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Spatial Analysis of Waste Management Facility Distribution Using GIS

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Abstract. Recently, waste has become an extraordinary phenomenon that has attracted the attention of all levels of society: authorities, local governments, environmentalists, and regional stakeholders at the village level. Based on DIY Regional Regulation No. 3 of 2013 concerning the Management of Household Waste and Waste Similar to Household Waste and Sleman Regency Regional Regulation No. 6 of 2023 concerning the Implementation of Waste Management, efforts to minimize the amount of waste are made by each waste bank collaborating with TPS3R in Sleman Regency. Based on temporary data from 178 waste banks, there are 97 active waste banks and 32 TPS3R in Sleman Regency. The objectives of this study are (1) To determine the distribution pattern of active waste banks in Sleman Regency and (2) To determine the accessibility of active waste banks to TPS3R locations. This study uses the nearest neighbour analysis method, and the accessibility of active waste bank locations to TPS3R locations is measured using the buffering method—data processing using a Geographic Information System (GIS). The results of this study indicate (1) the distribution pattern of active waste banks in Sleman Regency based on the nearest neighbour ratio value is 0.861485 (<1), indicating a spatial pattern that tends to be clustered or spread in groups; (2) the accessibility of active waste banks to the TPS3R location has not shown an even pattern, from 32 TPS3R only 10 TPS3R have two waste banks, the rest 0 - 8 waste banks. The buffering distance shows that the closer the two locations are, the more effective and efficient waste management will be, with a maximum accessibility distance of 4.1 km.

Keywords: Accessibility, Buffering, Geospatial Analysis, Nearest Neighbor Analysis, Waste Banks

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1. Introduction

Waste has become an extraordinary phenomenon that has attracted the attention of all levels of society: officials, local governments, environmentalists, and regional stakeholders at the village level. Based on DIY Regional Regulation Number 3 of 2013 concerning the Management of Household Waste and Waste Similar to Household Waste and Sleman Regency Regional Regulation Number 6 of 2023 concerning the Implementation of Waste Management [1], [2]. Waste management is used to reduce waste production from its source, namely households, carried out in order to create clean, healthy, and comfortable environmental conditions [3], [4]. The first stage of waste management is sorting between organic (easily decomposed) and non-organic (non-easily decomposed) waste. The second is the management of types of waste, such as organic waste, into compost, waste briquettes, and eco enzymes. Non-organic waste (plastic, paper, glass, metal) [5], [6]. All types of non-organic waste can be saved at the Waste Bank, where non-organic waste is collected or saved; the process of selling waste to collectors or waste worthy of being created into new products will be continued [7], [8]. Each waste bank cooperates with TPS3R in Sleman Regency to minimize the amount of waste. The Head of the Waste Management Section of the Sleman Regency Environmental Service (DLH) stated that there are inactive waste banks. TPS3R is a waste management place equipped with a waste processing system both organically and inorganically [9].

Small things done by households will significantly impact the environment through the waste bank program. The volume of non-organic waste will be reduced by half with the existence of a waste bank [7], [10]. Community waste banks are essential in supporting the Sleman Regency Environmental Service in creating a healthy, clean and comfortable environment [11]. The Sleman Regency DLH targets each village in the Sleman Regency to have 1 TPS3R; in reality, not all villages have TPS3R. There are 97 active waste banks out of 178 waste banks and 32 TPS3R in Sleman Regency. TPS3R assistance to villages in Sleman Regency reaches 1-2 villages; of course, it is less effective and optimal. Based on the spatial distribution data of active waste banks in Sleman Regency and the spatial distribution data of TPS3R locations available, it turns out that the distribution pattern and accessibility of both have not been mapped. Through these conditions, the research emphasizes the distribution pattern of waste banks with the analysis of the nearest neighbours and the accessibility of waste bank locations with TPS3R locations with buffering analysis, which is a geographical study. This study answers two questions:

1) What is the distribution pattern of waste banks still active in the Sleman Regency?
2) How is the accessibility between active Waste Banks in Sleman Regency and TPS3R?

Research with mapping between Waste Banks and TPS3R needs to be carried out in order to form a well-coordinated cooperation pattern in waste management.

2. Methods

2.1. Types of research

Quantitative descriptive research: descriptive research means analyzing and presenting data systematically to make it easy to understand and draw conclusions [12]. Quantitative research is done by processing the collected data in numbers and calculating it using specific formulas to obtain research results [13].

2.2. Data Types and Sources

The data used by researchers is secondary data. Secondary data will be collected from active waste bank location data and TPS3R location data in the Sleman Regency area. Secondary data collection will be carried out by utilizing data sourced from the Sleman Regency Environmental Service via the link: https://geoportal.slemankab.go.id/layers/geonode_data:geonode:a__3404_AR_50KB_BANKSAMPAH_SLEMAN_20170 for data on active waste banks in Sleman Regency and via the link: https://geoportal.slemankab.go.id/layers/geonode_data:geonode:a__3404_5KB_PT_TPS3R_KABSLEMAN_2022 for TPS3R data in Sleman Regency [14]. Other secondary data are the Indonesian

Topographical Map (RBI) and the Sleman Regency in Figures 2023 by the Central Statistics Agency [14], [15].

2.3. Data Collection Techniques

Documentation of this research document: Sleman Regency in Figures for 2023 for information on the area of Sleman Regency, digital Indonesian Earth Map with a scale of 1:25,000, which will be used as a base map for processing thematic maps of the reachability of active waste banks to TPS3R locations via the web GIS, softfile Indonesian Earth Map as a basic map for determining the administrative boundaries of Sleman Regency. Observation Collect notes regarding the location and geometric position of active waste banks in the Sleman Regency area and TPS3R using GPS tools. Researchers will check the locations of active waste banks and TPS3R.

2.4. Research Variables

As explained in Table 1 below:

Table 1. Research Variables

Research Object	Research Variables
Distribution patterns of waste banks that are still active	Distance from each other to active waste banks; The area of Sleman district; number of active waste bank points
Affordability between active Waste Banks and TPS3R	Location of active waste banks; number of active waste bank points; TPS3R location points, number of TPS3R points; and the area of Sleman Regency

2.5. Data Processing Techniques

Researchers will use a geographic information system (GIS) to assist in the analysis and provide an overview of the distribution pattern of active waste banks in Sleman Regency [16], [17]. This GIS can represent visualization through digital maps and spatial analysis [18], [19], [20]. The first stage of GIS work is the input stage; the active waste bank location data obtained is input into spatial data. The second stage of GIS work is the data processing and data analysis stage, which uses the nearest neighbour analysis available in GIS [21]. Next, the active waste bank data and TPS3R location data are overlayed, then Buffering is analyzed. The third stage of GIS work is the output stage, in the form of a thematic map of the reachability of active waste banks to TPS3R locations in Sleman Regency, which will be displayed or presented on the web (Web GIS) [22], [23].

2.6. Data analysis

The data obtained is then processed using GIS and analyzed to achieve research objectives. Geographical analysis using a spatial approach using GIS web-based mapping [24], [25], Nearest Neighbor Analysis, and Buffering analysis. The nearest neighbour analysis is a method where the distance is arbitrary to the nearest neighbour in a random pattern of several points. The nearest neighbour analysis is a quantitative geographic analysis method used to determine distribution patterns. The distribution pattern of location points is calculated using calculations that consider distance, number of locations, and area. The final result in the form of an index calculation has a range between 0 and 2.15 [26], [27], [28], [29].

In using the nearest neighbour analysis, it is necessary to pay attention to the following:

- Determining the boundaries of the research area, namely the administrative boundaries of Sleman Regency
- Changing the distribution pattern of waste banks into a point distribution pattern
- Giving a sequence number to each point to facilitate analysis
- Measuring the closest distance, namely the distance on a straight line between one point and another point that is its nearest neighbour and record the size of this distance
- Calculating the nearest neighbour index using the formula:

$$Rn = \frac{D\ (Obs)}{0.5\sqrt{\frac{a}{n}}} \quad (1)$$

Description:
Rn: Nearest Neighbor Value
D(Obs): average distance of nearest neighbour observation results
a: Area
n: number of points (locations)
The pattern is that there are three kinds of distribution variations, namely:

The distribution pattern is clustered if the distance between one location and another is close and tends to cluster in certain places, with an index value of zero (< 1).

Random distribution pattern if the distance between one location and another is irregular, with an index value of one (≥ one and < 2.15).

The distribution pattern is uniform/regular if the distance between one location and another is relatively the same, with an index value of two point fifteen (≥ 2.15).

Buffering analysis in GIS will show the reachability of active waste banks to TPS3R locations and the number of TPS3R location points [18]. The buffering technique is based on the TPS3R coverage provisions by the SNI 03-1733-2004 standard; namely, the clearance distance between the TPS3R and the waste bank is 30 m [19]. This will make it easier to carry out mapping, which can then be grouped into waste banks that collaborate with certain TPS3R [30].

3. Results and Discussion

The findings of this research are from previous data; field checks and observations have been carried out; 97 waste banks and 32 TPS3R have been successfully mapped.

3.1. Distribution pattern of active waste banks in Sleman Regency

Based on the results of nearest neighbour analysis using the ANN (Average Nearest Neighbor: Euclidean Distance) method carried out at the Waste Bank in Sleman Regency, the results show: Nearest Neighbor Ratio value, the resulting nearest-neighbor ratio is 0.861485. This value is smaller than one (<1), which indicates a spatial pattern that tends to be clustered (Figure 1) [31]. This means that the objects in the dataset (Waste Bank) are not scattered randomly or can be said to be uneven but tend to gather in certain areas.

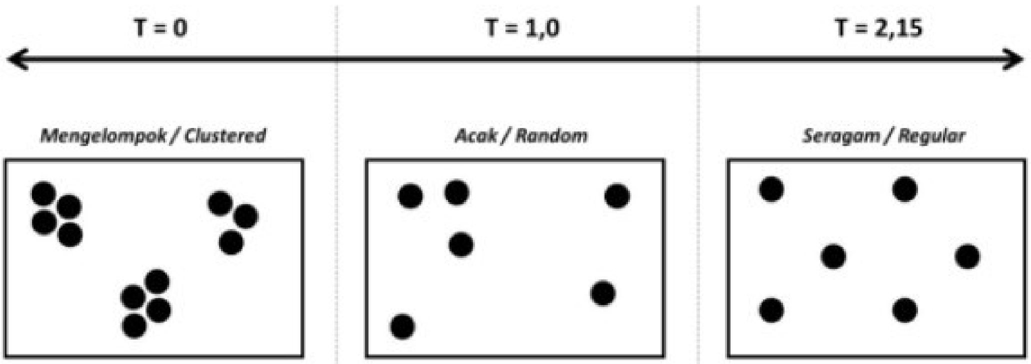

Figure 1. Types and Patterns of Settlement Distribution

Z-Score, the Z-score obtained was -2.609838, well outside the mean of ±1.96 for the 95% confidence level. This shows that the distribution pattern of these objects is very unlikely to occur randomly. The Z-score measures the standard distance from the mean value in spatial analysis. Z-Score (> 1.96) or Z-Score (< -1.96), then this value shows statistically significant results at the 95% confidence level. This means there is a 95% chance that the pattern identified is not coincidental (indicating a regular pattern or grouping). Meanwhile, suppose the Z-Score is between -1.96 and 1.96. In that case, the results are insignificant, indicating no strong evidence for a regular or clustered pattern (indicating a random pattern). In this context, a negative z-score indicates that the average distance between points is smaller than expected in a random distribution pattern, supporting the conclusion that the pattern is clustered or clustered.

Average Distance Comparison, the observed average distance (Observed et al.) is 1109.8709 meters, while the expected average distance (Expected et al.) is 1288.3229 meters. The observed average distance is smaller than expected, supporting the conclusion that the points in this dataset are closer to each other than would be expected in a random distribution. Measurement Method (Euclidean Distance): The method used to measure the distance between Waste Bank points in Sleman Regency is Euclidean Distance, a straight line distance measurement between two points in two-dimensional space [32]. The following are the results of waste bank data processing in the image (Figure 2).

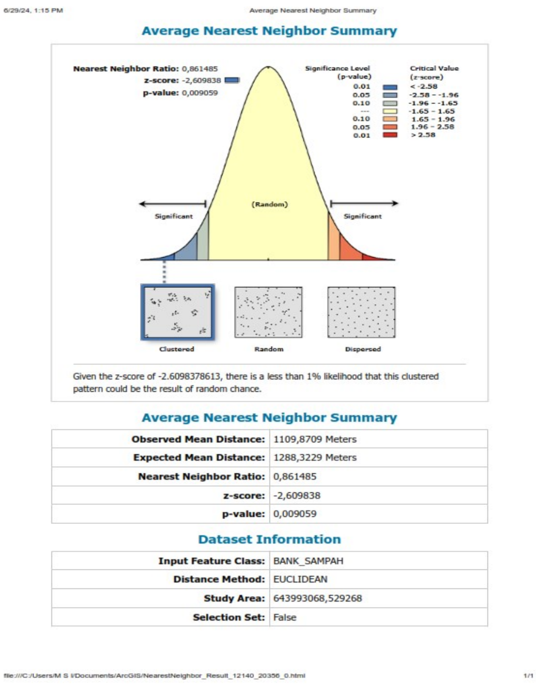

Figure 2. Nearest Neighbor Analysis
(Data Processing Results 2024)

The "Average Nearest Neighbor" analysis results show that Waste Banks' distribution in the Sleman Regency is not randomly distributed but clustered or clustered. A significant z-score shows that this distribution pattern is influenced by certain factors that cause these objects to gather in certain areas rather than being evenly distributed. This could indicate the existence of specific activity centres or areas that are more attractive for Waste Banks spread out in clusters.

3.2. Accessibility of active waste banks to TPS3R locations

The method used in analyzing the affordability value between the Waste Bank and TPS/TPS3R is the buffering method and a network analyst [33], [34], [35]. Both have the same value but have different outputs. Where on the map, the results of the buffer method produce the coverage area of each TPS/TPS3R to the location of the Waste Bank within its radius (reach), whereas on the map, the results of the road network analysis produce output in the form of a practical route (road) that the Waste Bank can reach to the nearest TPS/TPS3R. Buffering method, this method uses five (5) classifications in determining radius distance (reachability), namely at 1000 meters (1), 2000 meters (2), 3000 meters (3), 4000 meters (4), and 5000 meters (5). So, the results of the classification of Waste Bank reachability values with TPS/TPS3R produce the following map (Figure 3);

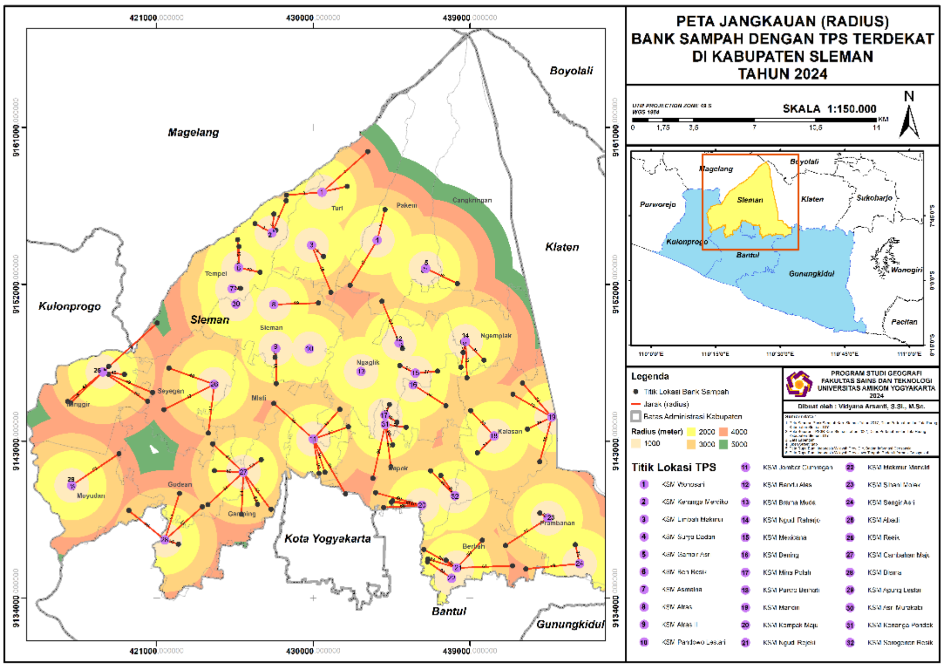

Figure 3. Waste Bank Coverage Map with the Nearest TPS
(Data Processing Results 2024)

Based on the results of data processing, it is known that the average reachability value of the Waste Bank with the nearest TPS/TPS3R is at a distance of ±1700 meters. Class 3, with a radius of 3000 meters, is the range with the highest Waste Bank intensity, namely 34 Waste Bank units, followed by class 2, with 26 Waste Bank units, and class 1, with a total of 25 Waste Bank units. The furthest distance obtained was 4194.7 meters, namely from the PSM Sahabat (Kerisan) Waste Bank point to the KSM Abadi TPS; this was because the location of the Waste Bank was less accessible than the nearest TPS/TPS3R point. Meanwhile, the closest distance obtained was 13.8 meters from the Waste Bank PSM Mexicana (Calukan) point to the KSM Mexicana TPS. KSM Abadi and KSM Cambahan Maju are the TPS/TPS3R with the highest level of reachability, where the two TPS/TPS3R can be reached by up to the nearest 8 Waste Bank units.

This accessibility will be analyzed based on location theory, where the distance factor will affect the increasing transportation costs incurred and the strength of the interaction [36]. The accessibility of active waste banks to the TPS3R location has not shown an even pattern; out of 32 TPS3R, only 10 TPS3R have two waste banks, and the rest have 0 - 8 waste banks. The buffering distance shows that the closer the two locations are, the more effective and efficient waste management will be, with a maximum accessibility distance of 4.1 km. Network analyst method, this road network method uses Sleman Regency road network data for 2022 from the Sleman Geoportal source. The data from road network processing in ArcGIS software produces the effective/shortest road access (route) from the starting point to the destination point, the waste bank access to the nearest TPS/TPS3R. The following is a map of the closest facilities between TPS and waste banks in Sleman Regency in 2024 (Figure 4):

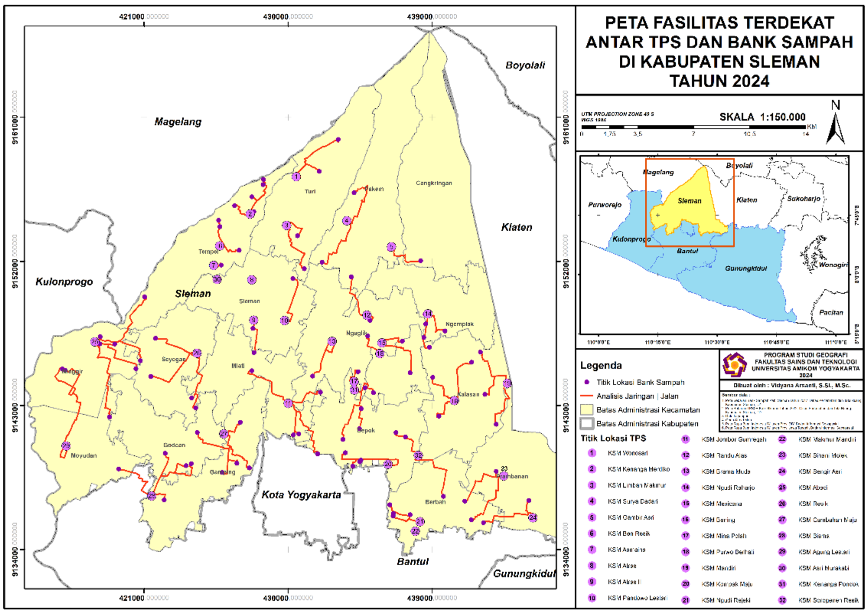

Figure 4. Map of Nearest Facilities Between TPS and Waste Bank
(Data Processing Results 2024)

The average distance obtained based on the length of the path/road between the waste bank and TPS/TPS3R is ±2571 meters. The longest distance reaches 8656.67 meters on the route between the PSM Banaran Berseri (Banaran) waste bank and the TPS KSM Agung Lestari. Meanwhile, the shortest distance is less than one meter (0.6 metres) on the route between the Gambiran Waste Bank and the Gambir Asri KSM TPS. The path length is less than one meter compared to the radius distance. The results of the previous buffer analysis show very different results, which could have occurred due to data errors or errors in the raw data, namely vector data (shapefile) of the Sleman Regency road network. It can be seen from the visualization on the map by looking at the spatial structure that describes the waste management service system and the road network that connects TPS3R with the surrounding waste banks to integrate and serve the function of waste management activities in the Sleman district area. The use of the buffer method in determining the reachability value of the Waste Bank location point with the nearest TPS/TPS3R and road network analysis in determining the effective/closest route/road between the Waste Bank location point and the TPS/TPS3R still needs to be validated in the field, so that with actual data available The results of the field survey can increase the level of accuracy of the analysis results.

4. Conclusion

The research concludes that the distribution pattern of active waste banks in Sleman Regency based on the nearest neighbour ratio value is 0.861485 (<1), indicating a spatial pattern that tends to be clustered or distributed in groups and the reachability of active waste banks to TPS3R locations has been shown on the map; the buffering distance used to determine reachability is a maximum of 4.1 km, there are 0 – 8 waste banks at each TPS3R, on average there are two waste banks at 10 TPS3R.

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