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Research Paper

Greedy Reduction Algorithm as the Heuristic Approach in Determining the Temporary Waste Disposal Sites in Sukarami Sub-District, Palembang, Indonesia

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Abstract
Waste is one of the problems in Palembang, Indonesia. The amount of waste in Palembang increases proportionally to the population yearly and can adversely affect the community. Therefore, we determine the optimal temporary waste disposal site (TWDS) to optimize the problems. The set covering model is the proper model for solving the location and allocation problem. In this study, data on the distance between each TWDS is needed in the set covering modeling. The novelty in this research is developing the ρ-median problem model, which is formed from the optimal solution of the set covering location problem (SCLP) model. Palembang consists of 18 sub-districts, of which the Sukarami sub-district has the highest population density. This study discussed the determination of strategic TWDS in the Sukarami sub-district using the SCLP model, the ρ-median problem, and a heuristic approach, namely the greedy reduction algorithm in solving the model. Based on the solution of the ρ-median problem model with LINGO 18.0 and the ρ-median problem solved by the greedy reduction algorithm, only three strategic TWDS were found for the Sukarami sub-district. The study results recommend a review of the existing TWDS and particularly the addition of a TWDS in Sukodadi and Talang Betutu villages, respectively.

Keywords
TWDS Location, Set Covering Location Problem, ρ-Median Problem, Greedy Reduction Algorithm

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1. INTRODUCTION

Palembang is the second-largest and most populous city on the Sumatera island after Medan and Indonesia's ninth most populous city. According to the Central Statistics Agency, in 2020, Palembang had around 8.5 million people with a population density of 92 people/km^2 and 18 sub-districts. Sukarami sub-district is one of the sub-districts in Palembang, which has crowded public places daily, such as Hajj Dormitory, KM 5 Market, Pasaraya, hotels, and automotive companies or dealers. The waste volume increases every day. The increase in waste impacts the environment and public health (Puspita et al., 2018). Waste is an object that is no longer useful and arises from the community environment in solid form, both organic and inorganic. Waste can come from markets, factories, offices, institutions, public buildings, community settlements, or community yards (Bangun et al., 2022).

The waste is collected in different temporary waste disposal sites (TWDS) in their respective locations (Yuliza et al., 2020). According to data from the Environment and Hygiene Service of Palembang City, TWDS are divided into several types: market TWDS, container TWDS, self-help TWDS, and unofficial TWDS. Market TWDS is located in the market area, usually in a concrete square tub. Container TWDS is found in market areas and sometimes around community settlements, usually in fibre containers. Self-help TWDS is located in residential areas such as complexes, schools, buildings, or public places, usually in a concrete square tub. Unofficial TWDS is generally located in community residential areas in front of the market, which are placed illegally. The waste collected at the TWDS will then be transported by dump truck to the final disposal site (FDS) in stages according to the transportation schedule from each TWDS, which is different in each region. Several factors hinder the transportation process, including the waste transportation routes with long distances between TWDS and disordered, the transportation equipment capacity, and the waste volume at each TWDS (Octarina et al., 2022b). In dealing with these problems, the set covering problem (SCP) model can be used to find solutions to this TWDS optimization problem (Octarina et al., 2022b).

Set covering is part of integer linear programming related to optimization, which concerns the location-allocation problems and aims to minimize the factors that affect the constraints in the model (Sitepu et al., 2022). SCP is one optimization problem in computer science (Crawford et al., 2018). The SCP application in daily life determines the waste vehicles routes, vehicle routes to pick up bus passengers at bus stops, scheduling flight crews, resource allocation, etc (Çalık and Fortz, 2019; Cubillos and Wøhlk, 2021; Roshanaei et al., 2017; Šarac et al., 2016). According to the model group, the SCP consists of the set covering location problem (SCLP), maximal covering location problem (MCLP), ρ-median problem, and ρ-center problem (Octarina et al., 2022a). The four models have a relationship in their solutions but differ in their objective functions. SCLP finds the optimum number of TWDS to serve all demand points (Jeong, 2017). MCLP aims to maximize the demand by a limited number of TWDS that can be served in standard time and p-median problem minimizes the distance between TWDS and sorts the routes (Guzmán et al., 2016). The ρ-center problem is the min-max multi-centre problem (Du et al., 2020). Previous research on SCP has been carried out (Crawford et al., 2018; Bangun et al., 2022; Çalık and Fortz, 2019; Daskin and Maass, 2019; Ahmadi-Javid et al., 2017; Kinsht and Petrunko, 2020; Kwon et al., 2020; Sitepu et al., 2019; Xu and Li, 2018).

A greedy reduction algorithm (GRA) is an algorithm to solve optimization problems such as optimizing facility locations, scheduling employee assignments, and scheduling lectures (Ardeshiri et al., 2015). In solving problems, GRA performs solutions based on a step-by-step solution in sequence so that the final solution can be the most optimal (Binev et al., 2018). The advantage of GRA compared to other algorithms is that it can find the best route in optimizing the distance, minimize costs, and optimize the facility allocation point (Shao et al., 2020). Previous research by Puspita et al. (2018) used the GRA in optimizing TWDS and found a solution, namely 3 TWDS, to meet the six villages demands. Ardeshiri et al. (2015) implemented the GRA for mixtures of exponential families and found the optimal solution, even with a limited computational budget, can provide significant results of 1%. Čertíková et al. (2020) concluded that greedy reduced basis algorithms could shorten the time and provide significant solutions.

This study determines the optimal TWDS in Sukarami sub-district using the SCP model and solved by GRA. This research's novelty is in improving the ρ-median problem model from the optimal solution of the SCLP model. The model and algorithm are expected to optimize the number of TWDS to meet all demand points in the sub-district. The exact solutions obtained from SCP and the heuristic solution using GRA are expected to provide the best solution and can be considered for Palembang City in determining strategic TWDS in the Sukarami sub-district.

2. EXPERIMENTAL SECTION

2.1 Methods

We discussed the method used in this research in this section. We also briefly discuss SCLP, the ρ-median problem, and a short description of the GRA. The steps of this research are listed as follows:

1. Collect data on TWDS names, locations, and the number of TWDS in each village in the Sukarami sub-district from the Palembang City Environment and Hygiene Service (DLHK Palembang).
2. Describe the data used, namely:
   a. Check TWDS location points according to the actual TWDS location.
   b. Measure the distance between TWDS and TWDS and between TWDS and the village in the Sukarami sub-district using google maps.
3. Define variables and parameters for the SCLP model and ρ-median problem.
4. Formulate the set covering model, namely the SCLP model and the ρ-median problem.
5. Find solutions to the SCLP model and ρ-median problem using the LINGO 18.0. application
6. Solve the ρ-median problem model and implement the GRA to solve the ρ-median problem model.
7. Recapitulate the calculation results of the SCLP model and the ρ-median problem.
8. Analyze the results of the SCLP, ρ-median problem, and the GRA.
9. Make conclusions

2.2 Set Covering Location Problem (SCLP)

SCLP is one of the optimization problems to find the optimum TWDS placements so that it can serve all demand points on the waste transportation distribution system (Octarina et al., 2022a). The SCLP model can be systematically written as follows:

$$\text{Minimize } Z_{SCLP} = \sum_{j \epsilon J} x_j \tag{1}$$

subject to

$$\sum_{j \epsilon J} x_j \geq 1, \forall j \epsilon J \tag{2}$$

$$x_j \epsilon \{0,1\}, \forall j \epsilon J \tag{3}$$

whereas

Z_{SCLP} = the number of TWDS location
J = the set of TWDS location with index j

The decision variables are:

$$x_j = \begin{cases} 1; \text{if the TWDS is allocated at } j\text{- } th \text{ location} \\ 0; \text{if the TWDS is not allocated at } j\text{-}th \text{ location} \end{cases}$$

The objective function 1 minimizes the number of TWDS locations. Constraint 2 ensures that at least one TWDS can meet each demand point and Constraint 3 is the binary Constraint.

2.3 ρ-Median Problem

The ρ-median problem finds ρ TWDS at location j to minimize the distance (Ahmadi-Javid et al., 2017). The ρ-median problem can be formulated as follows:

$$\text{Minimize } Z_{p-median} = \sum_{i\epsilon I} \sum_{j\epsilon J} d_{ij} x_{ij} \tag{4}$$

Subject to:

$$\sum_{i\epsilon J} x_{ij} = 1, \forall i \epsilon I \tag{5}$$

$$\sum_{i\epsilon j} y_j = p \tag{6}$$

$$x_{ij} \leq y_i, \forall i \epsilon I, \forall j \epsilon J \tag{7}$$

$$y_j \epsilon \{0,1\}, \forall j \epsilon J \tag{8}$$

$$x_{ij} \epsilon \{0,1\}, \forall i \epsilon I, \forall j \epsilon J \tag{9}$$

whereas

$Z_{\rho-Median}$ =the total of minimum distance from the demand point to the TWDS

I =the set of demand point with index i

J =the set of TWDS location with index j

p =the number of TWDS for facility allocation

d_{ij} =the distance between the i-th and the j-th location (metre)

The decision variables are:

$$y_j = \begin{cases} 1; \text{if the TWDS is allocated at } j\text{-}th \text{ location} \\ 0; \text{if the TWDS is not allocated at } j\text{-}th \text{ location} \end{cases}$$

$$x_{ij} = \begin{cases} 1; \text{if the TWDS is allocated at } j\text{-}th \text{ location} \\ 0; \text{if the TWDS is not allocated at } j\text{-}th \text{ location} \end{cases}$$

Equation 4 obtains the minimum distance from the demand point to the nearest facility TWDS. Whereas, Constraint 5 indicates the demand for each TWDS placement. Constraint 6 sets the maximum number of TWDS. Constraint 7 suggests that every TWDS placement should be given the same facilities, and Constraints 8 and 9 indicate that the problem is a binary integer.

2.4 Greedy Reduction Algorithm (GRA)

GRA is an algorithm commonly used to solve optimization problems, determining the optimal facility point. Several factors in optimizing the location include the distance between the facility locations and the location quality. GRA is an algorithm used to solve optimization problems sequentially, producing a local optimum at each step and producing the best final solution in a global optimum solution (Sanchez-Oro and Duarte, 2018). According to Muliyadi (2017), the Greedy algorithm has several important elements, the candidate set, solution set, selection function, feasibility function, and objective function. In this study, we implemented GRA to solve the ρ-median problem in getting the final solution. The steps of GRA are as follow:

1. Form a distance matrix D with size m×n.
2. Look for the dominating matrix value in all existing matrix columns, provided that the dominating column has a smaller value than the other column values or $d_{ik} \leq d_{il}$; $\forall$ i≠ k and $\forall$ i ≠ l.
3. Compare all columns with the dominant value from the selected column.
4. Find the optimum value by comparing the entry values between the selected dominant column.
5. Compare the selected dominant column pair with each column to looks for the optimum value.
6. Analyze the results of each step and recapitulate the results.

3. RESULT AND DISCUSSION

TWDS data in the Sukarami sub-district was obtained from DLHK Palembang, which was surveyed and grouped based on the TWDS location points in each village. Table 1 shows the distribution of TWDS based on village location points. There is only one TWDS in Talang Jambe Village, TWDS Talang Jambe, next to Public Cemetery. Kebun Bunga village has 6 TWDS and Sukarami has 8 TWDS. Suka Bangun, Suka Jaya, Sukodadi, and Talang Betutu villages do not have any TWDS. Next, the definition of variables for SCLP and the ρ-median problem model can be seen in Table 2.

The distance between each TWDS was obtained through direct measurements of the location with Google Maps. Table 3 states the distance between each TWDS (d_{ij}) in the Sukarami sub-district (in meters). The number labelled in yellow is the maximum distance between each TWDS based on DLHK Palembang provisions, which is less than 500 meters.

Table 3 states that the distance from TWDS Kolonel H Burlian beside Hotel DE Premium (x_1) to TWDS Naskah (x_2) is 610 meters, and so on. Using the data in Tables 2 and 3, we formulate the SCLP model.

Minimize

$$\begin{aligned} Z_{SCLP} = &x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + \\ &x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \end{aligned} \tag{10}$$

Subject to

Table 1. TWDS Based on Village Location Points

No	Village Names	TWDS Names
1	Talang Jambe	TWDS Talang Jambe next to Public Cemetery
2	Kebun Bunga	• TWDS Letjen Harun Sohar in front of Honda Dealer • TWDS Letjen Harun Sohar in front of Hajj Dormitory • TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque • TWDS Letjen Harun Sohar in front of Talang Kedondong • TWDS Letjen Harun Sohar in front of Auto 2000 TAA • TWDS Bambu Kuning Arah Rumah Sakit Pelabuhan
3	Sukarami	• TWDS Batujajar • TWDS Naskah • TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop • TWDS Kolonel H Burlian beside Lorong Dharma Agung • TWDS Kolonel H Burlian Simpang SMP 40 Palembang • TWDS Kolonel H Burlian beside Hotel DE Premium • TWDS Kolonel H Burlian in front of Bank BRI • TWDS Kolonel H Burlian beside Indomaret Bus Stop
4	Suka Bangun	-
5	Suka Jaya	-
6	Sukodadi	-
7	Talang Betutu	-

$$x_1 \geq 1 \tag{11}$$
$$x_2 + x_4 \geq 1 \tag{12}$$
$$x_3 \geq 1 \tag{13}$$
$$x_3 + x_4 + x_5 \geq 1 \tag{14}$$
$$x_4 + x_5 + x_6 \geq 1 \tag{15}$$
$$x_5 + x_6 \geq 1 \tag{16}$$
$$x_7 + x_8 \geq 1 \tag{17}$$
$$x_9 + x_{10} \geq 1 \tag{18}$$
$$x_{11} \geq 1 \tag{19}$$
$$x_{12} + x_{13} \geq 1 \tag{20}$$
$$x_{14} \geq 1 \tag{21}$$
$$x_{15} \geq 1 \tag{22}$$
$$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15} \epsilon \{0,1\} \tag{23}$$

Model 10 states that the objective function minimizes the number of TWDS to satisfy all demand points. Constraints (11) to (22) state that each TWDS must meet at least one request point. Constraint (23) states that the variables x_1 to $x_{(15)}$ are binary. The optimal solution of the model is attached in Table 4.

Table 2. The Definition of Variabless

Variable	The Definition of Variables
x_1	TWDS Kolonel H Burlian beside Hotel DE Premium
x_2	TWDS Naskah
x_3	TWDS Batujajar
x_4	TWDS Kolonel H Burlian beside Lorong Dharma Agung
x_5	TWDS Kolonel H Burlian Simpang SMPN 40 Palembang
x_6	TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop
x_7	TWDS Kolonel H Burlian beside Indomaret Bus Stop
x_8	TWDS Kolonel H Burlian in front of Bank BRI
x_9	TWDS Letjen Harun Sohar in front of Hajj Dormitory
x_{10}	TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque
x_{11}	TWDS Letjen Harun Sohar in front of Talang Kedondong
x_{12}	TWDS Letjen Harun Sohar in front of Honda Dealer
x_{13}	TWDS Letjen Harun Sohar Auto 2000 TAA
x_{14}	TWDS Bambu Kuning Arah Rumah Sakit Pelabuhan
x_{15}	TWDS Talang Jambe next to Public Cemetery
y_1	Talang Jambe Village
y_2	Kebun Bunga Village
y_3	Sukarami Village
y_4	Suka Bangun Village
y_5	Suka Jaya Village
y_6	Sukodadi Village
y_7	Talang Betutu Village

Table 4 states the optimal solution of the model using LINGO 18.0 software. In the solver status section, the model class is PILP (Pure Integer Linear Programming), which means the model is solved in PILP form. State means the resulting solution is globally optimal. The infeasibility of the model is 0. Iterations in the model are 0, meaning that the solution value has been obtained without iteration in programming. The extended solver status section shows that the method used in this case is the branch and bound. The objective value is 10, which means that the optimal number of locations in the model is ten facility locations. Generated memory used (GMU) is 22K, meaning the total memory allocation used is 22K. Elapsed runtime (ER) shows the total time to complete the model on LINGO 18.0, 2 seconds. The optimal variable values of the SCLP model are attached in Table 5.

Variables with 0 value mean that there are no facilities placed at the location, and variables with one value mean that there are facilities placed at the location. In Table 5, it can be seen that there are ten variables with one value, namely the variables x_1, x_3, x_4, x_6, x_8, x_{10}, x_{11}, x_{13}, x_{14}, x_{15} which means that the candidate locations should be in 10 TWDS locations, as shown in Table 6.

The distance between TWDS and villages in the Sukarami sub-district can be seen in Table 7. d_{11} shows that the distance between Jambe village and TWDS Kolonel H Burlian beside Hotel DE Premium is 7,400 meters, d_{13} shows that the distance between Jambe village and TWDS Batujajar is 5,800 meters, and so on.

Based on the data in Table 7, the ρ-median problem model is

Minimize

Table 3. The Distance between Each TWDS

i\ j	d_{ij}														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	610	2090	750	940	1330	2205	2330	3280	3360	4230	5010	5290	6490	7170
2	610	0	1480	380	570	960	1980	1960	2910	2990	3860	4640	4920	6120	6800
3	2090	1480	0	1850	2040	2430	3200	3430	4380	4460	5330	6110	6390	7590	8270
4	750	380	1850	0	190	580	1600	1580	2530	2610	3480	4260	4540	5740	6420
5	940	570	2040	190	0	390	1410	1390	2340	2420	3290	4070	4350	5550	6230
6	1330	960	2430	580	390	0	1020	1000	1950	2030	2900	3680	3960	5160	5840
7	2205	1980	3200	1600	1410	1020	0	200	1070	1150	2020	2800	3030	4230	4910
8	2330	1960	3430	1580	1390	1000	200	0	950	1030	1900	2680	2960	4160	4840
9	3280	2910	4380	2530	2340	1950	1070	950	0	80	950	1730	2010	3210	3890
10	3360	2990	4460	2610	2420	2030	1150	1030	80	0	870	1650	1930	3130	3810
11	4230	3860	5330	3480	3290	2900	2020	1900	950	870	0	780	1060	2260	2940
12	5010	4640	6110	4260	4070	3680	2800	2680	1730	1650	780	0	280	1480	2160
13	5290	4920	6390	4540	4350	3960	3030	2960	2010	1930	1060	280	0	1200	1880
14	6490	6120	7590	5740	5550	5160	4230	4160	3210	3130	2260	1480	1200	0	1230
15	7170	6800	8270	6420	6230	5840	4910	4840	3890	3810	2940	2160	1880	1230	0

Table 4. Optimal Solution of SCLP Model

	Solver Status
Model Class	PILP
State	Global Optimal
Objective	10
Infeasibility	0
Iterations	0
	Extended Solver Status
Solver Type	Branch and Bound
Best Objective	10
Objective Bound	10
Steps	0
Active	0
Update Interval	2
GMU (K)	22
ER (sec)	2

Table 5. Variable Value of SCLP Model

Variable	Value	Variable	Value	Variable	Value
x_1	1	x_6	1	x_{11}	1
x_2	0	x_7	0	x_{12}	0
x_3	1	x_8	1	x_{13}	1
x_4	1	x_9	0	x_{14}	1
x_5	0	x_{10}	1	x_{15}	1

Table 6. TWDS Candidate Locations

Variable	Name of TWDS
x_1	TWDS Kolonel H Burlian beside Hotel DE Premium
x_3	TWDS Batujajar
x_4	TWDS Kolonel H Burlian beside Lorong Dharma Agung
x_6	TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop
x_8	TWDS Kolonel H Burlian in front of Bank BRI
x_{10}	TWDS Kolonel H Burlian in front of Bank BRI
x_{11}	TWDS Letjen Harun Sohar in front of Talang Kedondong
x_{13}	TWDS Letjen Harun Sohar in front of Auto 2000 TAA
x_{14}	TWDS Bambu Kuning Arah Rumah Sakit Pelabuhan
x_{15}	TWDS Talang Jambe next to Public Cemetery

Table 7. The Distance between TWDS and Villages

i\j	d_{ij} 1	3	4	6	8	10	11	13	14	15
1	7400	5800	5900	6500	5500	4200	3600	3100	1900	1320
2	3200	2400	2410	2000	1000	4200	1510	1900	3300	3680
3	1700	1900	900	500	950	2300	3050	3800	5200	5580
4	1800	2800	2400	2900	4000	5300	6150	5400	6800	7280
5	1100	1600	1500	1900	3000	4300	4750	4100	5500	5820
6	5600	6000	4900	4400	3400	3800	4050	4900	6300	6780
7	10000	8400	9500	9100	8000	6700	6050	5800	4900	3980

$$\begin{aligned}Z_{P-Median} =\ &7400y_{11} + 5800y_{13} + 5900y_{14} + 6500y_{16}+\\ &5500y_{18} + 4200y_{110} + 3600y_{111} + 3100y_{113}+\\ &1900y_{114} + 1320y_{115} + 3200y_{21} + 2400y_{23}+\\ &2410y_{24} + 2000y_{26} + 1000y_{28} + 900y_{210}+\\ &1510y_{211} + 1900y_{213} + 3300y_{214} + 3680y_{215}+\\ &1700y_{31} + 1900y_{33} + 900y_{34} + 500y_{36} + 950y_{38}+\\ &2300y_{310} + 3050y_{311} + 3800y_{313} + 5200y_{314}+\\ &5580y_{315} + 1800y_{41} + 2800y_{43} + 2400y_{44}+\\ &2900y_{46} + 4000y_{48} + 5300y_{410} + 6150y_{411}+\\ &5400y_{413} + 6800y_{414} + 7280y_{415} + 1100y_{51}+\\ &1600y_{53} + 1500y_{54} + 1900y_{56} + 3000y_{58}+\\ &4300y_{510} + 4750y_{511} + 4100y_{513} + 5500y_{514}\\ &+ 5820y_{515} + 5600y_{61} + 6000y_{63} + 4900y_{64}+\\ &4400y_{66} + 3400y_{68} + 3800y_{610} + 4050y_{611}+\\ &4900y_{613} + 6300y_{614} + 6780y_{615} + 10000y_{71}+\\ &8400y_{73} + 9500y_{74} + 9100y_{76} + 8000y_{78}+\\ &6700y_{710} + 6050y_{711} + 5800y_{713} + 4900y_{714}+\\ &3980y_{715}\end{aligned} \tag{24}$$

Subject to

$$y_{11} + y_{13} + y_{14} + y_{16} + y_{18} + y_{110} + y_{111} + y_{113}+ y_{114} + y_{115} = 1 \tag{25}$$

$$y_{21} + y_{23} + y_{24} + y_{26} + y_{28} + y_{210} + y_{211} + y_{213}+ y_{214} + y_{215} = 1 \tag{26}$$

$$y_{31} + y_{33} + y_{34} + y_{36} + y_{38} + y_{310} + y_{311} + y_{313}+ y_{314} + y_{315} = 1 \tag{27}$$

$$y_{41} + y_{43} + y_{44} + y_{46} + y_{48} + y_{410} + y_{411} + y_{413}+ y_{414} + y_{415} = 1 \tag{28}$$

$$y_{51} + y_{53} + y_{54} + y_{56} + y_{58} + y_{510} + y_{511} + y_{513}+ y_{514} + y_{515} = 1 \tag{29}$$

$$y_{61} + y_{63} + y_{64} + y_{66} + y_{68} + y_{610} + y_{611} + y_{613}+ y_{614} + y_{615} = 1 \tag{30}$$

$$y_{71} + y_{73} + y_{74} + y_{76} + y_{78} + y_{710} + y_{711} + y_{713}+ y_{714} + y_{715} = 1 \tag{31}$$

$$x_1 + x_3 + x_4 + x_6 + x_8 + x_{10} + x_{11} + x_{13} + x_{14}+ x_{15} = 10 \tag{32}$$

$$y_{11}, y_{21}, y_{31}, y_{41}, y_{51}, y_{61}, y_{71} \leq x_1 \tag{33}$$

$$y_{13}, y_{23}, y_{33}, y_{43}, y_{53}, y_{63}, y_{73} \leq x_3 \tag{34}$$

$$y_{14}, y_{24}, y_{34}, y_{44}, y_{54}, y_{64}, y_{74} \leq x_4 \tag{35}$$

$$y_{16}, y_{26}, y_{36}, y_{46}, y_{56}, y_{66}, y_{76} \leq x_6 \tag{36}$$

$$y_{18}, y_{28}, y_{38}, y_{48}, y_{58}, y_{68}, y_{78} \leq x_8 \tag{37}$$

$$y_{110}, y_{210}, y_{310}, y_{410}, y_{510}, y_{610}, y_{710} \leq x_{10} \tag{38}$$

$$y_{111}, y_{211}, y_{311}, y_{411}, y_{511}, y_{611}, y_{711} \leq x_{11} \tag{39}$$

$$y_{113}, y_{213}, y_{313}, y_{413}, y_{513}, y_{613}, y_{713} \leq x_{13} \tag{40}$$

$$y_{114}, y_{214}, y_{314}, y_{414}, y_{514}, y_{614}, y_{714} \leq x_{14} \tag{41}$$

$$y_{115}, y_{215}, y_{315}, y_{415}, y_{515}, y_{615}, y_{715} \leq x_{15} \tag{42}$$

$$\begin{aligned}&y_{11}, y_{21}, y_{31}, y_{41}, y_{51}, y_{61}, y_{71}, y_{13}, y_{23}, y_{33}\\ &y_{43}, y_{53}, y_{63}, y_{73}, y_{14}, y_{24}, y_{34}, y_{44}, y_{54},\\ &y_{64}, y_{74}, y_{16}, y_{26}, y_{36}, y_{46}, y_{56}, y_{66}, y_{76}, y_{18},\\ &y_{28}, y_{38}, y_{48}, y_{58}, y_{68}, y_{78}, y_{110}, y_{210}, y_{310},\\ &y_{410}, y_{510}, y_{610}, y_{710}, y_{111}, y_{211}, y_{311}, y_{411},\\ &y_{511}, y_{611}, y_{711}, y_{113}, y_{213}, y_{313}, y_{413},\\ &y_{513}, y_{613}, y_{713}, y_{114}, y_{214}, y_{314}, y_{414}, y_{514},\\ &y_{614}, y_{714}, y_{115}, y_{215}, y_{315}, y_{415}, y_{515}, y_{615},\\ &y_{715} \epsilon \{0,1\}\end{aligned} \tag{43}$$

$$x_1, x_3, x_4, x_6, x_8, x_{10}, x_{11}, x_{13}, x_{14}, x_{15} \epsilon \{0.1\} \tag{44}$$

Model 24 minimizes the distance between the village and TWDS, Constraints 25 - 31 are the limitation of demand points in each village, and Constraint 32 states that the numbers of facility locations are 10 locations. Constraints 33 to 42 are limitations for location requests. Constraints 43 ensure that the variable limitation for village and TWDS are non-negative and integer. The solution of the model obtained using the LINGO 18.0 software is attached in Table 8.

Table 8 in the extended solver status section shows the method used in this case is the Branch and Bound method. The objective value obtained is 13000. GMU is 53K, which means the amount of memory allocation used is 53K. ER shows the total time used to complete the model on LINGO 18.0, 2 seconds. The optimal solutions are y_{115}=y_{210}=y_{36}= y_{41}= y_{51}=y_{68}=y_{715}=1 which mean

1. The demand in Talang Jambe village (y_1) is located at

Table 8. Optimal Solutions of ρ-Median Problem Model

	Solver Status
Model Class	PILP
State	Global Optimal
Objective	13000
Infeasibility	0
Iterations	0
	Extended Solver Status
Solver Type	Branch and Bound
Best Objective	13000
Objective Bound	13000
Steps	0
Active	0
Update Interval	2
GMU (K)	53
ER (sec)	2

TWDS Talang Jambe next to Public Cemetery (x_{15})

2. The demand in Kebun Bunga village (y_2) is located at TWDS Letjen Harun Sohar infront of Al-Hikmah Mosque (x_{10})
3. The demand in Sukarami villag (y_3) is located at TWDS Kolonel H Burlian behind Mitra Bangunan bus stop (x_6)
4. The demand in Suka Bangun village (y_4) is located at TWDS Kolonel H Burlian beside Hotel DE Premium (x_1)
5. The demand in Suka Jaya villagex (y_5) is located at TWDS Kolonel H Burlian beside Hotel DE Premium (x_1)
6. The demand in Sukodadi village (y_6) is located at TWDS Kolonel H Burlian in front of Bank BRI (x_8)
7. The demand in Talang Betutu village (y_7) is located at TWDS Talang Jambe next to Public Cemetery (x_{15})

The TWDS obtained from the ρ-median problem model is solved by GRA in the next stage. The steps of GRA are as follows: Step 1:

$$D = \begin{bmatrix} 7400 & 5800 & 5900 & 6500 & 5500 & 4200 & 3600 & 3100 & 1900 & 1320 \\ 3200 & 2400 & 2410 & 2000 & 1000 & 900 & 1510 & 1900 & 3300 & 3680 \\ 1700 & 1900 & 900 & 500 & 950 & 2300 & 3050 & 3800 & 5200 & 5580 \\ 1800 & 2800 & 2400 & 2900 & 4000 & 5300 & 6150 & 5400 & 6800 & 7280 \\ 1100 & 1600 & 1500 & 1900 & 3000 & 4300 & 4750 & 4100 & 5500 & 5820 \\ 5600 & 6000 & 4900 & 4400 & 3400 & 3800 & 4050 & 4900 & 66300 & 6780 \\ 10000 & 8400 & 9500 & 8000 & 6700 & 6050 & 5800 & 4900 & 3980 & \end{bmatrix}$$

Determine the distance matrix D between villages and TWDS in the Sukarami sub-district.

Step 2 :

Compare matrix columns to get the dominating column by comparing each entry in the matrix column.

$$\begin{array}{cc} \text{Column 1} & \text{Column 3} \\ \begin{bmatrix} 7400 \\ 3200 \\ 1700 \\ 1800 \\ 1100 \\ 5600 \\ 10000 \end{bmatrix} & \begin{bmatrix} 5800 \\ 2400 \\ 1900 \\ 2800 \\ 1600 \\ 6000 \\ 8400 \end{bmatrix} \end{array}$$

Compare the matrix column 1 with the matrix column 3. The matrix column 1 is the column with the dominant value because column 1 has more dominant values than column 3.

$$\begin{array}{cc} \text{Column 3} & \text{Column 4} \\ \begin{bmatrix} 5800 \\ 2400 \\ 1900 \\ 2800 \\ 1600 \\ 6000 \\ 8400 \end{bmatrix} & \begin{bmatrix} 5900 \\ 2410 \\ 900 \\ 2400 \\ 1500 \\ 4900 \\ 8500 \end{bmatrix} \end{array}$$

Compare the matrix column 3 with the matrix column 4. The matrix column 4 is the column with the dominant value because column 4 has more dominant values than column 3. The column comparison continues until the comparison of columns 1 and 15. Based on the results of the column comparison, it is found that columns 8, 10, and 11 are more dominant than other columns. Thus, columns 8, 10, and 11 are solutions for the ρ-median model.

Step 3:

Compare each column entry with the dominating result column, find, and add the smallest dominant value.

Comparison with column 8

Column 1 and 8

$$\begin{bmatrix} 7400 \\ 3200 \\ 1700 \\ 1800 \\ 1100 \\ 5600 \\ 10000 \end{bmatrix} \quad \begin{bmatrix} 5500 \\ 1000 \\ 950 \\ 4000 \\ 3000 \\ 3400 \\ 8000 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 1 and 8, so 5500+1000+950+1800+1100+3400+8000=21750

Column 3 and 8

$$\begin{bmatrix} 5800 \\ 2400 \\ 1900 \\ 2800 \\ 1600 \\ 6000 \\ 8400 \end{bmatrix} \quad \begin{bmatrix} 5500 \\ 1000 \\ 950 \\ 4000 \\ 3000 \\ 3400 \\ 8000 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 3 and 8, so 5500+1000+950+2800 +1600+3400+8000= 23250

The comparison continues until the comparison of columns 15 and 8. The dominant results from comparing each column with matrix column 8 are attached in Table 9.

Table 9. The Dominant Results from Comparing Each Column with Matrix Column 8

Column	1	3	4	6	10	11	13	14	15
8	21,750	23,250	22,700	23,200	23,150	22,510	21,250	19,150	17,650

Based on Table 9, the minimum value of the comparison between columns 8 and 1 is 21,750. The minimum value of the comparison between columns 8 and 3 is 23,250 and continues until the minimum value of columns 8 and 15. The least value is in column 15, as the solution of facility location (8,15).

Comparison with column 10

Column 1 and 10

$$\begin{bmatrix} 7400 \\ 3200 \\ 1700 \\ 1800 \\ 1100 \\ 5600 \\ 10000 \end{bmatrix} \begin{bmatrix} 4200 \\ 900 \\ 230 \\ 5300 \\ 4300 \\ 3800 \\ 6700 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 1 and 10, so 4200+900+1700+1800 +1100+3800 +6700=20200

Column 3 and 10

$$\begin{bmatrix} 5800 \\ 2400 \\ 1900 \\ 2800 \\ 1600 \\ 6000 \\ 2400 \end{bmatrix} \begin{bmatrix} 4200 \\ 900 \\ 2300 \\ 5300 \\ 4300 \\ 3800 \\ 6700 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 3 and 10, so 4200+900+1900+2800+1600+ +3800+6700=21900

The comparison continues until the comparison of columns 15 and 10. The dominant results from comparing each column with matrix column 10 are attached in Table 10.

Based on Table 10, the minimum value of the comparison between columns 10 and 1 is 20,200. The minimum value of the comparison between columns 10 and 3 is 21,900 and continues until the minimum value of columns 10 and 15. The least value is in column 1, as the solution of facility location (10,1).

Step 4 :

Compare the selected dominant column pair with each column and find the optimum value. For pairs of columns (8,15) with columns 1,3,4,6,10,11,13,14

Column (8,15) with column 1

$$\begin{bmatrix} 5500 \\ 1000 \\ 950 \\ 4000 \\ 3000 \\ 3400 \\ 8000 \end{bmatrix} \begin{bmatrix} 1320 \\ 3680 \\ 5580 \\ 7280 \\ 5820 \\ 6780 \\ 3980 \end{bmatrix} \begin{bmatrix} 7400 \\ 3200 \\ 1700 \\ 1800 \\ 1100 \\ 5600 \\ 10000 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 8,15, and 1, so 1320+ 1000+950+1800 +1100 +3400+3980= 13550

Column (8,15) with column 3

$$\begin{bmatrix} 5500 \\ 1000 \\ 950 \\ 4000 \\ 3000 \\ 3400 \\ 8000 \end{bmatrix} \begin{bmatrix} 1320 \\ 3680 \\ 5580 \\ 7280 \\ 5820 \\ 6780 \\ 3980 \end{bmatrix} \begin{bmatrix} 5800 \\ 2400 \\ 1900 \\ 2800 \\ 1600 \\ 6000 \\ 8400 \end{bmatrix} \longrightarrow$$

We add the smallest dominant value from each row of column 8,15, and 3, so 1320+1000 +950+2800 +1600+3400 +3980= 15050

The comparison continues until the comparison of columns (8,15) and 14. The dominant results from comparing each column with matrix column (8,15) are attached in Table 11.

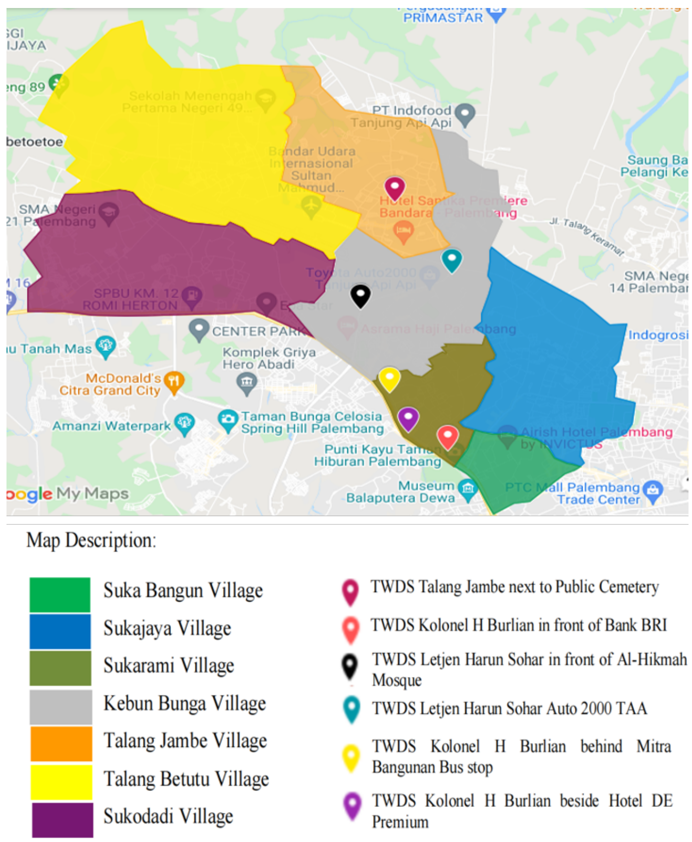

Figure 1. The Strategic TWDS in Sukarami Sub-District

Based on Table 11, the minimum value of the comparison between columns (8,15) and 1 is 13,550. The minimum value of the comparison between columns (8,15) and 3 is 15,050 and continues until the minimum value of columns (8,15) and 14. The least value is in column 1, as the solution of facility location (8,15,1).

For pairs of columns (8,15,1) with columns 3,4,6,10,11,13,

Table 10. The Dominant Results from Comparing Each Column with Matrix Column 10

Column	1	3	4	6	8	11	13	14	15
10	20,200	21,900	20,400	20,900	23,150	26,250	25,300	23,400	21,900

Table 11. The Dominant Results from Comparing Each Column with Matrix Column (8,15)

Column	1	3	4	6	10	11	13	14
(8,15)	3,550	15,050	14,500	15,000	17,550	17,650	17,650	17,650

14

Column (8,15,1) with column 3

$$\begin{bmatrix}5500\\1000\\950\\4000\\3000\\3400\\8000\end{bmatrix}\begin{bmatrix}1320\\3680\\5580\\7280\\5820\\6780\\3980\end{bmatrix}\begin{bmatrix}7400\\3200\\1700\\1800\\1100\\5600\\10000\end{bmatrix}\begin{bmatrix}5800\\2400\\1900\\2800\\1600\\6000\\8400\end{bmatrix}\longrightarrow$$

We add the smallest dominant value from each row of column 8,15, 1 and 3, so 1320+1000+ 950+1800 +1100+3400 +3980= 13550

Column (8,15,1) with column 4

$$\begin{bmatrix}5500\\1000\\950\\4000\\3000\\3400\\8000\end{bmatrix}\begin{bmatrix}1320\\3680\\5580\\7280\\5820\\6780\\3980\end{bmatrix}\begin{bmatrix}7400\\3200\\1700\\1800\\1100\\5600\\10000\end{bmatrix}\begin{bmatrix}5900\\2410\\900\\2400\\1500\\4900\\9500\end{bmatrix}\longrightarrow$$

We add the smallest dominant value from each row of column 8,15, 1 and 4, so 1320+1000+900+1800+ 1100+3400+3980= 13550

The comparison continues until the comparison of columns (8,15,1) and 14. The dominant results from comparing each column with matrix column (8,15,1) are attached in Table 12.

Based on Table 12, the minimum value of the comparison between columns (8,15,1) and 3 is 13,550. The minimum value of the comparison between columns (8,15,1) and 4 is 13,550 and continues until the minimum value of columns (8,15,1) and 14. The least value is in column 6 which is 13,100. For pairs of columns (10,1) with columns 3,4,6,8,11,13,14, 15

Column (10,1) with column 3

$$\begin{bmatrix}4200\\900\\2300\\5300\\4300\\3800\\6700\end{bmatrix}\quad\begin{bmatrix}7400\\3200\\1700\\1800\\1100\\5600\\10000\end{bmatrix}\quad\begin{bmatrix}5800\\2400\\2400\\1900\\2800\\1600\\6000\end{bmatrix}\longrightarrow$$

We add the smallest dominant value from each row of column 8,1, and 3, so 14200 +900+1700+1800 +1100+3800+6700 = 20200

Column (10,1) with column 4

$$\begin{bmatrix}4200\\900\\2300\\5300\\4300\\3800\\6700\end{bmatrix}\quad\begin{bmatrix}7400\\3200\\1700\\1800\\1100\\5600\\10000\end{bmatrix}\quad\begin{bmatrix}5900\\2410\\900\\2400\\1500\\4900\\9500\end{bmatrix}\longrightarrow$$

We add the smallest dominant value from each row of column 8,1, and 4, so 4200+ 900+9001800+1100+ 3800+6700= 19400

The comparison continues until the comparison of columns (10,1) and 15. The dominant results from comparing each column with matrix column (10,1) are attached in Table 13.

Based on Table 13, the minimum value of the comparison between columns (10,1) and 3 is 20,200. The minimum value of the comparison between columns (10,1) and 4 is 19,400 and continues until the minimum value of columns (10,1) and 15. The least value is in column 15 which is 14,600.

Step 5 :

Analyze the results of each step. Based on steps 1 to 4, it is found that the completion of the first pair of columns is 8,15,1,6 and the second pair of columns is 10,1,15 with the following explanation:

1. 8 is matrix column 8, which shows TWDS Kolonel H Burlian in front of Bank BRI.
2. 15 is matrix column 15, which shows TWDS Talang Jambe next to Public Cemetery.
3. 1 is matrix column 1, which shows TWDS Kolonel H Burlian beside Hotel DE Premium.
4. 6 is matrix column 6, which shows TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop.
5. 10 is matrix column 10, which shows TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque.
6. 1 is matrix column 1, which shows TWDS Kolonel H Burlian beside Hotel DE Premium.
7. 15 is matrix column 15, which shows TWDS Letjen Harun Sohar in front of Auto 2000 TAA.

The solution of the ρ-median problem model that GRA solved is shown in Table 14.

Based on Table 14, the demand in Talang Jambe village will be located at TWDS Kolonel H Burlian in front of Bank BRI. The demand in Kebun Bunga village will be located at TWDS Talang Jambe next to Public Cemetery, and so on. The comparisons of ρ-median calculation results using LINGO 18.0 software and GRA are shown in Table 15.

Based on the comparison of the calculation results from

Table 12. The Dominant Results from Comparing Each Column with Matrix Column (8,15,1)

Column	3	4	6	10	11	13	14
(8,15,1)	13,550	13,550	13,100	13,450	13,550	13,550	13,550

Table 13. The Dominant Results from Comparing Each Column with Matrix Column (10,1)

Column	3	4	6	8	11	13	14	15
(10,1)	20,200	19,400	19,000	19,050	18,950	18,200	16,100	14,600

Table 14. The Solution of The ρ-Median Problem Model Using GRA

No	Village	Solution of GRA
1	Talang Jambe	TWDS Kolonel H Burlian in front of Bank BRI
2	Kebun Bunga	TWDS Talang Jambe next to Public Cemetery
3	Sukarami	TWDS Kolonel H Burlian beside Hotel DE Premium
4	Suka Bangun	TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop
5	Suka Jaya	TWDS Letjen Harun Sohar infront of Al-Hikmah Mosque
6	Sukodadi	TWDS Kolonel H Burlian beside Hotel DE Premium
7	Talang Betutu	TWDS Letjen Harun Sohar in front of Auto 2000 TAA

Table 15. The Comparisons of ρ-Median Solution Using LINGO 18.0 software and GRA

No	Demand	Recommended TWDS Locations LINGO 18.0	GRA
1	Talang Jambe Village	TWDS Talang Jambe next to Public Cemetery	TWDS Kolonel H Burlian in front of Bank BRI
2	Kebun Bunga Village	TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque	TWDS Talang Jambe next to Public Cemetery
3	Sukarami Village	TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop	TWDS Kolonel H Burlian beside Hotel DE Premium
4	Suka Bangun Village	TWDS Kolonel H Burlian beside Hotel DE Premium	TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop
5	Suka Jaya Village	TWDS Kolonel H Burlian beside Hotel DE Premium	TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque
6	Sukodadi Village	TWDS Kolonel H Burlian in front of Bank BRI	TWDS Kolonel H Burlian beside Hotel DE Premium
7	Talang Betutu Village	TWDS Talang Jambe next to Public Cemetery	TWDS Letjen Harun Sohar in front of Auto 2000 TAA

Table 15 with Table 1, it turns out that there is a discrepancy between the demand in each village and the specified TWDS. According to LINGO solutions, the appropriate TWDS for Talang Jambe Village should be placed at TWDS Talang Jambe next to Public Cemetery. Whereas, based on the GRA, the appropriate TWDS is TWDS Kolonel H Burlian in front of Bank BRI. Differences in solutions also occur in other villages. By analyzing the optimal solution from LINGO 18.0, GRA, and the current locations of TWDS, this research recommends the strategic TWDS as follows.

1. TWDS Talang Jambe next to Public Cemetery will serve the demand in Talang Jambe village.
2. TWDS Letjen Harun Sohar infront of Al-Hikmah Mosque will serve the demand in Kebun Bunga and Suka Jaya village.
3. TWDS Kolonel H Burlian beside Hotel DE Premium will serve the demand in Sukarami and Suka Bangun village.
4. We recommend to add some new TWDS in Sukodadi and Talang Betutu village.

4. CONCLUSION

From the results and discussion, we only got three strategic TWDS in the Sukarami Sub-District. By analyzing the optimal solution from LINGO 18.0, GRA, and the current locations of TWDS, this research recommends TDWS Talang Jambe next to Public Cemetery, TWDS Kolonel H Burlian in front of Bank BRI, TWDS Letjen Harun Sohar in front of Al-Hikmah Mosque, TWDS Letjen Harun Sohar Auto 2000 TAA, TWDS Kolonel H Burlian behind Mitra Bangunan Bus Stop, and TWDS Kolonel H Burlian beside Hotel DE Premium. We also recommended adding some new TWDS in Sukodadi and Talang Betutu villages because no TWDS is serving these two villages now. The strategic TWDS can be seen in Figure 1. We can use other heuristic approaches for further research and add additional constraints to improve the model.

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