PLANNING FOR DETERMINING THE LOCATION OF INTEGRATED WASTE PROCESSING SITE (TPST) USING A GEOGRAPHIC INFORMATION SYSTEM (GIS) AND THE SIMPLE ADDITIVE WEIGHTING (SAW) METHOD IN DENPASAR CITY, BALI

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ABSTRACT

The waste problem in big cities in Indonesia is still an environmental issue that never ends. By increasing the population, land conversion in several areas, lack of waste processing facilities and lack of awareness are factors contributing to the waste problem. In 2020, waste services in Denpasar only reached 67.5%, so management of the waste produced is not yet optimal. An integrated waste processing method from upstream to downstream is needed before the waste ends up in the landfill. By functioning optimally, the quality and quantity of waste processing at the TPST in Denpasar, the presence of an overcapacity landfill in Suwung can reduce the burden of waste in the landfill. The existence of a TPST is very necessary in Denpasar, which so far has not been optimal, so a decision is needed to determine the location of the TPST in the Denpasar area. There are 2 methods used in the research method, the first is the use of the SAW method of decision-making system (DSS) and the second is digitization of mapping using GIS. Analysis of the decision-making system (DSS) using the SAW method using mathematical analysis, decision matrices and priority scales. The results of the research show that the priorities for determining TPST locations were obtained by areas that were priority I for TPST development using the SAW method, namely Kesiman and Padang Sambian with a value of 80-100. Priority I area is also included in the low rainfall area category according to rainfall data for the Denpasar city area. There are 10 priority II regions and 25 priority III regions. So, the Kesiman and Padang Sambian areas have the highest priority compared to other areas in Denpasar Bali for TPST development.

Keywords: GIS, SAW, TPA, TPST, waste management

INTRODUCTION

Bali Province is a world-class tourist destination favored by both domestic and international tourists. This has undoubtedly had a positive impact on the regional economy and the development of supporting infrastructure. Furthermore, it has led to high consumption activity among local residents and tourists, resulting in significant waste generation.

According to data from the Ministry of Environment and Forestry (KLHK), Bali Province generated 915,500 tons of waste in 2021. This makes Bali the eighth-largest waste-producing province in Indonesia. When broken down by region, the highest waste generation in Bali came from Denpasar City, with 349,500 tons in 2021. Next in line are Gianyar Regency with 141,400 tons of waste, Buleleng Regency with 123,700 tons, Badung Regency with 116,700 tons, and Tabanan Regency with 84,200 tons. Based on its source, the majority of waste in Bali comes from household activities, accounting for 40.58% of the province's total waste. Followed by waste from commercial activities 18.22% and from markets 17%.

The waste collection system in Denpasar City generally utilizes temporary storage sites (TPS), where household waste is collected at the TPS and then transported to the final disposal site (TPA). The number and capacity of TPS in Denpasar City still do not meet the city's waste management needs. This limited number and capacity are also influenced by the limited land available for TPS placement in the central urban area. The lack of clear direction and strategy for determining the location and distribution of TPS, coupled with the limited land in urban areas and the difficulty of constructing adequate TPS that meet standards, has led to serious problems such as waste being scattered around the TPS, which has reduced the aesthetics of the environment (Achmad, 2015). According to data from the Ministry of Environment and Forestry (DKLH), as of July 2023, the Suwung TPA received an average of 690 tons of waste per day from the Denpasar City Environment Agency (DLHK), the Badung Regency Environment Agency (DLHK), and private entities in Denpasar and Badung. Ten to 12 garbage trucks transport waste to the TPA daily. This indicates that the landfill is overcapacity, leading to serious environmental problems. This problem is exacerbated by, in addition to the increasing daily waste volume, management at smaller levels, such as the waste disposal sites (TPS) and waste disposal sites (TPST), which are sometimes suboptimal, leading to waste being sent directly to the landfill. This is inconsistent with the proper waste management process from upstream to downstream. The number of TPS and TPST is considered insufficient and disproportionate to the increasing daily waste volume. This is due to the constraints of policy, land use, and a lack of technical and scientific analysis.

Based on this background, a study is needed to determine the ideal TPST location using scientific methods, such as "Planning for Determining the Location of Integrated Waste Processing Sites (TPST) Using Geographic Information Systems (GIS) and the Simple Additive Weighting (SAW) Method in Denpasar City, Bali."

METHODS

Research Design

The research plan design can be seen in Figure 1 below. As can be seen in the picture, the concept of this research begins with conducting field observations to be able to analyze the main problem, equate perceptions with research members, and design problem-solving ideas according to the researcher's expertise.

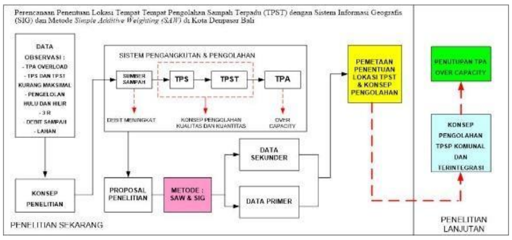

Figure 1. Research Design Chart

The research plan is divided into two parts: current research and follow-up research. These two stages are expected to provide short-, medium-, and long-term solutions to waste management issues in Denpasar in particular and Bali in general.

The current research focuses on determining the location criteria for waste disposal sites (yellow block diagram) using two methods (purple block): SAW and GIS. These two methods are expected to complement each other in scientific analysis to determine the ideal location for waste disposal sites.

The next stage of research, after determining the location criteria and the scientific study, is expected to continue with technical studies for the construction phase. The establishment of these waste disposal sites will facilitate optimal waste processing and oxidation, thereby reducing the burden on the landfill (TPA). Furthermore, in the long term, if all TPS and TPST function properly, the existence of landfills (TPA) can be reduced or even eliminated.

Research Location and Timeline

The research location is in the Denpasar area of Bali, and the research period is six months, from September 2023 to February 2024. In addition to data from field observations and literature studies, two data sources were used in this study.

The primary data used in this study consist of data processed using the SAW method, including matrices, matrix normalization, and mathematical calculations. In addition, primary data also include data obtained from digitization, map overlay, and analysis using ArcView software. Meanwhile, the secondary data used in this study include spatial data such as administrative map data for the City of

Denpasar, topographic data of each sub-district, land use map data for the City of Denpasar, rainfall map data for the City of Denpasar, and population density data for the City of Denpasar. Secondary data also include data related to weighting criteria, matrices, and calculation formulas used in SAW analysis.

Research implementation

The implementation stages of this research are divided into four stages:

Preparation Stage

This stage focuses on the initial phases before the research begins, including research preparation, literature review, and research observations. Research observations include field visits to polling stations (TPS), TPST, and landfills (TPA). In addition, this stage includes discussions between team members and the lead researcher to establish a shared understanding of the research objectives, benefits, and other supporting factors.

Data Collection Stage

The data collection stage is divided into two parts: primary data collection and secondary data collection. Primary data collection is obtained from direct research using two methods: SAW and GIS digitization, while secondary data is obtained from literature studies, literature, and other supporting data such as maps and the topology of Denpasar.

Data Processing Stage

At this stage, data processing is carried out using two methods, one of which is a Decision Support System (DSS) using the SAW method. This method emphasizes mathematical analysis through the use of matrices, normalization, and prioritization based on several calculation formulas aimed at determining values that serve as supporting decision-making criteria for a given problem, such as determining the criteria for selecting an integrated temporary waste processing (TPST) location. The steps in applying the SAW method begin with determining the criteria (Ci) that will be used as references in decision-making. Next, the suitability rating of each alternative is determined for each criterion. A decision matrix is then constructed based on the criteria (Ci) and normalized using equations adjusted to the attribute type, whether benefit attributes or cost attributes, to produce a normalized matrix R. Finally, the ranking process is conducted by summing the results of multiplying the normalized matrix R by the preference weight vector to obtain the highest value. This highest value, for example alternative A1, is selected as the best alternative and serves as the decision-making solution in the SPK (Survey Planning and Decision Making) method.

Location mapping using spatial analysis with GIS

To further deepen the analysis and refine the results of the first method, spatial analysis was continued using ArcView software with GIS. This software analysis emphasizes digitizing overlays supported by secondary maps, such as land use maps, population density, rainfall, natural disaster vulnerability levels of a region, and other supporting map data. All analysis steps are performed using ArcView GIS software.

The results of this analysis are expected to support decision-making in the first method (SAW) to be more accurate and scientifically measurable, supported by primary and secondary data.

RESULTS AND DISCUSSION

Data Analysis Using SAW

The criteria used in this study to calculate the priority values for determining the location of the TPST are: C1 = Population density, C2 = Availability of road access, C3 = Number of TPS (landfill sites), C4 = Availability of land, and C5 = Disaster-prone area. When adjusted for the number of attributes, these criteria include C1, C2, C3, and C4 as benefit attributes, and C5 as cost attributes.

The population density criterion is directly proportional to the amount of waste generated in the area, therefore, the population density criterion is a priority in determining the location of the TPST. Similarly, the availability of road access that will serve as a transportation route to the location, the number of TPS (landfill sites) supporting the TPST, and the availability of land sufficient to meet the ideal needs for an integrated waste sorting location are factors in the priority scale for TPST development (benefit). Meanwhile, the criteria for disaster-prone areas are a factor in considering a location for a landfill (TPST).

Based on data on the population of sub-districts and villages in Denpasar City, with four population density classifications (Kingma, 1991), the following data were obtained:

Table 1. Population Density Classification of Denpasar City

Population/km^2	**Classification**	**Rating**
< 8.842	Low	1
8843 - 17.685	Moderate	2
17.686 -26.528	High	3
> 26.529	Very High	4

The criteria for the availability of polling stations are categorized into 3 groups, namely Priority 1, 2, and 3. Priority 1 indicates that the area does not have a polling station or only 1 polling station for one sub-district, Priority 2 indicates that there are 2 to 3 polling stations for 1 sub-district, Priority 3 indicates that there are more than 3 polling stations in 1 sub-district. Determining the range of the number of polling stations utilizes a statistical formula which can be seen in Table 2. below.

Table 2. Priority scale Number of TPA

Number of polling stations	**Priority**	**Rating**
>3	Priority 1	1
2-3	Priority 2	2
<=1	Priority 3	3

The results of the SAW analysis of each of the criteria used, such as C1 = Population density, C2 = Availability of road access, C3 = Number of polling stations, C4 = Availability of land, C5 = Disaster-prone areas, are obtained in the following table:

Table 3. Research data based on each criteria

ALTERNATIVE	C1	C2	C3	C4	C5
K1	4029	1	3	There is	disaster-prone
K2	24603	1	3	There is	not prone to disasters
K3	39397	1	3	There is	not prone to disasters
K4	23228	1	3	There is	not prone to disasters
K5	11434	1	3	There is	not prone to disasters
K6	9509	1	3	There is	disaster-prone
K7	17078	1	3	There is	not prone to disasters
K8	30297	1	3	There is	not prone to disasters
K9	7685	1	3	There is	disaster-prone
K10	11111	1	2	There is	disaster-prone
K11	13202	1	3	There is	not prone to disasters
K12	7840	1	3	There is	not prone to disasters

K13	9271	1	3	There is	not prone to disasters
K14	10187	1	3	There is	not prone to disasters
K15	14101	1	2	There is	not prone to disasters
K16	12761	1	3	There is	not prone to disasters
K17	10733	1	3	There is	not prone to disasters
K18	18523	1	3	There is	not prone to disasters
K19	8104	1	3	There is	not prone to disasters
K20	7069	1	3	There is	not prone to disasters
K21	7531	1	3	There is	not prone to disasters
K22	9229	1	3	There is	not prone to disasters
K23	20962	1	3	There is	not prone to disasters
K24	28525	1	3	There is	not prone to disasters
K25	20100	1	3	There is	not prone to disasters
K26	32647	1	3	There is	not prone to disasters
K27	14143	1	3	There is	not prone to disasters
K28	11822	1	2	There is	not prone to disasters
K29	4312	1	3	There is	not prone to disasters
K30	12637	1	3	There is	not prone to disasters
K31	16920	1	3	There is	not prone to disasters
K32	16809	1	3	There is	not prone to disasters
K33	15019	1	3	There is	not prone to disasters
K34	10074	1	3	There is	not prone to disasters
K35	14354	1	3	There is	not prone to disasters
K36	9369	1	3	There is	not prone to disasters

K37	7098	1	3	There is	not prone to disasters
K38	13670	1	3	There is	not prone to disasters
K39	28114	1	3	There is	not prone to disasters
K40	18637	1	3	There is	not prone to disasters
K41	22671	1	3	There is	not prone to disasters
K42	8711	1	3	There is	not prone to disasters
K43	18085	1	3	There is	not prone to disasters

The results of processing the data in the table above, in accordance with the ranking criteria, are:

Table 4. Data Processing Results

ALTERNATIVE	C1	C2	C3	C4	C5
K1	1	1	3	1	1
K2	3	1	3	1	2
K3	4	1	3	1	2
K4	3	1	3	1	2
K5	2	1	3	1	2
K6	2	1	3	1	1
K7	2	1	3	1	2
K8	4	1	3	1	2
K9	1	1	3	1	1
K10	2	1	2	1	1
K11	2	1	3	1	2
K12	1	1	3	1	2
K13	2	1	3	1	2
K14	2	1	3	1	2
K15	2	1	2	1	2
K16	2	1	3	1	2
K17	2	1	3	1	2
K18	3	1	3	1	2
K19	1	1	3	1	2

K20	1	1	3	1	2
K21	1	1	3	1	2
K22	2	1	3	1	2
K23	3	1	3	1	2
K24	4	1	3	1	2
K25	3	1	3	1	2
K26	4	1	3	1	2
K27	2	1	3	1	2
K28	2	1	2	1	2
K29	1	1	3	1	2
K30	2	1	3	1	2
K31	2	1	3	1	2
K32	2	1	3	1	2
K33	2	1	3	1	2
K34	2	1	3	1	2
K35	2	1	3	1	2
K36	2	1	3	1	2
K37	1	1	3	1	2
K38	2	1	3	1	2
K39	4	1	3	1	2
K40	3	1	3	1	2
K41	3	1	3	1	2
K42	1	1	3	1	2
K43	3	1	3	1	2

From the table above, the following decision matrix X is obtained:

24

X =

1	1	3	1	0
3	1	3	1	1
4	1	3	1	1
3	1	3	1	1
…	…	…	…	…
3	1	3	1	1

Next, the above matrix will be normalized based on the equations according to the predetermined criteria types. The results of the normalization process can be seen below:

$$R11 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{4} = 0.25$$
$$R21 = \frac{3}{Max(A1; \dots A43)} = \frac{3}{4} = 0.75$$
$$R31 = \frac{4}{Max(A1; \dots A43)} = \frac{4}{4} = 1$$
$$R41 = \frac{3}{Max(A1; \dots A43)} = \frac{3}{4} = 0.75$$
$$R12 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$
$$R22 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$
$$R32 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$
$$R42 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$

$$R13 = \frac{3}{Max(A1; \dots A43)} = \frac{3}{3} = 1$$
$$R23 = \frac{3}{Max(A1; \dots A43)} = \frac{3}{3} = 1$$
$$R33 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$
$$R43 = \frac{1}{Max(A1; \dots A43)} = \frac{1}{1} = 1$$
$$R14 = \frac{Min\ (A1; \dots A43)}{1} = \frac{1}{1} = 1$$
$$R24 = \frac{Min\ (A1; \dots A43)}{1} = \frac{1}{1} = 1$$
$$R34 = \frac{Min\ (A1; \dots A43)}{1} = \frac{1}{1} = 1$$
$$R44 = \frac{Min\ (A1; \dots A43)}{1} = \frac{1}{1} = 1$$
$$R15 = \frac{Min\ (A1; \dots A43)}{1} = \frac{1}{1} = 1$$
$$R25 = \frac{Min\ (A1; \dots A43)}{2} = \frac{1}{2} = 0.5$$
$$R35 = \frac{Min\ (A1; \dots A43)}{2} = \frac{1}{2} = 0.5$$
$$R45 = \frac{Min\ (A1; \dots A43)}{2} = \frac{1}{2} = 0.5$$

From the normalization results above, the following values are obtained :

$R11 = 0.25$
$R12 = 1$
$R13 = 1$
$R14 = 1$
$R15 = 0.5$

Normalize the x-matrix to R using alternative 1, Serangan, as an example. Then, assign a weight based on its importance level, according to the technical guidelines for the establishment of a waste treatment plant (TPST) from Cipta Karya, at 20%. This yields:
V1 = (20 x 0.25) + (20 x 1) + (20 x 1) + (20 x 1) + (20 x 0.5)
= 5 + 20 + 20 + 20 + 10 = 75
Continuing the calculation using the same method, the values of V1 – V43 are as follows:

Table 5. Tabel Priority Locations for TPST in Denpasar City

No	Alternative	% match	Priority
1	SERANGAN	75	Priority II
2	PEDUNGAN	80	Priority II
3	SESETAN	80	Priority II
4	PANJER	75	Priority II
5	RENON	70	Priority III
6	SANUR	60	Priority III
7	SIDAKARYA	70	Priority III
8	PEMOGAN	80	Priority II
9	SANUR KAJA	70	Priority III
10	SANUR KAUH	72	Priority III
11	KESIMAN	100	Priority I
12	SUMERTA	80	Priority II
13	DANGIN PURI	75	Priority III
14	PENATIH	75	Priority III
15	DANGIN PURI KELOD	80	Priority II
16	SUMERTA KELOD	78	Priority III
17	KESIMAN PETILAN	90	Priority I
18	KESIMAN KERTALANGU	95	Priority II
19	SUMERTA KAJA	75	Priority III
20	SUMERTA KAUH	80	Priority II
21	PENATIH DANGIN PURI	77	Priority III
22	DAUH PURI	78	Priority III
23	PEMECUTAN	75	Priority III
24	PADANGSAMBIAN	80	Priority II
25	PADANGSAMBIAN KELOD	84	Priority II
26	PEMECUTAN KELOD	78	Priority III
27	DAUH PURI KAUH	75	Priority III
28	DAUH PURI KELOD	75	Priority III
29	DAUH PURI KANGIN	78	Priority III
30	TEGAL HARUM	80	Priority II
31	TEGAL KERTHA	78	Priority III
32	PADANG SAMBIAN KAJA	85	Priority I
33	TONJA	75	Priority III
34	UBUNG	80	Priority II
35	PEGUYANGAN	75	Priority III
36	DANGIN PURI KANGIN	78	Priority III
37	DANGIN PURI KAUH	75	Priority III
38	DANGIN PURI KAJA	78	Priority III

39	PEMECUTAN KAJA	75	Priority III
40	DAUH PURI KAJA	75	Priority III
41	UBUNG KAJA	80	Priority II
42	PEGUYANGAN KAJA	75	Priority III
43	PEGUYANGAN KANGIN	75	Priority III

As seen in the table above, the Kesiman and Padang Sambian areas are the priority I areas for the TPST development planning area.

CONCLUSION

The conclusions and recommendations derived from this study indicate that the determination of TPST locations was conducted using two complementary methods, namely the SPK SAW method and Geographic Information Systems (GIS) analysis using ArcView software. The results of the SAW method show that the Priority I areas for TPST development are Kesiman and Padang Sambian, which obtained scores ranging from 80 to 100. In addition, the analysis identifies 10 areas classified as Priority II and 25 areas classified as Priority III.

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