5*(3), 41–51. Retrieved from http://ejournal3.undip.ac.id/index.php/geodesi/article/view/12821

Rawung, F. C. (2015). Efektivitas Ruang Terbuka Hijau (RTH) dalam mereduksi emisi Gas Rumah Kaca (GRK) di kawasan Perkotaan Boroko. *Media Matrasain*, *12*(2), 17-32.https://doi.org/10.35793/matrasain.v12i2.9204

Sapriyadi, M., Milantara, N., Fauzan, Putra, T. H. A., & Fakhruzy. (2024). Minat warga dalam memanfaatkan RTH saat pandemic Covid-19 (studi kasus Taman Kota Syech Kukut, Kota Solok). *Journal of Forest Science Avicennia*, *7*(1). 48-64. https://doi.org/10.22219/avicennia.v7i1.31203

Schuch, G., Serrao-Neumann, S., Morgan, E., Choy, & D. L. (2017). Water in the city: green open spaces, land use planning and flood management – An Australian case study. *Land Use Policy*, *63*, 539-550. https://doi.org/10.1016/j.landusepol.2017.01.042

Setiawan, B., & Piggawati, B. (2014). Penentuan prioritas ruang terbuka hijau di kecamatan serengan kota

Surakarta. *Jurnal Teknik PWK*, *3*(1), 145-153. https://doi.org/10.14710/tpwk.2014.4443

Wardani, A. K., Cahyono, A. B., & Martono, D. B. (2016). Analisis metode delineasi bidang tanah pada citra resolusi tinggi dalam pembuatan kadaster lengkap. *Jurnal Teknik ITS*, *5*(2), 380-384. https://doi.org/10.12962/j23373539.v5i2.17173

Wibisono, P., Miladan, N., & Utomo, R. P. (2023). Hubungan Perubahan Kerapatan Vegetasi dan Bangunan terhadap Suhu Permukaan Lahan: Studi Kasus di Aglomerasi Perkotaan Surakarta. *Desa-Kota*, *5*(1), 148-162. https://doi.org/10.20961/desa-kota.v5i1.63639.148-162

Wicaksono, R. A., & Zuharnen, Z. (2017). Pemanfaatan Citra Penginderaan Jauh Resolusi Tinggi dan Sistem Informasi Geografis (SIG) untuk Menentukan Lokasi Prioritas Pembangunan Ruang Terbuka Hijau (RTH) di Kota Surakarta. *Jurnal Bumi Indonesia*, *6*(3), 1-8. Retrieved from http://etd.repository.ugm.ac.id/penelitian/detail/114620

Yu, P., Wei, Y., Ma, L., Wang, B., Esther H.K. Yung, & Chen, Y. (2024). Urbanization and the urban critical zone. *Earth Critical Zone*, *1*(1), 1-11. https://doi.org/10.1016/j.ecz.2024.100011

Zahrotunisa, S., Jatmiko, R.H., & Widyatmanti, W. (2020). Analisis pengaruh suhu permukaan lahan terhadap elemen iklim mikro di Surakarta menggunakan citra penginderaan jauh multitemporal. *Majalah Ilmiah Globë*, *22*(1), 31-40. https://doi.org/10.24895/MIG.2020.22-1.952

Zhou, W., Wang, J., Qian, Y., Pickett, S. T. A., Li, W., & Han, L. (2018). The rapid but “invisible” changes in urban greenspace: A comparative study of nine Chinese cities. *Science of the Total Environment,* 627, 1572-1584. https://doi.org/10.1016/j.scitotenv.2018.01.335