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Analysis of the Potential Impact of Transfer Stations on Waste Transportation Patterns in Bandung City: A GIS-Based Approach

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Abstract: The increasing population has led to higher consumption and the generation of household waste, particularly in the Bandung Raya area. The Legok Nangka Final Processing and Disposal Site (TPPAS) is planned as a solution for regional waste management after the Sarimukti landfill has completed its operational period. The service area of the Legok Nangka TPPAS follows the service area of the Sarimukti landfill, which includes the City of Bandung, the City of Cimahi, Bandung Regency, and West Bandung Regency. Given the existing conditions of the Legok Nangka TPPAS location, which is relatively far from the city and regency centers that generate waste, an alternative Intermediate Transfer Station (SPA) is needed. This facility can reduce waste volume while increasing waste density by three times. This research focuses on analyzing alternative locations for the Intermediate Transfer Station (SPA) in the City of Bandung to enhance the efficiency of waste transportation to the Legok Nangka TPPAS using Geographic Information System (GIS) based on Network Analysis. The results of this study indicate that the implementation of the Intermediate Transfer Station (SPA) significantly improves waste transportation efficiency. With a capacity of 500 tons per day, the SPA reduces the volume of waste directly sent to the Legok Nangka TPPAS by 26%. The distance and travel time for trucks are reduced by 23.97% for pool 1 and 25.91% for pool 2, respectively. Efficiency is also evident in the reduction of fuel consumption and carbon emissions, with decreases of up to 25.91%. The average number of trips required is 83 trips per day, indicating a reduction in long-distance travel to the TPPAS. These findings underscore the importance of the SPA in sustainable waste management in the City of Bandung.

Keyword: Legok Nangka Regional Waste Processing and Final Disposal Site (TPPAS), Waste Management, Waste Generation, Intermediate Transfer Station (ITS), Geographic Information System (GIS).

INTRODUCTION

The growing population results in heightened community consumption, subsequently leading to an increase in household waste and refuse. The rising levels of waste and garbage, coupled with inadequate management by both the community and government, have resulted in significant waste accumulation in various regions of Indonesia, particularly in the Bandung Raya area. In 2020, the regional waste management service in the Metro Bandung area, based in Sarimukti, Cipatat District, West Bandung Regency, concluded its operational period. This service was managed by the UPTD Waste Management TPA/TPST Regional (PSTR) of the West Java Provincial Environmental Agency. The TPPAS Legoknangka, situated in Nagreg District, functions as a waste management system capable of servicing multiple cities and regencies within the Sarimukti TPA service area, specifically the City of Bandung, City of Cimahi, Bandung Regency, and West Bandung Regency. An alternative Intermediary System (SPA) is required due to the TPPAS Legok Nangka location's considerable distance from the city and regency centers that generate the waste. This system must fulfill the requirement of having a TPA situated more than 25 km away, with waste generation surpassing 500 tons per day. It is essential to consider multiple factors, including the current conditions of the TPS, SPA, and TPPAS Legok Nangka, predictions of waste generation, population density, road characteristics, travel distance and time, frequency, and the resulting carbon emissions.

A Transfer Station represents a type of waste management facility. The process involves reducing waste volume to achieve a threefold increase in waste density, thereby minimizing the number of transport trips required. (Setiadewi, 2014). Additionally, there is a reduction in transportation costs, improved time efficiency, and a decrease in emissions. Nevertheless, its disadvantages may encompass increased operational expenses associated with managing the SPA and the requirement for supplementary infrastructure. The growing population results in heightened community consumption, subsequently leading to an increase in household waste and refuse. The rising levels of waste and garbage, coupled with inadequate management by both the community and government, have resulted in significant waste accumulation in various regions of Indonesia, particularly in the Bandung Raya area. In 2020, the regional waste management service in the Metro Bandung area, based in Sarimukti, Cipatat District, West Bandung Regency, concluded its operational period. This service was managed by the UPTD Waste Management TPA/TPST Regional (PSTR) of the West Java Provincial Environmental Agency. The TPPAS Legoknangka, situated in Nagreg District, functions as a waste management system capable of servicing multiple cities and regencies within the Sarimukti TPA service area, specifically the City of Bandung, City of Cimahi, Bandung Regency, and West Bandung Regency. An alternative Intermediary System (SPA) is required due to the TPPAS Legok Nangka location's considerable distance from the city and regency centers that generate the waste. This system must fulfill the requirement of having a TPA situated more than 25 km away, with waste generation surpassing 500 tons per day. It is essential to consider multiple factors, including the current conditions of the TPS, SPA, and TPPAS Legok Nangka, predictions of waste generation, population density, road characteristics, travel distance and time, frequency, and the resulting carbon emissions.

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METHOD

The data analysis technique that will be employed consists of 4 stages to achieve the desired objectives and goals of the research, namely: The data analysis technique that will be employed consists of 4 stages to achieve the desired objectives and goals of the research, namely:

Identifying the existing conditions of the location. Identifying the existing conditions of the location.

The first stage is to identify the existing conditions of the Temporary Disposal Sites (TPS) in the Bandung Raya area, alternative locations for the Final Waste Disposal Site (SPA), and the Legok Nangka Waste Processing Site (TPPAS), as well as the volume of waste (tons/day) from the existing TPS. The data was then analyzed spatially. Spatial analysis is a collection of techniques that can be used to process Geographic Information System (GIS) data, which is the process of transforming spatial data into information that can be understood and interpreted by users. It involves mathematical, statistical, logical operations, or models applied to spatial data to produce outputs that align with the analysis objectives, such as: 1) Topographic and environmental analysis, which involves analyzing the topographic conditions of each potential SPA location regarding potential environmental impacts to ensure that the location is suitable from both technical and environmental aspects, and 2) Distance and accessibility, which entails calculating the distance from each potential SPA location to the Legok Nangka TPPAS, the road leading to the TPPAS location, and the distance from existing TPS (waste generation centers) to the potential SPA locations and to the Legok Nangka TPPAS, as well as optimizing road accessibility to the TPPAS location based on the criteria/requirements of the Transfer Station using GIS.

Waste generation prediction

The second stage involves using quantitative descriptive analysis, which includes calculating the Total Waste Generation (tons/day) predicted based on the existing capacity of each waste collection point (TPS) and the capacity of the Legok Nangka Waste Processing Facility (TPPAS). This is done through secondary data collection or by conducting interviews and observations regarding the total trips of waste collection trucks at each TPS, using the volume/capacity method for waste. Waste generation predictions are necessary to determine the capacity required for the Waste Management Facility (SPA) to handle the amount/volume of waste that will be transferred from the collection locations (TPS) to the SPA and then to the TPPAS. Therefore, the capacity of the SPA must align with the estimated waste generation.

$$Vs = P0 \times v$$

Information:

Vs = Volume of waste generated

P0 = Population Size

v = Average waste volume (3 L/person /day)

Eficiency of SPA Existance

The third stage involves using quantitative descriptive analysis to describe the efficiency of SPA existence in relation to waste transportation patterns. This includes descriptive analysis related to population density and road characteristics, followed by quantitative analysis to calculate:

1) Distance traveled and travel time of the waste transport vehicle/truck.
   To calculate the distance and travel time of the waste transport vehicle/truck (km/day), we use the route distance from the Temporary Disposal Site (TPS) to the Final Disposal Site (TPPAS) using GIS data obtained from the first stage. Then, we calculate the travel time (hours/day) and the total daily travel time.
   Travel time (Hours) = Distance of one trip (km) / Average speed (km/hour).
   Total travel time (hours/day) = Travel Time for One Trip (hours) x Number of Trips Per Day.
2) Trips
   Calculating the number of trips that can be made from the TPS to the TPPAS through each alternative SPA location based on the travel time that has been calculated. This includes evaluating operational efficiency, such as the number of trips that can be made in a day. The movement of waste collection trucks in Bandung City starts from the pools, which consist of two pools in Bandung City: Pool Cibeunying on Jalan Sedang Serang and Pool Ubermanik on Jalan Pasir Impun No. 46, Pasir Impun Village.
3) Carbon Emission
   To obtain carbon emissions, it involves estimating based on the usage from the combustion of diesel/fuel (gasoline) in waste transport trucks and the emission factors that have been established from various guideline sources in units of grams of CO_2 per kilometer (g CO_2/km).
   CO_2 Emissions = Fuel Consumption x Emission Factor
4) Selection of the Final Location for the Transition Station
5) The SPA scale for cats must meet technical requirements such as:
   - The area of the SPA is larger than 20,000 m^2
   - The production of waste generation exceeds 500 tons per day.
   - The placement of the SPA can be within the city
   - City-scale SPA facilities are equipped with ramps, compaction equipment, special transport tools, and leachate storage.Leachate treatment can be carried out at a landfill or waste disposal site and
   - The location of the SPA placement should be at least 1 km away from the nearest settlement.
     The selection of the final SPA location is done by comparing all alternative locations based on the analysis of population density, road characteristics, distance, travel time, routing, operational efficiency, and emissions.

Transport Route / Transportation Route

The final stage in the site selection process for the SPA is to determine and analyze the transportation routes from the waste source (existing waste collection points) to the selected SPA and from the SPA to the Legok Nangka waste processing facility. The transportation route and operational aspects of waste transportation activities must consider:

1) Transportation patterns

2) Types of equipment or transportation facilities
3) Transportation routes
4) Transportation operations
5) Aspects of financing

The guidelines that can be used in creating a route greatly depend on several factors, are:

1) Existing traffic regulations
2) Workers, size, and type of transportation equipment
3) If possible, the route should start and end near the main road, using the topography and physical conditions of the area as route boundaries
4) In hilly areas, try to start the route from the top and end at the bottom
5) The route is designed so that the last container/temporary storage that will be transported is the one closest to the final disposal site.
6) Waste generated in busy areas/traffic congestion is collected as early as possible;
7) Areas that generate the most waste are collected first
8) Areas that generate little waste are aimed to be collected on the same day.

Several factors that influence transportation operations, are:

1) The mode of transportation used
2) Transport equipment used
3) Number of personnel
4) Location of the polling station or waste management site.

RESULT AND DISCUSSION

To optimize the presence of SPAs in relation to waste transportation patterns using Network Analysis, which is one of the methods of geographic information system analysis for conducting spatial analysis based on networks, such as routes and travel directions to determine the shortest path while considering traffic rules that include one-way/two-way streets, allowed left-right turns, dead ends, closed or unusable roads, and underpasses/overpasses.

For the planned quantity of waste for the SPA, which is 500 tons/day, the calculations for the waste entering the SPA based on the four research areas are as follows: 280.16 tons per day for Bandung City, 115.32 tons for Bandung Regency, 64.1 tons for Cimahi City, and 40.93 tons for West Bandung Regency. The efficiency of the SPA's existence on the waste transportation pattern uses 2 scenarios as follows:

- Scenario 1 (Before): Without SPA, where waste comes from all TPS based on the waste allocation of the service area for each regency/city directly to the TPPAS Legok Nangka.
- Scenario 2 (After): With SPA, where waste comes from existing TPS based on the SPA capacity and the waste allocation of the service area for each regency/city.

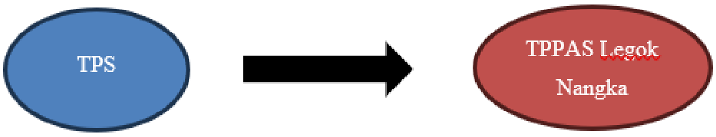

Figure 1. Transportation Pattern for Waste Management Scenario 1 the Intermediate Transfer Station (ITS)

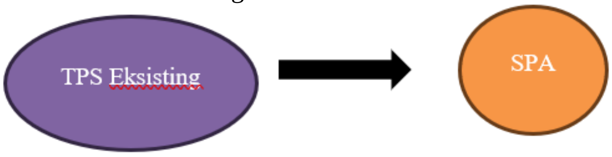

Figure 2. Transportation Pattern for Waste Management Scenario 2 with the Intermediate Transfer Station (ITS)

The results of the research will be presented in the form of a comparison table between scenario 1 and scenario 2, which includes distance and travel time, fuel consumption, emission factors, trips, and waste truck transportation routes without SPA and with SPA, displayed in the form of images.

Table I. Recapitulation of Distance and Travel Time Efficiency for Scenarios 1 and 2 in Bandung City

Scenarios	Pool 1		Pool 2	
	Distance (km)	Travel Time (Minutes)	Distance (km)	Travel Time (Minutes)
1	4424,432451	7584,741345	4637,278062	7949,619535
2	1060,637738	1818,236122	1201,89914	2060,398526
Total	**3363,7947**	**5767**	**3435,4**	**5889**
Efficiency	**23,97 %**	**23,97%**	**25,91%**	**25,91%**

The efficiency of distance and travel time is calculated based on the extent of reduction in distance and travel time that occurs with the presence of the SPA compared to without the SPA.

Table II. Recapitulation of Fuel Consumption and Carbon Emissions Efficiency for Scenarios 1 and 2 in Bandung City

Scenarios	Pool 1		Pool 2	
	Fuel Consumption (Liters)	Carbon Emissions (g CO_2/km)	Fuel Consumption (Liters)	Carbon Emissions (g CO_2/km)
1	4.424,43	8.420.579,84	2.782,367	8.825.667,60
2	636,3826426	2018605,742	721,1394842	2287454,444
Total	**3.788,05**	**6.401.974,10**	**2.061,23**	**6.538.213,16**
Efficiency	**14,38 %**	**23,97 %**	**25,91 %**	**25,91 %**

The efficiency of fuel consumption and carbon emissions is calculated based on the extent of reduction in fuel consumption and carbon emissions that occurs with the presence of the SPA compared to without the SPA.

Waste Transportation Routes

The waste transportation route for scenario 1 consists of 94 TPS and 50 TPS. The results of the waste transportation route were obtained from Spatial Analysis using Network Analysis, as shown in Figure 3 below:

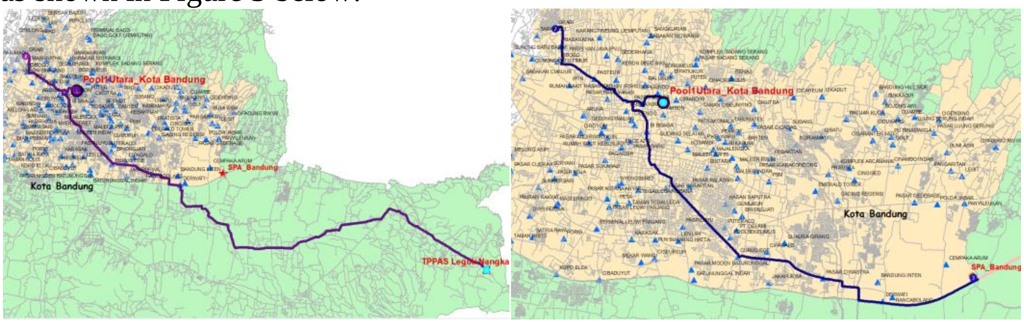

Figure 3. Map of Waste Truck Transportation Route from Pool 1 Bandung City to Orari TPS towards SPA Bandung City and TPPAS Legok Nangka

Based on the analysis of waste transportation routes using network analysis, the presence of the SPA indicates that the waste transportation routes are more efficient, namely:

1) With a waste capacity at the SPA of 500 tons/day, it reduces 26% of waste that directly goes to the TPPAS Legok Nangka.

2) The travel distance and travel time of waste collection trucks are more efficient with the existence of the SPA, reducing distance and travel time by 23.97% for pool 1 and 25.91% for pool 2.
3) Fuel consumption (BBM) and carbon emissions are more efficient with the existence of the SPA, with reductions of 14.38% and 23.97% for pool 1, and 25.91% for pool 2, respectively.
4) The number of trips required with the existence of the SPA is an average of 83 trips/day, meaning that with the SPA, trucks do not need to travel the same long distance to TPPAS Legok Nangka, but only to the SPA, thus also reducing fuel consumption, carbon emissions, and travel time.

CONCLUSION

The implementation of Intermediate Transfer Stations (SPA) in the Bandung is crucial for enhancing waste management efficiency, particularly in light of the increasing population and waste generation. The establishment of SPAs is projected to improve transportation efficiency by reducing travel distances and times, which can lead to a decrease in fuel consumption and carbon emissions by approximately 20-30%. Additionally, SPAs facilitate a threefold increase in waste density, significantly minimizing the number of transport trips required to the Legok Nangka Waste Processing and Final Disposal Site (TPPAS). The research employs Geographic Information Systems (GIS) for network analysis, identifying optimal SPA locations based on factors such as population density, road characteristics, and waste generation predictions. This strategic approach not only enhances operational efficiency but also positively impacts community health and environmental quality by reducing emissions from waste collection vehicles.

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