p-ISSN 2460-0768 e-ISSN 2597-6044
https://doi.org/10.20961/ge.v9i2.72638
GeoEco, Vol. 9, No 2. July 2023 Page. 198-214
https://jurnal.uns.ac.id/GeoEco/article/view/72638

DETERMINING TRANS JOGJA BUS STOP LOCATIONS USING A COMBINATION OF SPATIAL ANALYSIS AND FUZZY LOGIC

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ARTICLE INFO

Article History
Received : 28/03/2023
Revised : 15/06/2023
Accepted : 02/07/2023

Citation:
Yudinugroho, M., Apriyanti, D., Lidyani, L., (2023). Determining Trans Jogja Bus Stop Locations Using a Combination of Spatial Analysis and Fuzzy Logic. GeoEco. Vol. 9, No. 2.

ABSTRACT

The increase in population from migration coupled with natural growth resulted in a high population density in Yogyakarta City, with a negative impact of traffic congestion due to the number of vehicles that were not proportional to road capacity. One of the efforts to lessen congestion was through efficient public transportation. Trans Jogja can be one of the solutions to this problem. However, despite having up to 90 stops in Yogyakarta City, the existing stop locations are not evenly distributed. Thus, in order to propose appropriate bus stop locations, this study aimed to utilize the weighting and utilization of GIS, based on a number of factors usithe ng fuzzy logic method. The result showed that the weight of eh parameter also influenced locations with a high suitability. Values with a high match were pixel values ranging from 6.824 to 9.49. The location of high suitability was close to the road around the location with a high level of crowds, such as office areas, shopping centers, hotels, educational facilities, and tourism. This study proved that fuzzy logic could be used as a tool in spatial analysis to obtain criteria for a location by considering the probability of correctness of each selected parameter.

Keywords: *bus stop locations; fuzzy logic method; public transportation; spatial analysis; traffic congestion.*

INTRODUCTION

Yogyakarta City, uniquely coined as a home for tourists and education, brought forth many migrants, and with the substantial role of tourism and education sectors, resulted in the emergence of urbanization in Yogyakarta. The increase in population from migration coupled with well-preserved natural environmental growth resulted in a high population density in Yogyakarta City. According to data from the Central Statistics Agency-Badan Pusat Statistik (BPS), from 2014 to 2017, the population growth rate of Yogyakarta City was 1.13%. With high population growth, the population of Yogyakarta City in 2017 was recorded at 422.732 people with a population density of 13,007 people/km². One negative impact of the highest density and population growth was traffic congestion due to the number of vehicles that were proportional to road capacity.

Based on a survey conducted by the Inrix research institute quoted by Tribun Jogja and Kompas.com, congestion in Yogyakarta ranked 4th in Indonesia and 60th globally (Raharjo, 2018; Ramadhiani, 2018). The number of private vehicles recorded by BPS amounted to 490,427 in 2017, exceeding the road capacity in Yogyakarta City. Susanto et al. (2014) stated that the degree of saturation on one of the roads in Yogyakarta City, namely Jalan Urip Sumoharjo, exceeded its ideal limit.

Various problems regarding motorized vehicles in Yogyakarta City can be caused by no regulations to accomodate the minimum number of passengers on four-wheeled vehicles. Of these shortcomings, one of the efforts that can be made is through efficient public transportation. Trans Jogja, which operates in Yogyakarta City and its surrounding areas, can be one of the solutions to decrease congestion. However, although the Trans Jogja bus network was recorded to have 90 stops in Yogyakarta City, the existing stop locations are not evenly distributed.

In selecting appropriate bus stop locations, some crucial factors which came into play were environmental conditions of the existing bus stop facility, accessibility, and the function of said bus stop, which could serve as a shelter or transit point (Corazza, 2019). There were several methods in selecting locations to evaluate and plan transportation, one of them namely through GIS modelling. Utilization of GIS technology can increase the feasibility and time efficiency (Demi et al., 2016). Other applications using GIS approach are network analysis, spatial multi-criteria analysis, analytical hierarchy process, and application of fuzzy logic (Corazza & Favaretto, 2019; Pourghasemi et al., 2012).

Previous study by Huang (2014) combined the computation using raster and vector data to optimise bus stop distribution. Compared to Saghapour et al. (2016) which examined the effect of public transport service frequency and population density. The result shows Public Transport Accessibility Index (PTAI) provides a practical means of measuring levels of accessibility within metropolitan areas. Unfortunately, none of them combines the method with fuzzy logic to create a spatial model of bus stops. Selecting new bus stops using spatial optimisation can be used to enhance strategic planning (Shatnawi et al., 2020).

Fuzzy logic is an invention from Boolean operators which state that a value is not limited to only the numbers 0 and 1, and there are other values between those two numbers, such as 0,01 to 0,99 (Gartner et al., 2008). Fuzzy logic can be applied to many computation, Astuti et al. (2021) used fuzzy to evaluate the deployment of public transportation while Zhu et al. (2014) experienced fuzzy and GIS to create landslide susceptibility map. Hence, fuzzy method is able to give a larger range of values in spatial probability if used in spatial analysis. Thus, this study aimed to utilize the weighting and utilization of GIS based on a number of factors in selecting bus stop locations using the fuzzy logic method.

MATERIALS AND METHODS

Materials

Materials in this studi shown in **Table 1**.

Table 1. Sources of the data

Data	Sources
Distribution of offices, shopping centers, hotels, education, and tourism in Yogyakarta City	Open Street Map
Distribution of industries and parks in Yogyakarta City	
Location of bus stops in Yogyakarta City	
Land cover data in the form of forests, rivers, agriculture, and vacant land in Yogyakarta City	Indonesian Digital Topographic Map Page 1408-223 & 1408-224
Highway function data in Yogyakarta City	
Topographic data in Yogyakarta City	

Source: Researcher Analysis, 2023

Criteria

There were several criteria for creating bus stop locations. One was set in the criteria Directorate General of Land Transportation - Dirjen Perhubungan Darat No 271/HK.105/DRJD/96 (Table 1). Based on these criteria, it was modified to get a suitable location for making bus stops. In this case, it was used for updating existing Trans Jogja locations based on OSM data (March 25, 2019). Several other criteria which can be used were:

a. Bus stop locations with crowd centers were grouped based on high (0-200 m), medium (0-300 m), and low (750 m) crowds.
b. The proposed bus stop location of the existing bus stop with modifications to the Director General

p-ISSN 2460-0768 e-ISSN 2597-6044
https://doi.org/10.20961/ge.v9i2.72638

of Land Transportation criteria - Dirjen Perhubungan Darat No 271/HK.105/DRJD/96 About technical guidelines for engineering public passenger vehicle stops where the criteria for the city was 300 – 400 m from the previous location.

c. The bus stop location was within a radius of 10 m from the road
d. The location of the bus stop must be more than 200 m against the river.

Table 2. Bust stop location criteria

Zone	Land Usage	Location	Stopping Distance (m)
1.	The center of very crowded activity (markets, shops)	CBD, Urban	200-300
2.	Crowded (School, Office, Community Service)	Urban	300-400
3.	Residential areas	Urban	300-400
4.	Mix crowded (residential areas, schools, community service)	Suburban	300-500
5.	Mix Low-Crowded (residential areas, fields, bare land)	Suburban	500-1000

Source: Decree of the Director General of Land Transportation NO: 271/HK 105/DRJD/96

Based on the conceptual model and spatial processing, several fuzzy can be used in SAGA software, including sigmoidal, Jshaped, and linear. The difference in the fuzzy is that the value. Obtained from the graph formed, as shown in **Figure 1.**

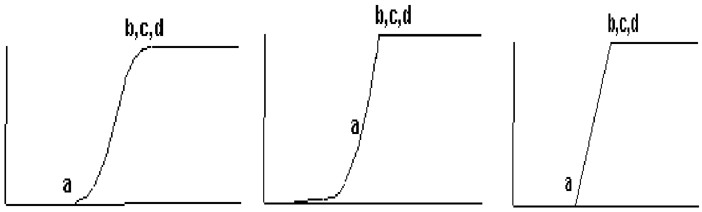

Figure 1. Graphs using fuzzy sigmoidal (left), Jshaped (center), and linear (right)
Source: (Modified Zhu et al., 2014)

The fuzzy logic used in this experiment was linear, where linear fuzzy was mathematically written as the following:

$\mu(x) = 0 \; if \; x < \min \mu(x) = 1 \; if \; x > max,$ otherwise $\mu(x) = \frac{(x - \min)}{(\max - \min)}$

Where min and max referred to user input.

Weighting Method of Each Parameters

a. High Crowd Location

The distance to the high school center (offices, shopping centers, hotels, educational facilities, tourism) was at least 200 m with a score of 1. Furthermore, a fuzzy analysis was carried out with a radius of more than 200 m with a score of 0. Fuzzy analysis table at high-crowd locations shown in **Table 3.**

Table 3. Fuzzy analysis table at high-crowd locations

Distance Criteria	Fuzzy Weighting
Located in a radius of 0 – 200 m from high crowd points.	1
Located in a radius of 200 – 300 m from high crowd points	1 - 0
Located at a radius of more than 300 m	0

FUNCTION:
If (dist≤200) f_highcrowd= 1

If (dist 200 - 300) f_highcrowd = $\frac{x-200}{300-200}$
if (dist≥300) f_highcrowd= 0

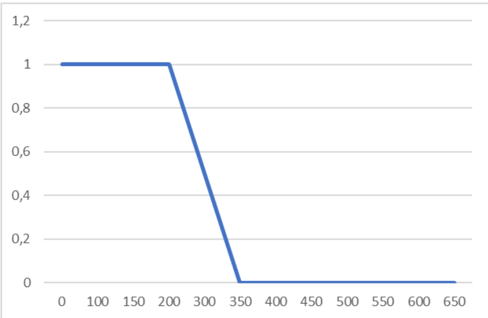

Figure 2. Fuzzy analysis charts in high crowd locations

b. Medium Crowd Location

Distance to medium crowd centers (industry, health facilities, and parks) with a minimum stopping distance of 300 m with a weight of 1. Furthermore, fuzzy analysis with a radius of 300 – 400 and more than that weighted 0. Fuzzy analysis table in medium crowd locations shown in **Table 4.**

Table 4. Fuzzy analysis table in medium crowd locations

Distance Criteria	Fuzzy Weighting
Located in a radius 0 – 300 m from medium crowd points.	1
Located in a radius of 300 – 400 m from medium crowd points.	0 - 1
Located at a radius of more than 400 m.	0

FUNCTION:
If (dist≤300) f_mediumcrowd = 1

If (dist 300 - 400) f_mediumcrowd = $\frac{(x-300)}{(400-300)}$
if (dist≥300) f_mediumcrowd = 0

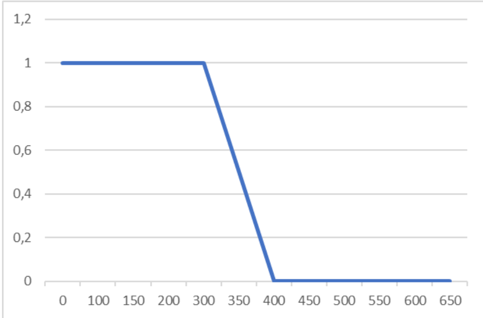

Figure 3. Fuzzy graph analysis at medium crowd location

c. Low Crowd Location

Distance to low crowd centers (forest, agriculture, freshwater, and vacant land) with an ideal distance of 750 m. In the process, fuzzy analysis was carried out with a radius of 500 – 750 m and 750 – 1000 m. More than that weighted 0. Fuzzy analysis table in low crowd locations shown in **Table 5.**

Table 5. Fuzzy analysis table in low crowd locations

Distance Criteria	Fuzzy Weighting
Located in radius 0 - 500 m	0
Located in a radius of 500 – 750 m from low crowd points	0 - 1
Located in a radius of 750 – 1000 m from the low crowd point	1 - 1
Located at a radius of more than 1000 m	0

FUNCTION:
if (dist≥1000) f_lowcrowd = 0

If (dist 0 - 100) f_lowcrowd = $\frac{(x-0)}{(1000-0)}$

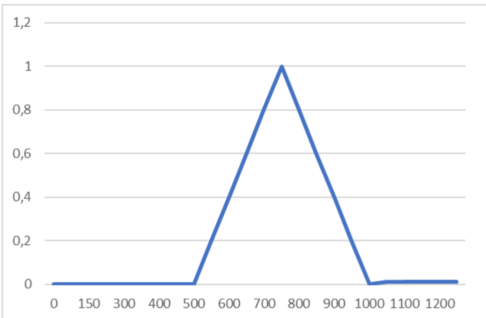

Figure 4. Fuzzy graph analysis at low crowd location

d. Existing Bus Stops

The proposed bus stop location was 300 – 400m. The fuzzy process was carried out at a distance of 200 – 350 m and 400 – 500 m from the existing location. Fuzzy analysis table on existing bus stops shown in **Table 6.**

Table 6. Fuzzy analysis table on existing bus stops

Distance Criteria	Fuzzy Weighting
Located at a radius of less than 200 m	0
Located in a radius 200 – 300	0-1
Located within a radius of 300 – 400 m from the bus stop location	1
Located in radius 400 - 500 m	1-0
Located at a radius of more than 500 m	0

FUNCTION:
If (dist ≤200) f_bus= 0

If (dist 200 - 300) f_bus= $\frac{(x-200)}{(200-300)}$

If (dist 300 - 400) f_bus = 1

If (dist 400 - 500) f_bus =1- $\frac{(x-400)}{(500-400)}$

If (dist≥500) f_bus = 0

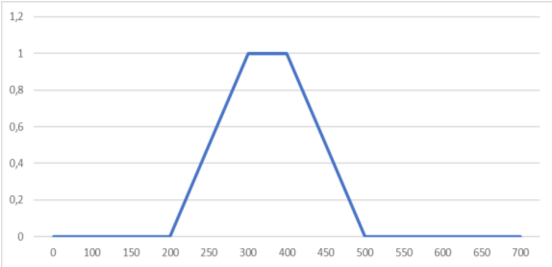

Figure 5. Fuzzy graph analysis at existing bus stop locations

e. Distance to Road

The ideal bus stop location was 10 m from the road body. Fuzzy distance to road analysis shown in **Table 7.**

Table 7. Fuzzy distance to road analysis table

Distance Criteria	Fuzzy Weighting
Located in radius 0 – 10 m from the road.	1
Located in a radius 10-20 m from the road.	1 - 0
Located at a radius of more than 20 m.	0

FUNCTION:

If (dist 0-10) f_road = $\frac{(x-0)}{(10)}$

If (dist 10 - 20) f_road = 1- $\frac{(x-10)}{(20-10)}$

if (dist≥100) f_road = 0

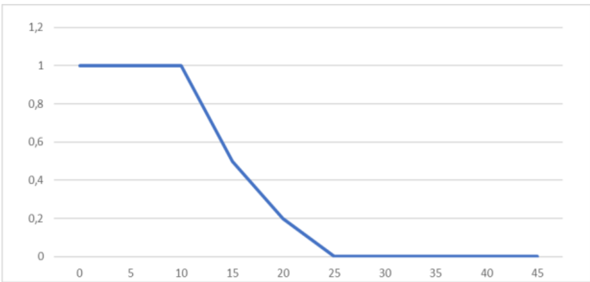

Figure 6. Fuzzy graph analysis distance against road

f. Degree of Slope

The location of the bus stop was on a flat morphology (0-2%) of Yogyakarta City. Fuzzy analysis table on slope morphology shown in **Table 8**.

Table 8. Fuzzy analysis table on slope morphology

Slope class	Fuzzy Weighting
0 – 8 % (Flat - Undullation)	1
> 8%	0

g. Population Density

The population had a large share in determining the location of bus stops. The location of bus stops was classified based on population density in each sub-district. Fuzzy analysis table on population density shown in **Table 9.**

Table 9. Fuzzy analysis table on population density

Population	Fuzzy Weighting
0 – 12500	0
> 12500	1

h. Distance from River

The location of the bus stop was credibly made with a distance of more than 200 m. This was done to avoid overflowing river flows or flooding impacts. Distance from river based on fuzzy criteria shown in T**able 10.**

Table 10. Distance from river based on fuzzy criteria

Distance Criteria	Fuzzy Weighting
Located in radius 200 m	0
Located at a radius of more than 200m	1

i. Weighting Calculation

Weighting Formula = $\frac{max\ value - min\ value}{Number\ of\ classes}$

$= \frac{9,5 - 1,5}{3} = 2,66$

Weighting Calculation shown in **Table 11.**

Table 11. Weighting Calculation Table

Distance Criteria	Weighting
High Crowds	2
Medium Crowds	1
Low Crowd	1
Distance from existing bus location	1
Distance to the road	2
Slope morphology	1
Population Density	0,5
River Distance	1
TOTAL	9,5

j. Weighting result

Weighting Results shown in **Table 12.**

Table 12. Weighting Results Table

Location suitability	Total Fuzzy Weighting	Description
Alternative I	1.5 – 4.164	Not Suitable
Alternative II	4.165 – 6.824	Less Suitable
Alternative III	6.824 -9.49	Very Suitable

RESULTS AND DISCUSSION

Results

The process of making the latest Trans Jogja location suitability map began with processing vector data into raster data. The process made use of Euclidean Distance tools for parameters of high-crowd locations, medium-crowd locations, low-crowd locations, and distance to old bus locations, road bodies, and river flow. In contrast, topography used slope tools, and population density used polygon to raster tools.

The process of making fuzzy logic using SAGA software. The process utilized fuzzify tools where the selected fuzzy processing was linear fuzzy. The processing interface was obtained with the following flow (**Figure 7**).

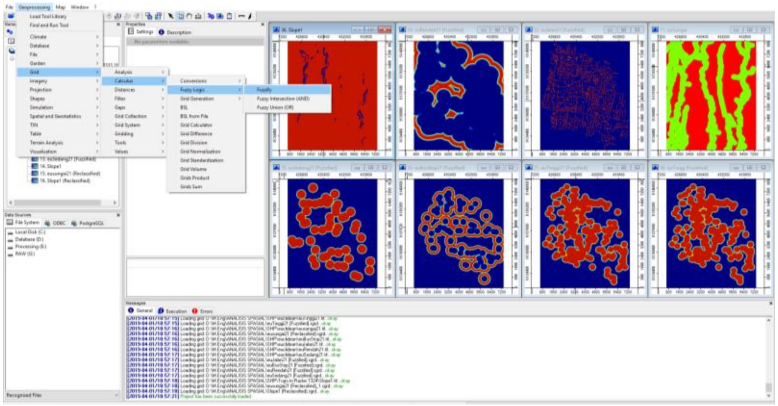

Figure 7. Interface of processing flow in SAGA

Module Fuzzify

Translates grid values into fuzzy set membership as preparation for fuzzy logic analysis.

- Author: Victor Olaya (c) 2004
- Specification: grid
- Menu: Grid|Calculus|Fuzzy Logic

Parameters

	Name	Type	Identifier	Description	Constraints
Input	Grid	Grid (input)	INPUT	-	-
Output	Fuzzified Grid	Grid (output)	OUTPUT	-	-
Options	A	Floating point	A	Values lower than A will be set to 0.	Default: 10.000000
	B	Floating point	B	Values between A and B increase from 0 to 1, values between B and C will be set to 1.	Default: 10.000000
	C	Floating point	C	Values between B and C will be set to 1, values between C and D decrease from 1 to 0.	Default: 10.000000
	D	Floating point	D	Values greater than D will be set to 0.	Default: 10.000000
	Membership Function Type	Choice	TYPE	-	Available Choices: [0] linear [1] sigmoidal [2] j-shaped Default: 0
	Adjust to Grid	Boolean	AUTOFIT	Automatically adjust control points to grid's data range	Default: 1

Figure 8. Fuzzify Module
(Source: http://www.saga-gis.org/saga_tool_doc/2.2.0/grid_calculus_11.html)

The results of each parameter using fuzzy and bolean were then calculated using a raster calculator. The following results were obtained in images in **Figure 9-15.**

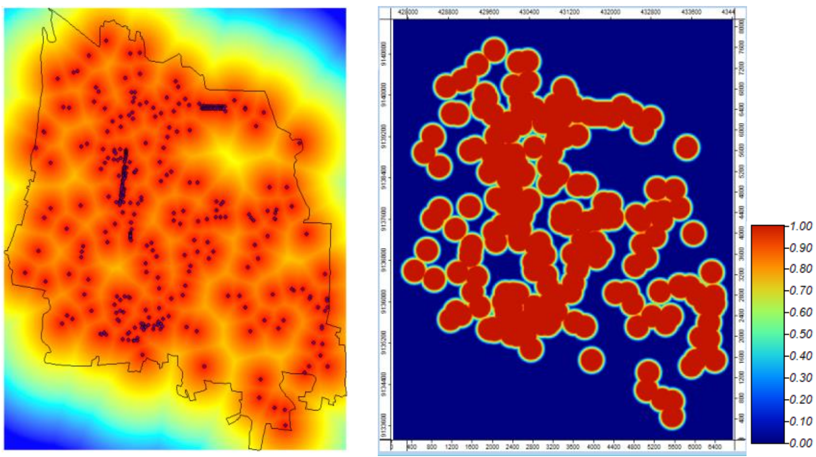

Figure 9. High crowd location data is a raster (left) and recalculated pixel values using fuzzy logic (right)

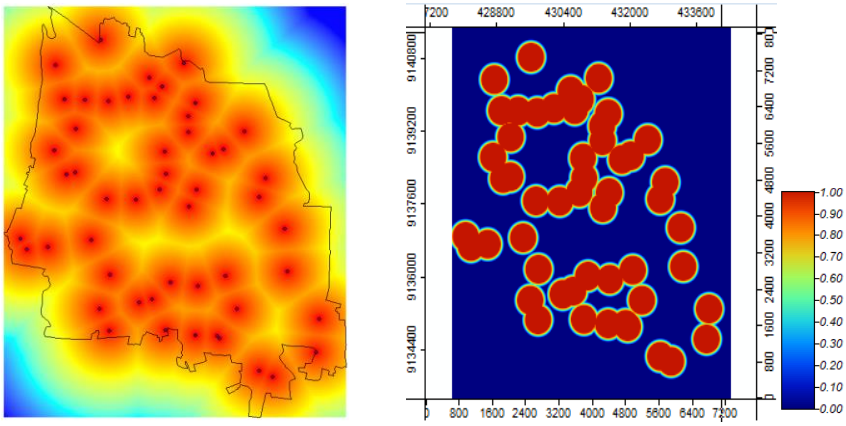

Figure 10. Medium crowded location data is being raster (left) and recalculated pixel values using fuzzy logic (right).

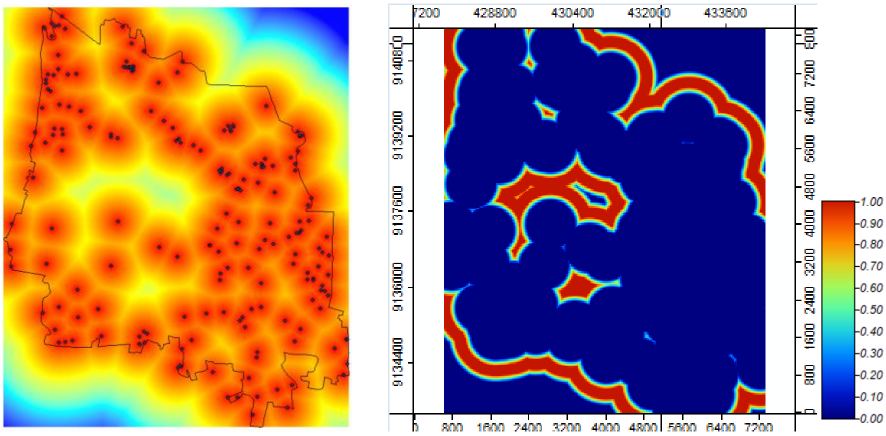

Figure 11. Low-crowd location data is used as raster data (left) and then recalculated pixel values using fuzzy logic (right).

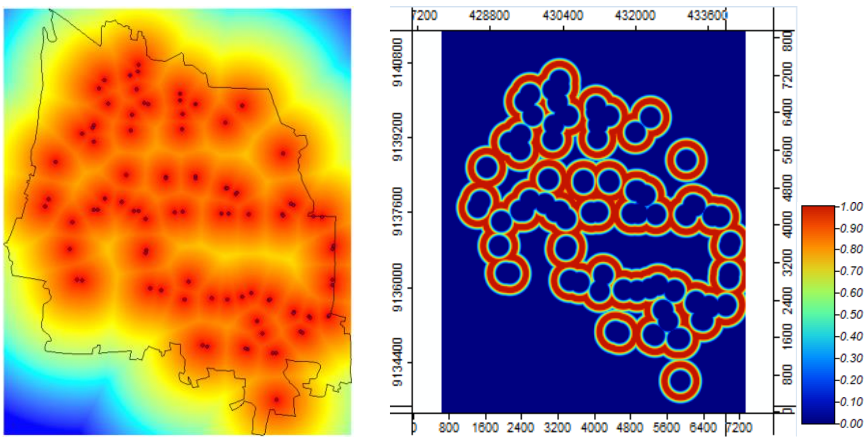

Figure 12. The existing bus stop location data is a raster (left) and then recalculated the pixel value using fuzzy logic (right).

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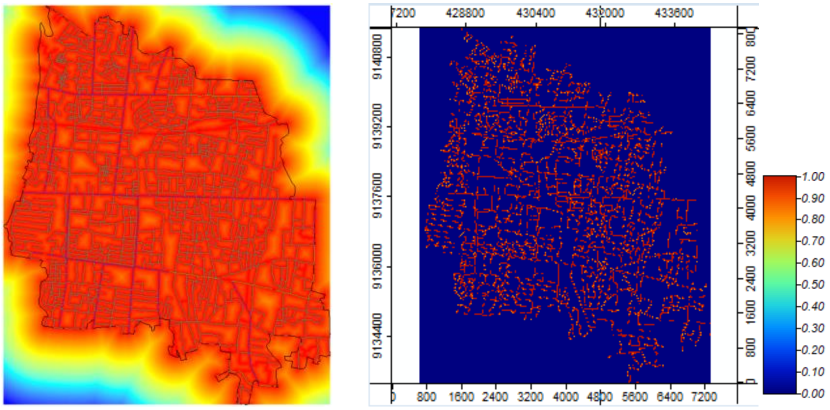

Figure 13. The road location data is formed into raster data (left) and then recalculated the pixel value using fuzzy logic (right).

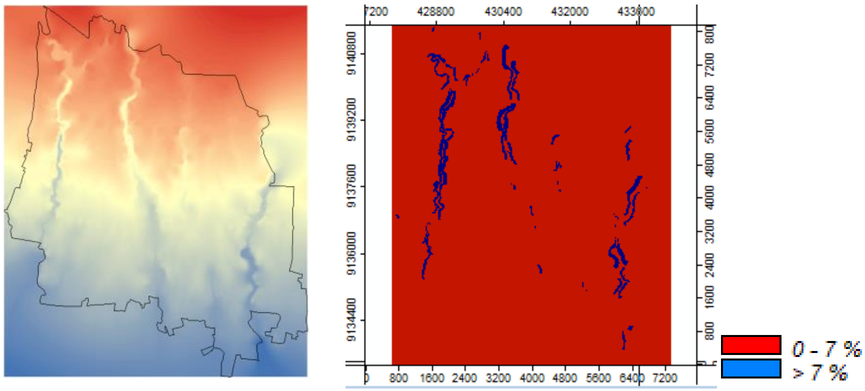

Figure 14. Digital Elevation Model data (left) and recalculated pixel values using fuzzy logic based on slope classification (right).

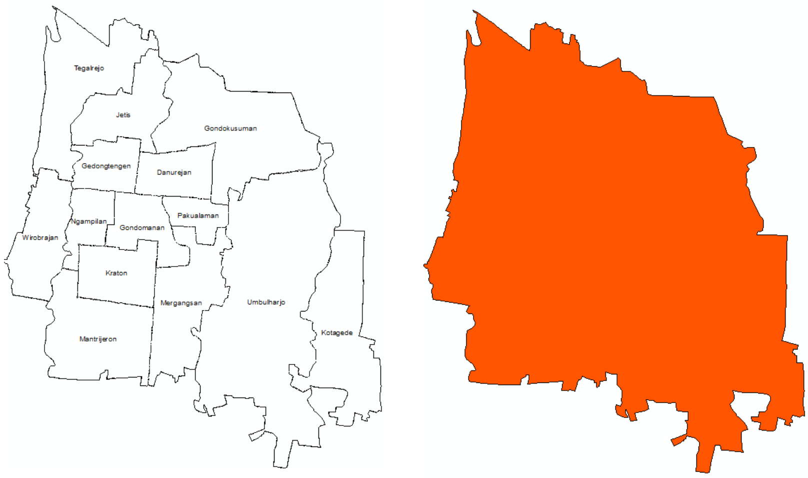

Figure 15. The population density value becomes homogeneous because all sub-districts are classified as having high density.

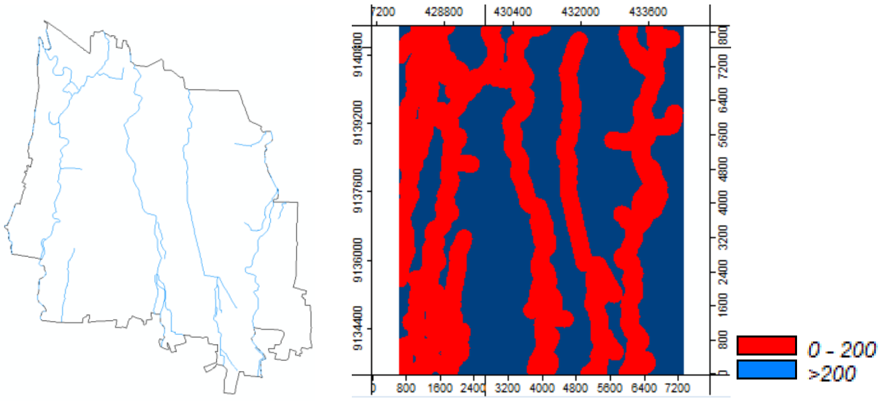

Figure 16. Euclidean Distance from the river

Several spatial data, namely **Figure 15**, **Figure 16**, and **Figure 17**, were not applicable with fuzzy logic due to the class division that was already based on existing boolean criteria. The results were calculated using a raster calculator with a predetermined value to obtain the output as **Figure 17.**

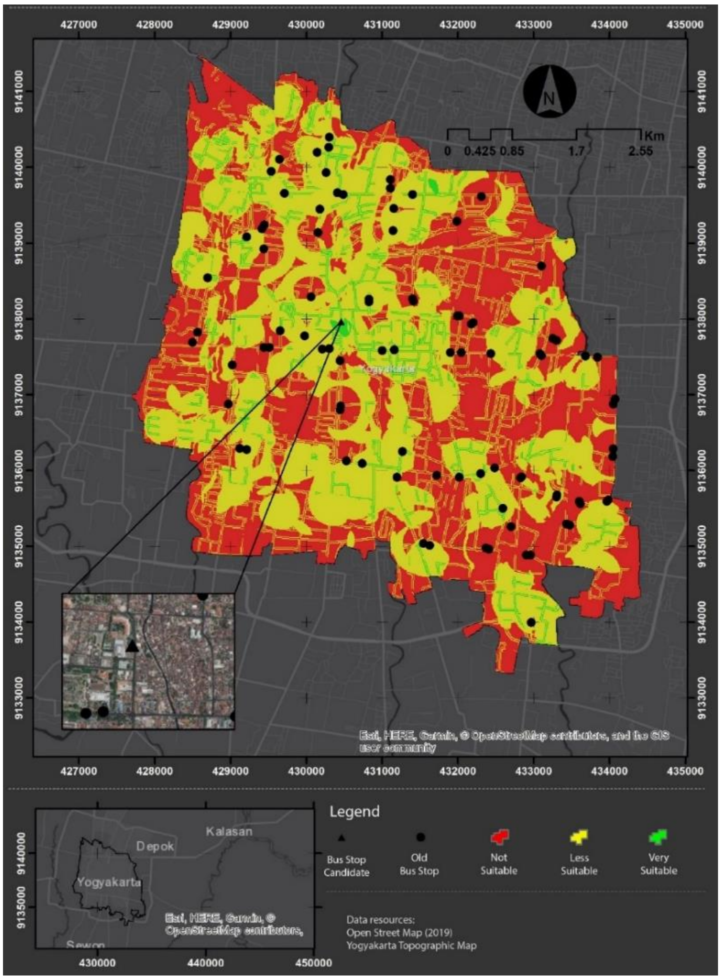

Figure 17. Map of Suitable Location for Updating Trans Jogja Bus Stop Using Fuzzy Logic Method

Discussion

The result of fuzzy calculations affected the pixel value of each parameter. In addition, locations that had high suitability were also influenced by the weight of each parameter. Based on the classification, there were three categories of suitable updated locations for the bus stop, including not suitable area, less suitable, and very suitable (**Table 12**). Values with a high match were pixel values ranging from 6,82 to 9,5, which is classified as a very suitable area with 1.199 km2 of Yogyakarta City. Furthermore, less suitable areas compromised a larger portion of around 53% of the total area, and the not suitable area accounted for more than two-fifths.

Table 12. Detail coverage of bus stop suitability class

Location suitability	Coverage (Km^2)
Not Suitable	13.88
Less Suitable	17.90
Very Suitable	1.199

Combining fuzzy logic and overlay function in GIS modelling shows excellent results of specific suitable locations to build a bus station. In contrast to Boolean logic, which had values of 0 and 1, that stated right and wrong based on similarities to criteria could drive the result to be less specific.

The density of existing bus stop locations and the distribution of locations with a high suitability level were spread evenly around Yogyakarta. However, not all zones with a high suitability level were built for bus stops. Very suitable zones were clustered in the city's centre and the northwest. This can be a consideration in making a candidate for a bus stop location.

The location of high suitability was close to the road around the location with a high level of crowds, such as office areas, shopping centers, hotels, educational facilities, and tourism. One example of a highly suitable location was in Gondomanan District, which was precisely close to Malioboro Street and Melia Purosani Hotel. There were no bus stops on this section of the road, so the proposed location can be considered in making a stop location.

However, in the making of bus stops location, it is necessary to pay attention to other aspects, such as feasibility studies on social aspects, regional planning, and environmental condition.

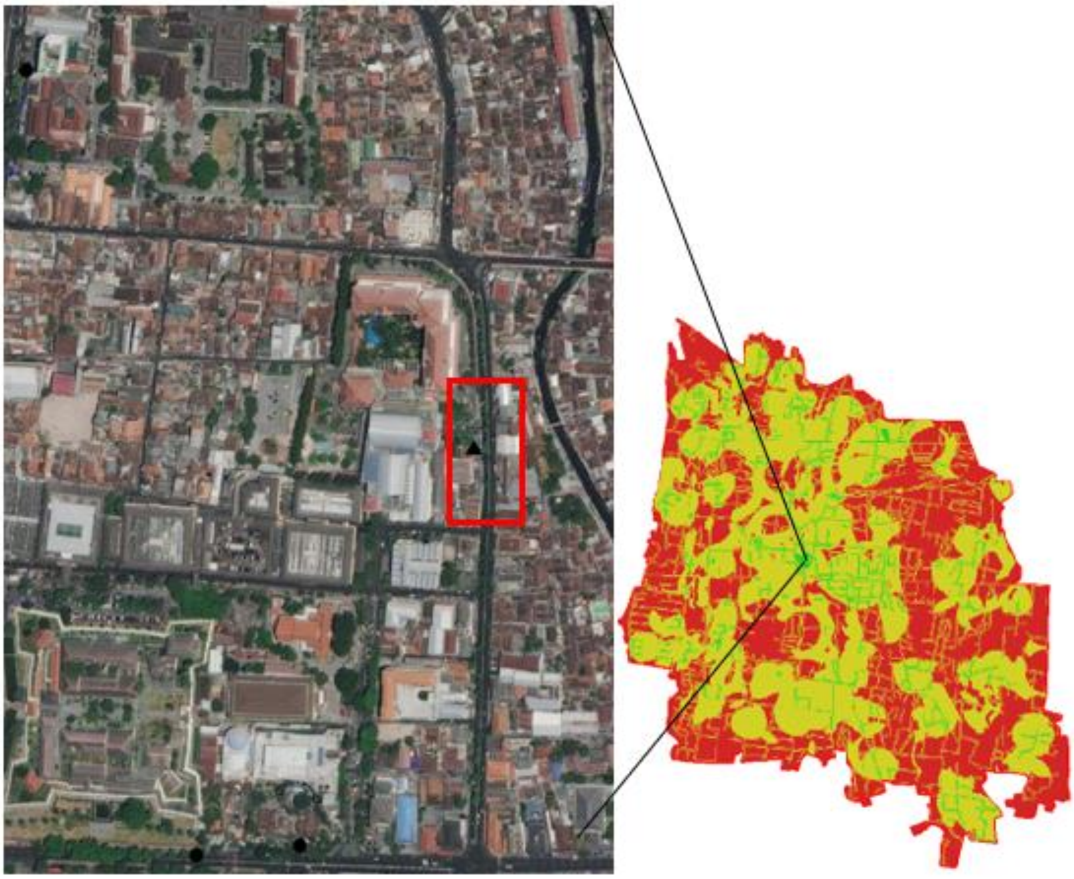

Figure **18.** The road section in Gondomanan District, precisely close to Malioboro and Melia Purosani Hotel, where there are no bus stop

CONCLUSIONS

Locations with suitable areas for bus stops were scattered throughout the city of Yogyakarta, with an area of 1,199 km. In comparison, locations with less suitable areas are 17.9 km, and locations that were not suitable for bus stop construction were 13.88 km. Updating bus stop locations can be adjusted around the green zone and consider ease of access and feasibility studies according to existing regulations. Based on the research that had been done on the location of the suitability of the latest bus stop, it could be concluded that Fuzzy Logic could be used as a tool that could aid in spatial analysis to obtain criteria for a location by considering the probability of correctness of each selected parameter.

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