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GIS-BASED EVALUATION OF THE INTEGRATED WASTE MANAGEMENT SITE IN SIDODADI VILLAGE

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ABSRACT

This study evaluates the effectiveness of the Integrated Waste Management Facility (TPST) service in Sidodadi Sub-district, Wonomulyo District, Polewali Mandar Regency, using a spatial analysis approach based on the location–allocation method implemented in ArcGIS. The research is motivated by the high population density of Sidodadi, which has led to an increase in waste generation, while only a single TPST facility is currently operational. A quantitative descriptive method was applied, utilizing primary data from field observations and secondary spatial data, including building point data, road network data, and high-resolution satellite imagery. Spatial analysis was conducted by mapping waste generation at the building level, performing network-based distance analysis along the road network (as opposed to straight-line/Euclidean distance), and modeling TPST service coverage using a location–allocation model. The model parameters included a service distance cutoff of ≤ 1 km and facility capacity constraints based on the maximum number of households that can be served within a given facility. The results indicate that the existing TPST can serve approximately 600 households, corresponding to only about 15,84 % of the total residential buildings in Sidodadi Sub-district. Consequently, a significant proportion of densely populated residential areas remains outside the effective service coverage. This limited coverage is primarily influenced by insufficient facility capacity and service distances exceeding the defined cutoff. The study recommends the development of additional TPST facilities at strategically selected locations to increase service coverage percentage and enhance the efficiency and sustainability of waste management in Sidodadi Sub-district.

Keywords: Integrated Waste Management Facility, location-allocation, waste generation, spatial analysis

1. INTRODUCTION

Rapid urbanization in Indonesian cities has significantly increased municipal solid waste production, creating complex environmental and socio-economic challenges for urban waste management systems [1] [2]. While major metropolitan areas in Indonesia have received considerable attention in waste management research and policy interventions, small-sized cities continue to face persistent and often overlooked difficulties [3]. Operational inefficiencies further exacerbate waste management challenges in small cities. Inadequate planning of waste collection points and limited transportation capacity often result in irregular waste collection services, encouraging illegal dumping behavior [4]. Such structural deficiencies reflect broader limitations in urban management systems, where technical and spatial planning capacities remain underdeveloped. This problem also occured in Polewali Mandar, West Sulawesi [5] [6], especially in the Sidodadi area [7] [8].

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Sidodadi plays a strategic role as a Local Activity Center or *Pusat Kegiatan Lokal (PKL)* with high economic activity intensity that supports trade, services, and distribution of goods at the sub-district level [9] [10]. The presence of key facilities such as the main market, dawn market, distribution center, banking area, main transportation routes, and its proximity to the terminal area make Sidodadi an economic node that plays a role in the movement of goods and people across sub-districts. Functionally, Sidodadi is not only the locus of economic activity for the Wonomulyo community, but also a central point connecting trade dynamics at the district level. Thus, the consistency of this development direction indicates that Sidodadi has an important position as a local growth center that drives the economic structure of the Polewali Mandar region. Waste problem in Sidodadi is mainly sourced from residential areas resulting from various community activities, such as trade, services, and household activities [7].

Figure 1. Waste problem in Sidodadi

Recent studies shows that there are many people lacking access to formal waste collection and processing services (e.g., TPST and 3R facilities) [11] [12]. Existing infrastructure can't spatially cover the entirety of residential areas, particularly in smaller municipalities with limited planning capacity and constrained land use options, leading to pockets of the urban population that remain underserved by formal waste processing infrastructure (TPST deployment in sub-districts remains inadequate to meet dispersed residential needs). Currently, Sidodadi has only 1 (one) active Integrated Waste Management Facility (TPST) for waste management services [13]. According to SNI 3242 of 2008 concerning waste management in residential areas, the specifications for a neighborhood-scale waste recycling building are only capable of serving around 3,000 (three thousand) people [14]. Consequently, a TPST evaluation must be conducted to ensure compliance with SNI and determine the TPST service area in Sidodadi to evaluate whether the existing facility can cover all residential area. Therefore, this research aims to determine the coverage area of TPST services, including the distribution of waste generation and the extent of underserved areas, to provide recommendations for sustainable waste management. The main objective of this study is to assess the effectiveness of TPST services in reaching residential areas [15]. The evaluation results are expected to provide an overview for planning TPST facilities and waste collection networks in Sidodadi Village in accordance with spatial principles.

Although GIS has been widely used in urban waste management, research evaluating the spatial effectiveness of existing landfill services for settlements remains limited. Most studies focus on location or route optimization, without integrating national service capacity standards such as SNI 3242:2008. This gap is crucial in small towns and local activity centers (PKL) such as Sidodadi, which have high economic activity but are served by only one landfill. Therefore, this study aims to evaluate the coverage and effectiveness of landfill services in Sidodadi using GIS to identify underserved areas as a basis for sustainable waste management planning.

2. RESEARCH METHOD

This research uses a quantitative method with a spatial approach to describe the distribution and rate of change in area in a region [16]. To conduct network analysis in Sidodadi Subdistrict, the required data

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were obtained from several sources, with measurements and projections standardized to enable integration into the Geographic Information System and spatial data for this study [17]. This type of research, when viewed from an application perspective, falls under the applied research category [18]. This research is considered developmental research. Data collection in this study was conducted through field observations. Data sources in this study are divided into two groups:

a. Secondary data were obtained from literature reviews and official sources and consisted of spatial data in raster and vector formats. These data included high-resolution satellite imagery, which was digitized into vector data to extract land cover and building points; vector data of road networks; vector data of building locations; and spatial data of existing TPST facilities. Road network data were used to construct a network dataset in ArcGIS, enabling distance-based service analysis along the actual road network.
b. Primary data were collected through direct field observations in Sidodadi Village to verify the location, condition, and accessibility of the existing TPST. This information was used to validate spatial data and served as a reference for determining service coverage and operational feasibility of the TPST.

The data analysis technique used in this study is spatial modeling to identify service areas using network analysis. The data analysis steps are as follows:

a. Waste Generation
Waste generation in residential areas can be measured using a spatial approach based on building points. Spatial analysis using building points is effective for mapping variations in household waste generation between densely populated and low-density areas.[19] The use of individual building data as waste source points in GIS models improves the accuracy of generation volume estimates and the efficiency of local waste collection systems.[20] Because every building is a unit with the potential to generate waste, in a spatial context, building points are used to represent waste-generation sources and average per capita generation (kg/person/day). In ArcGIS, waste generation calculated from building points can be calculated using the following formula.[20]:

$$Q_{total} = \sum(Q_i \times N_i) \qquad (1)$$

Description :
Q_i : Average generation per individual/activity in building-i
N_i : Number of individuals in building-i

b. Spatial Data Preparation
Involved integrating building points (as demand points), TPST locations (as facilities), and the road network dataset was configured with connectivity rules at intersections to ensure continuous routing. The impedance parameter was defined as network distance, representing the actual travel distance along the road network from the TPST to each building point.

c. Service Capacity of Integrated Waste Management Facilities
Network analysis was conducted using a location-allocation model with a capacitated coverage setting. In this model, capacity refers to the maximum waste handling capability of the TPST, expressed as waste volume per day (kg/day). Demand from each building point was allocated to the TPST until the facilty's capacity limit was reached. Buildings exceeding this capacity were classified as unserved, even if they were located within the distance-based service area. This approach enables evaluation of TPST service coverage by considering both spatial accessibility and facilty capacity constraints.

The stages of this analysis are presented in the following figure.

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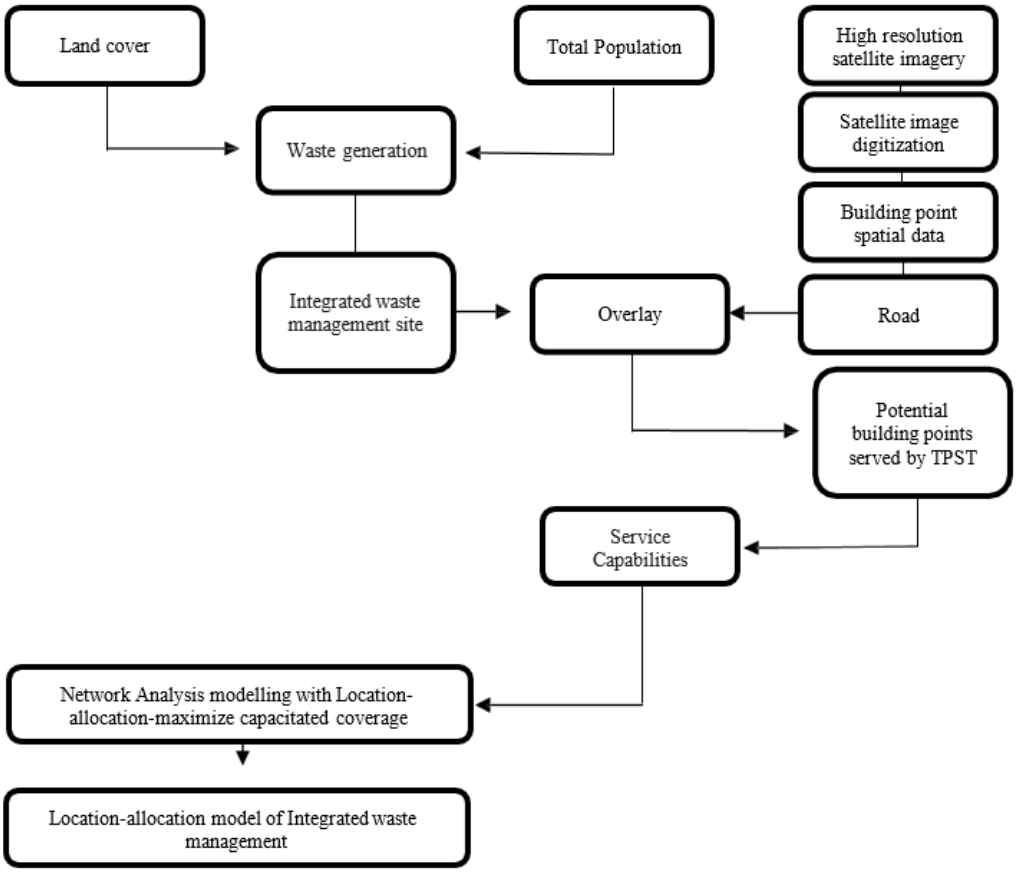

Figure 2. Stages of analysis data

3. RESULT AND DISCUSSION

In spatial planning theory, infrastructure provision including TPST is fundamentally guided by the principles of service coverage, accessibility, and spatial equity, which require that public facilities be distributed in a manner that effectively serves all residential areas. This gap in spatial planning and coverage undermines the potential of TPSTs to improve environmental outcomes and equitably support sustainable waste management [21] [22]. The planning of a new integrated waste processing facility (TPST) must begin with a systematic evaluation of existing waste management infrastructure to determine its spatial service performance. Empirical studies demonstrate that GIS-based spatial analysis is a robust approach for assessing the distribution and accessibility of waste facilities, enabling the identification of underserved areas or "blank spots" where current systems fail to provide adequate service [23]. Such spatial gap analysis is critical in facility planning, as it provides an evidence-based foundation for determining the necessity, scale, and location of new waste processing infrastructure [24]. In Indonesia, this planning approach is consistent with the mandate of Law No. 18/2008 on Waste Management and the National Policy and Strategy for Household Waste Management (Jakstranas), which emphasize the optimization of local-scale waste processing facilities and the reduction of waste transported to final disposal sites. By evaluating whether existing TPST in Sidodadi can effectively serve all residential areas, local governments can align waste infrastructure development with spatial planning objectives, improve service equity, and enhance the efficiency and sustainability of urban waste management systems [25].

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3.1. Waste generation in residential areas in Sidodadi Subdistrict

According to SNI 19-3964-1994, if field observations are not yet available, then to calculate the system size, the following waste generation figures can be used:[26]

1. Medium municipal waste generation unit 2,75-3,25 L/L/ L/person/day or 0,070-0,080 kg/person/day.
2. Small city waste generation unit 2,5-2,75 L/person/day or 0,625-0,70 kg/person/day. Description: for medium cities, the population is 100,000<p< 500,000, and for small cities, the population is < 100.000. Waste generation in Sidodadi Village is estimated using existing population data. Therefore, the waste generation calculation is as follows:

$$Q = 26.612\ M^3 \qquad (2)$$

Based on the results of the analysis of waste generation in Sidodadi Village and field observation data, there is only 1 (one) Integrated Waste Management Facility (TPST). [13]. The results of the waste generation analysis in Sidodadi Village, using a Geographic Information System (GIS) approach with ArcGIS software, produced the following distribution map.

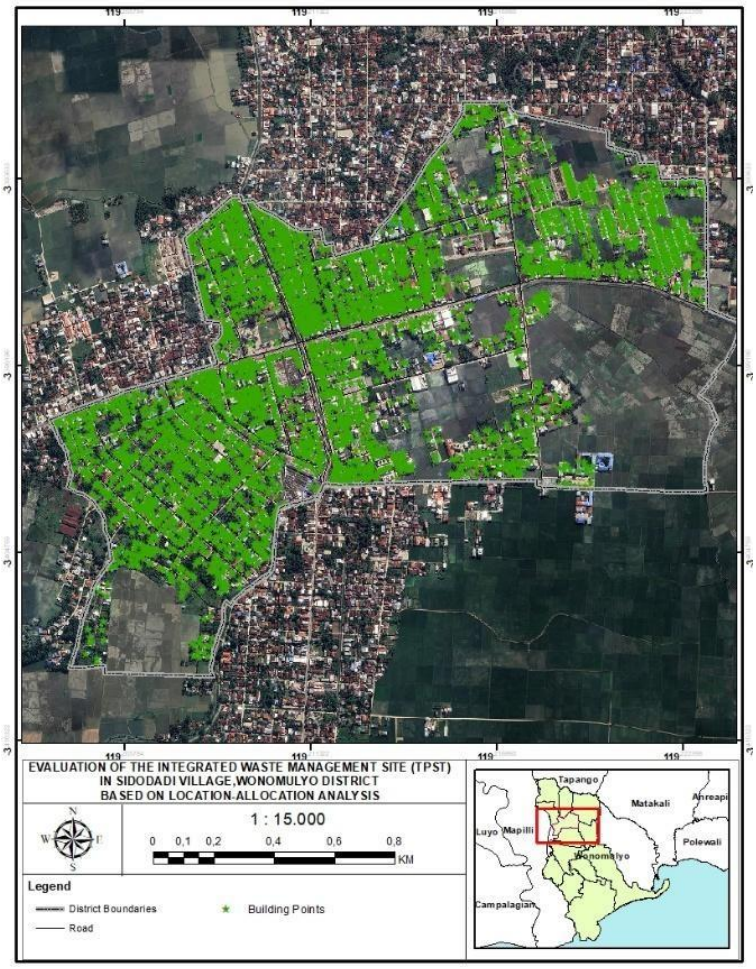

Figure 3. Waste generation map using building points.

Based on the building distribution map in Sidodadi Village, Wonomulyo District, it can be seen that residential areas with high building density are spread across the central to northern parts of the study area. The distribution of building points indicated by green symbols depicts potential locations for household waste generation. The denser the distribution of building points in an area, the greater the potential for waste generation. This indicates that the highest waste generation is expected in densely populated residential areas. At the same time, areas in the south and east, dominated by agricultural

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land, have fewer buildings, resulting in relatively low waste generation.

3.2. Integrated Waste Management Site (TPST) located in Sidodadi Subdistrict

The Integrated Waste Management Site (TPST) in Sidodadi Village, Wonomulyo District, is a neighborhood-scale waste-processing facility that collects, sorts, and processes household waste [14] [7]. Based on spatial analysis in Sidodadi Village, the existing TPST serves only a small number of buildings and depends on its service capacity. The results of the spatial analysis are presented in the following map.

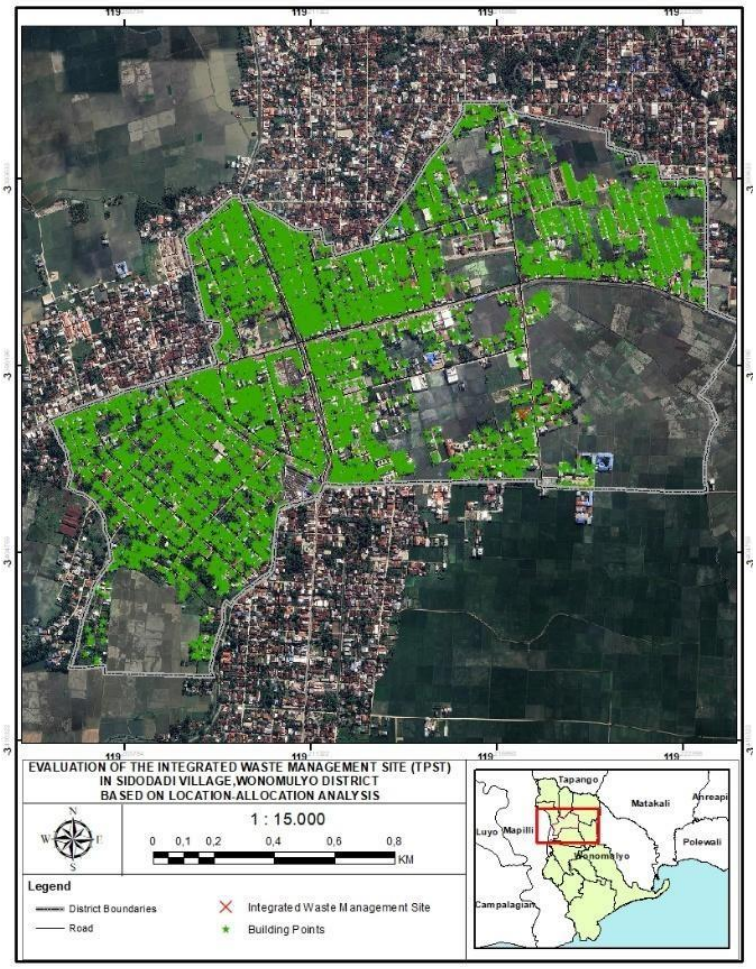

Figure 4. Map of Integrated Waste Management Sites (TPST) in Sidodadi Subdistrict

The location of Integrated Waste Management Sites (TPST) is closely linked to the spatial distribution of population activity. Densely populated residential areas are the primary sources of waste generation due to high levels of domestic activity, including household consumption, small- scale trade, and services [27]. The reason more waste is retained at its source is the availability and distance of available landfills (TPST). The optimal distance between the waste source and the management facility is ≤ 1 km to ensure efficient transportation and collection.[28] The availability of TPSTs far from densely populated residential areas will directly affect waste accumulation in the surrounding areas. Therefore, the technical recommendation is to relocate these facilities to locations close to the primary sources of waste generation, ensuring they can reach all residential areas within an efficient service radius [29].

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3.3. Location Modeling – Allocation of Integrated Waste Management Sites (TPST) in Sidodadi Village

The location-allocation Modeling of the Integrated Waste Management Site (TPST) in Sidodadi Village aims to account for the distribution of waste generation across building points by considering the TPST's service capabilities. The location-allocation approach based on spatial analysis in ArcGIS is the most appropriate method for identifying optimal facility locations to minimize waste transport distances and maximize service coverage [30]. In this context, Modeling is carried out by integrating building-based waste generation data, road network maps, and the existing capacity of TPSTs to analyze the extent to which the current service area can cover densely populated areas. Spatial Modeling is presented in the form of a map as follows:

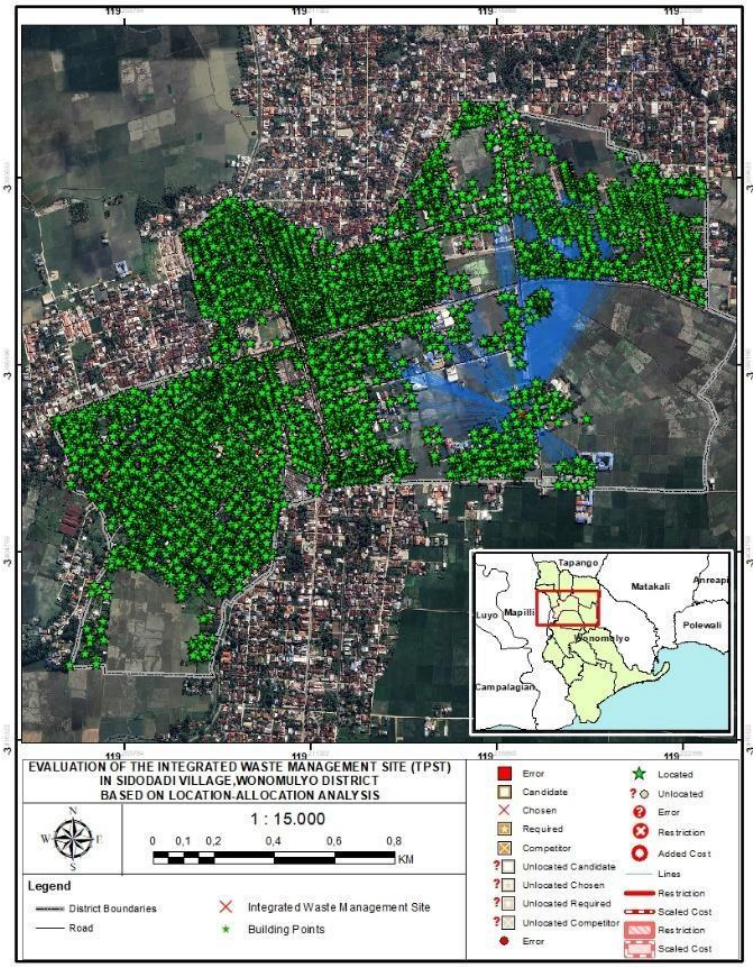

Figure 5. Location Map – Allocation of Integrated Waste Management Sites (TPST) in Sidodadi Village

Based on a location-allocation analysis in Sidodadi Village using ArcGIS, the distribution of building points that contribute to waste generation is uneven. On the map, the service coverage of the Integrated Waste Management Site (TPST) extends only to a small area near the facility, marked in blue and representing the optimal service radius. Meanwhile, most densely populated areas have not been served effectively, as evidenced by the large number of green building points outside the coverage area. The mapping results show that the TPST can serve only 600 families using the building-point approach. Assuming 1 (one) house is occupied by 1 (one family). The number of serviced and unserviced buildings is shown in the following table.

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Table 1. Table of the number of buildings served and not served by TPST

TPST	Served	600
	Not Served	3189
Total Building		3789

This finding implies that the current TPST location and service capacity are insufficient to accommodate the spatial distribution of waste generation, highlighting the need for facility expansion, relocation, or the development of additional TPST units. These results provide practical input for local governments in formulating spatially informed waste management policies and prioritizing infrastructure investment to improve service equity and coverage.

4. CONCLUSION

Based on the location–allocation spatial analysis in ArcGIS, the existing TPST in Sidodadi Village demonstrates limited service performance. Using a network-based distance model with a facility capacity constraint of 3,000 people (SNI 3242-2008), the model results indicate that the TPST covers only ±600 households, equivalent to less than 25% of the estimated service demand. Coverage analysis shows that more than 70% of residential building points, particularly in the central and northern areas of the village, fall outside the effective service area. This suboptimal performance is primarily influenced by capacity limitations and excessive network travel distances exceeding the defined cutoff. Therefore, the addition of new TPST locations in high-density zones and the optimization of the waste collection network are required to increase service coverage, improve spatial equity, and enhance the overall efficiency of the waste management system in Sidodadi Village.

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