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The Bender's decomposition model to optimize temporary waste disposal sites based on general algebraic modeling system

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ABSTRACT

Waste constitutes a substantial problem in urban and residential locales, as the volume of refuse escalates in tandem with population increase, deteriorating community quality of life. One solution to this problem is to provide temporary waste disposal sites (TWDS). This research discussed optimizing TWDS in the Sukarami Subdistrict, Palembang City, which consists of seven villages. The current TWDS in the Sukarami Subdistrict is irregular, with some sites located close together and others far apart. The optimization problem is solved by formulating the set covering problem (SCP) model, namely the set covering location problem (SCLP), the p-Median problem, and the Bender's decomposition model. All models were solved using the general algebraic modeling system (GAMS) software. The research introduces a Bender's decomposition model based on the SCLP model. The Sukarami Subdistrict has 29 TWDS located in only five villages. Using the SCLP and Bender's decomposition models, the study identified 19 optimal TWDS in the Sukarami Subdistrict. Based on the solution of the p-Median problem, there are seven TWDS that can meet each village's demand. This study recommends the optimal TWDS obtained from the Bender's decomposition model. Additionally, two TWDS are recommended to be added, each in Sukodadi and Talang Betutu villages.

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1. INTRODUCTION

Waste denotes wasted objects or items that are no longer functional or sought after. The volume of waste is escalating alongside population growth, potentially diminishing the quality of life for residents in the vicinity [1]. Inadequate waste management can lead to health issues caused by the contamination of air, water, and soil by disease vectors. Waste management necessitates careful consideration, as it can adversely affect the environment if neglected [2]. A viable solution to this issue in urban or residential areas is the establishment of temporary waste disposal sites (TWDS). TWDS functions as a location where cleaners transfer garbage to recycling, waste sorting, waste processing, or final disposal sites (FDS). Every region must establish its trash disposal sites. A strategically positioned TWDS is the first step in controlling and maintaining a clean environment. Bangun *et al.* [3] states that Palembang City is a metropolis that continuously produces increasing volumes of waste due to population growth. The population density in Palembang City is the leading cause of this increase. Each person in Palembang City contributes 0.8% of daily waste, resulting in a weekly volume of around 800-900 metric tons. On weekends and holidays, the volume of waste can increase to 1,000 metric tons.

This study examines the positioning of TWDS in the Sukarami Subdistrict. In 2020, the central bureau of statistics (CBS) reported that the Sukarami Subdistrict has the highest population and the second largest area among the 18 Subdistrict in Palembang City, South Sumatra Province. The population is 158,246, covering an area of 5,145.9 hectares, featuring multiple residential complexes, offices, and an industrial sector involved in diverse activities. The department of environment and hygiene (DEH) oversees trash management, transportation, and sanitation matters in the Sukarami Subdistrict. Updating the position points of the 29 government-provided TWDS across various urban villages is essential for effective waste disposal and environmental cleanliness. Determining the position of TWDS presents challenges, as two villages in the Sukarami Subdistrict lack waste stations, and the distance between TWDS requires adjustment. This problem leads to littering and the accumulation of excessive rubbish at the current disposal sites.

Optimizing TWDS constitutes an optimization challenge. This issue entails identifying an optimal solution that satisfies particular constraints while minimizing or maximizing the objective function [4]–[7]. The set covering problem (SCP) is a programming approach designed to minimize the number of service facility sites while ensuring coverage of all demand points [8]–[10]. SCP applications in daily life encompass task allocation to machines, workforce assignment, and optimizing waste collection routes to reduce expenses and completion duration [11]–[16]. The SCP model comprises several interconnected models, including the set covering location problem (SCLP) and the p-Median problem [17]. The SCLP aims to determine the optimal number of facilities available for placement [18], while the p-Median problem seeks to minimize the total distance, travel time, or cost between each request and the nearest facility by determining the location of facilities, enabling optimal choices [19]. The SCP model has led to the development of the Bender's decomposition model, which is famous for solving complex problems such as stochastic and nonlinear programming problems [20]. It is one of the most influential and standard models for handling sizable mixed integer problems (MIP). The original problem is reformulated into two problems with fewer variables: the master problem (MP) and the sub problem (SP) [21]. The Bender's decomposition model is used to find both the feasible solution and the lower bound of the problem. The lower bound is then used to find a feasible solution [22].

Several previous studies have been conducted on location determination using SCP [11], [15], [23]–[29]. Octarina *et al.* [25] determined the location of TWDS in Bukit Kecil Subdistrict by modelling the Robust-SCP and analyzed the optimal solutions by using sensitivity analisis. The result showed that the solution remains optimal if the coefficient change is within the coefficient interval value. Research has already been conducted to determine the TWDS in the Sukarami Subdistrict [26]. Octarina *et al.* [26] found only six optimal TWDS in the Sukarami Subdistrict by using greedy reduction algorithm. The number of TWDS obtained is minimal, with each village possessing only a single optimal TWDS. The novelty of this research lies in the updated number of TWDS and the development of the SCP model, specifically the Bender's decomposition model. DEH can consider this solution to determine the location of strategic TWDS. Based on the studies mentioned above, researchers determined the strategic location for TWDS in the Sukarami Subdistrict using the SCP model formulation, namely SCLP and p-Median problem, and formulated the Bender's decomposition model. All models were solved using the general algebraic modeling system (GAMS) software.

2. METHODS

The research process involves some steps. Firstly, the names of TWDS in the Sukarami Subdistrict from DEH Palembang City will be collected and presented as data tables. Then, determine variables and parameters for the SCLP, p-Median problem, and Bender's decomposition models in the Sukarami Subdistrict. Measure the distance between TWDS in the Sukarami Subdistrict using Google Maps. The data, variables, and parameters were used to formulate the SCP model, namely SCLP. The objective function of SCLP was formed based on the number of TWDS in the Sukarami Subdistrict, and the constraints were determined by the distance between TWDS, which was limited to 500 metres. The p-Median problem model was formulated based on the optimal solutions of the SCLP model. The objective function of the p-Median problem model was based on the distance between villages in the Sukarami Subdistrict, and the TWDS facilities were obtained from the SCLP results. The Bender's decomposition model is also formulated to solve the SCP. The steps taken in the Bender's decomposition model formulation is as follows:

– Consider a primal problem where variable y is the problem variable (MP).

$$\text{Minimize } Z = c^T x + d^T y \tag{1}$$

subject to:

$$Ax + By \leq b \quad (2)$$

$$Fy \leq p \quad (3)$$

$$x, y \in \{0,1\} \quad (4)$$

assume the y variable is fixed ($y = \bar{y}$), with:
Z : objective function
c^T : row vector with n element
d^T : row vector with q element
A : matrix of size $m \times n$
B : matrix of size $m \times q$
b : right hand side of the constraint (column vector of m constant)
x : column vector of n continue variable
y : column vector of integer variable q
q : number of integer variables
p : right hand side of constraints
F : matrix of variables that will be fixed

- The primal problem can be transformed to SP as follows:

$$\text{Minimize } Z = c^T x + d^T \bar{y} \quad (5)$$

subject to:

$$Ax \leq b - B\bar{y} \quad (6)$$

$$x \in \mathbb{R}^n \quad (7)$$

- The dual SP form is solved because its solution does not depend on the y variable and is equal to SP. The form of the dual SP is as follows:

$$\text{Maximize } (b - B\bar{y})u \quad (8)$$

subject to:

$$A^T u \leq C \quad (9)$$

$$u \in \mathbb{R}^m \quad (10)$$

with u is a solution of dual SP.

- The optimal value of the dual SP is finite if the value of y obtained from the previous MP is flexible for SP. This solution leads to an extreme point in the solution of the dual SP which is equal to the optimality cut. The optimality cut is then added to the MP.

$$\bar{u}_i^T (b - By) + d^T y - z \leq 0 \qquad \forall i = 1, \dots., I \quad (11)$$

- Conversely, suppose y is infeasible, and the dual SP does not reach a feasible solution through the given variable y. In that case, the dual SP should be restricted by the feasibility cut and should be added to MP as follows:

$$\bar{v}_j^T (b - By) \leq 0 \qquad \forall j = 1, \dots., J \quad (12)$$

where $\bar{v}_j^T$ is extrim vector of dual SP.

– In the context of this study, it is important to note that, in each iteration, only one optimality cut and one feasibility cut become active. Given this, the following formulation is used to define the MP:

$$\text{Minimize } Z \quad (13)$$

subject to:

$$Fy \leq p \quad (14)$$

$$\bar{u}_i^T(b - By) + d^T y - z \leq 0, \forall i = 1, \dots, I \quad (15)$$

$$\bar{v}_j^T(b - By) \leq 0, \forall j = 1, \dots, J \quad (16)$$

$$z \in \mathbb{R}^n, y \in \mathbb{Z}^q \quad (17)$$

3. RESULTS AND DISCUSSION

This chapter discusses the data used in the study, the determination of the number and location of TWDS in the Sukarami Subdistrict, Palembang City, the formulation of the SCP model, namely the SCLP model, the p-median problem model, and the formulation of the Bender's decomposition model in solving SCP. There are 29 TWDS in the Sukarami Subdistrict spread across 5 villages: Sukabangun, Sukarami, Kebun Bunga, Talang Kelapa, and Sukajaya. Villages and TWDS in the Sukarami Subdistrict are further defined using variables, as shown in Table 1 and Table 2.

Table 1. Variables definition of villages in the Sukarami Subdistrict

Variable	Definition of variable
Y_1	Sukabangun Village
Y_2	Sukarami Village
Y_3	Kebun Bunga Village
Y_4	Talang Jambe Village
Y_5	Sukajaya Village
Y_6	Sukodadi Village
Y_7	Talang Betutu Village

Table 2. Variables definition of TWDS in the Sukarami Subdistrict

Variable	Definition of variable	Variable	Definition of variable
X_1	TWDS KM 5 Market (Palimo) Basement	X_{15}	TWDS Kolonel H Burlian Street Kebun Bunga Road Intersection
X_2	TWDS Kolonel H Burlian Street in front of KM 5 motorbike workshop	X_{16}	TWDS Lubuk Kawah Street behind Auto 2000 TAA
X_3	TWDS Kolonel H Burlian Street in front of EX Indah Sari	X_{17}	TWDS Illegal Perjuangan Street
X_4	TWDS Sukabangun 1 Street (Chinese Grave)	X_{18}	TWDS Letjen Harun Sohar Street New Hajj Dormitory
X_5	TWDS Sukabangun 2 Street (Chinese Grave)	X_{19}	TWDS Letjen Harun Sohar Street in front of Mosque
X_6	TWDS Kolonel H Burlian Street Sukamaju Road Intersection	X_{20}	TWDS opposite Sederhana 88 TAA Restaurant
X_7	TWDS Kolonel H Burlian Street beside DE Premium Hotel	X_{21}	TWDS Letjen Harun Sohar Street Talang Kedondong
X_8	TWDS Naskah Street	X_{22}	TWDS Letjen Harun Sohar Street Honda Dealer
X_9	TWDS Batu Jajar Street	X_{23}	TWDS Letjen Harun Sohar Street Auto 2000 TAA
X_{10}	TWDS Kolonel H Burlian Street beside Dharma Agung Hotel Lane	X_{24}	TWDS Bambu Kuning Street
X_{11}	TWDS Kolonel H Burlian Street SMPN 40 Palembang Intersection	X_{25}	TWDS Talang Jambe Street
X_{12}	TWDS Kolonel H Burlian Street in front of Mitra Bangunan bus stop	X_{26}	TWDS Sukawinatan Market
X_{13}	TWDS Kolonel H Burlian Street beside Trakindo Lane	X_{27}	TWDS Bima Lane
X_{14}	TWDS Kolonel H Burlian Perindustrian Road Intersection (Kebun Bunga A bus stop)	X_{28}	TWDS Gotong Royong IV Street
		X_{29}	TWDS Talang Kerikil Grave

3.1. Formulation of the SCLP model

By using the distance data between each TWDS, variables in Table 1 and Table 2, the next step is formulating the SCLP model. The formulation of the SCLP model is as follows:

$$\text{Minimize } Z_{SCLP} = \sum_{j=1}^{29} X_j \quad (18)$$

subject to:

$$X_1 + X_2 \geq 1 \quad (19)$$

$$X_3 + X_6 \geq 1 \quad (20)$$

$$X_4 \geq 1 \quad (21)$$

$$X_5 \geq 1 \quad (22)$$

$$X_3 + X_6 + X_7 \geq 1 \quad (23)$$

$$X_6 + X_7 \geq 1 \quad (24)$$

$$X_8 + X_{10} \geq 1 \quad (25)$$

$$X_9 \geq 1 \quad (26)$$

$$X_8 + X_{10} + X_{11} \geq 1 \quad (27)$$

$$X_{10} + X_{11} + X_{12} \geq 1 \quad (28)$$

$$X_{11} + X_{12} \geq 1 \quad (29)$$

$$X_{13} \geq 1 \quad (30)$$

$$X_{14} + X_{15} + X_{17} \geq 1 \quad (31)$$

$$X_{16} \geq 1 \quad (32)$$

$$X_{18} + X_{19} \geq 1 \quad (33)$$

$$X_{18} + X_{19} + X_{20} \geq 1 \quad (34)$$

$$X_{19} + X_{20} \geq 1 \quad (35)$$

$$X_{21} \geq 1 \quad (36)$$

$$X_{22} + X_{23} \geq 1 \quad (37)$$

$$X_{24} \geq 1 \quad (38)$$

$$X_{25} \geq 1 \quad (39)$$

$$X_{26} \geq 1 \quad (40)$$

$$X_{27} \geq 1 \quad (41)$$

$$X_{28} \geq 1 \quad (42)$$

$$X_{29} \geq 1 \quad (43)$$

$$X_j \in \{0,1\}, j = 1, 2, \ldots, 29 \quad (44)$$

The optimal solution and variables for the SCLP model of Sukarami Subdistrict using GAMS can be seen in Table 3. From Table 3, it can be seen in model statistics that block refers to the GAMS equations and variables, namely block of equations of 26 and block of variables of 30. The number of singles refers to the rows and columns in the generated problem, namely 26 and 30. Non-zero elements refer to the number of non-zero coefficients in the matrix. Generation time is the time taken since the syntax check was completed, which is 0.031 seconds. Table 3 describes the optimal solution of 19, which can be seen in the objective value with the time required by the software, which is 0.015 seconds, and the number of iterations used by the solver, which is 7, with a limit of 2,000,000,000. Based on Table 3, the optimal TWDS should be located at TWDS Kolonel H Burlian Street in front of KM 5 motorbike workshop, TWDS Sukabangun 1 Street (Chinese Grave), TWDS Sukabangun 2 Street (Chinese Grave), TWDS Kolonel H Burlian Street Sukamaju Road Intersection, TWDS Naskah Street, TWDS Batu Jajar Street, TWDS Kolonel H Burlian Street in front of Mitra Bangunan bus stop, TWDS Kolonel H Burlian Street beside Trakindo Lane, TWDS Lubuk Kawah Belakang Street behind Auto 2000 TAA, TWDS Illegal Perjuangan Street, TWDS Letjen Harun Sohar Street in front of Mosque, TWDS Letjen Harun Sohar Street Talang Kedondong, TWDS Letjen Harun Sohar Auto 2000 TAA, TWDS Bambu Kuning Street, TWDS Talang Jambe Street, TWDS Sukawinatan Market, TWDS Bima Lane, TWDS Gotong Royong IV Street, and TWDS Talang Kerikil Grave.

Table 3. Optimal solution of the SCLP model using GAMS

Model statistics		
Block of equations	26	
Block of variables	30	
Non zero elements	73	
Single equations	26	
Single variables	30	
Generation time	0.031 Seconds	
Execution time	0.031 Seconds	
Solve summary		
Solver status	1 normal completion	
Model status	1 optimal	
Objective value	19.0000	
Resource usage, limit	0.015	1000.000
Iteration count, limit	7	2000000000

3.2. Formulation of the p-median problem

The p-median problem model used data from the location of TWDS and demand in the Sukarami Subdistrict. The location of the facilities used was obtained from solving the SCLP model and denoted by j, while i represents the location of the village demand. Table 4 shows the distance between villages and optimal TWDS obtained from the results of solving SCLP using GAMS. By using the data in Table 4, the formulation of the p-median problem is

Table 4. Distance between villages and TWDS in the Sukarami Subdistrict according to SCLP completion

d_{ij}	2	4	5	6	8	9	12	13	16	17	19
1	1000	500	2700	2000	2800	5200	4100	4700	4600	5900	6300
2	3100	3200	4900	1900	1600	1600	500	1100	5300	2300	2800
3	4800	4900	7300	3600	3100	2000	2200	1500	1400	2100	1800
4	10000	10000	7300	8800	10000	7300	7400	6700	3700	6100	5800
5	1800	900	2000	950	2000	3700	2600	3200	3200	4400	4800
6	7100	7100	8800	5800	7000	4300	4400	3800	5900	3100	3400
7	12000	13000	9900	11000	12000	9700	9900	9200	6200	8500	8800

d_{ij}	21	23	24	25	26	27	28	29
1	7200	5500	7400	8000	3600	3300	3800	4100
2	3600	4800	6200	6800	5800	5500	6000	6300
3	1500	2000	3400	4000	6700	7100	7100	8000
4	4300	3200	2800	1500	6700	7100	7200	8000
5	5700	4100	6000	6600	2800	2600	3100	3300
6	4300	5500	6900	7400	10000	11000	11000	11000
7	6800	5800	5300	4100	9300	9700	9700	11000

Minimize $Z_{p-Median} = 1000Y_{1,2} + 500Y_{1,4} + 2700Y_{1,5} + 2000Y_{1,6} + 2800Y_{1,8} + 5200Y_{1,9} + 4100Y_{1,12} + 4700Y_{1,13} + 4600Y_{1,16} + 5900Y_{1,17} + 6300Y_{1,19} + 7200Y_{1,21} + 5500Y_{1,23} + 7400Y_{1,24} +$

$$8000Y_{1,25} + 3600Y_{1,26} + 3300Y_{1,27} + 3800Y_{1,28} + 4100Y_{1,29} + 3100Y_{2,2} + 3200Y_{2,4} + 4900Y_{2,5} + 1900Y_{2,6} + 1600Y_{2,8} + 1600Y_{2,9} + 500Y_{2,12} + 1100Y_{2,13} + 5300Y_{2,16} + 2300Y_{2,17} + 2800Y_{2,19} + 3600Y_{2,21} + 4800Y_{2,23} + 6200Y_{2,24} + 6800Y_{2,25} + 5800Y_{2,26} + 5500Y_{2,27} + 6000Y_{2,28} + 6300Y_{2,29} + 4800Y_{3,2} + 4900Y_{3,4} + 7300Y_{3,5} + 3600Y_{3,6} + 3100Y_{3,8} + 2000Y_{3,9} + 2200Y_{3,12} + 1500Y_{3,13} + 1400Y_{3,16} + 2100Y_{3,17} + 1800Y_{3,19} + 1500Y_{3,21} + 2000Y_{3,23} + 3400Y_{3,24} + 4000Y_{3,25} + 6700Y_{3,26} + 7100Y_{3,27} + 7100Y_{3,28} + 8000Y_{3,29} + 10000Y_{4,2} + 10000Y_{4,4} + 7300Y_{4,5} + 8800Y_{4,6} + 10000Y_{4,8} + 7300Y_{4,9} + 7400Y_{4,12} + 6700Y_{4,13} + 3700Y_{4,16} + 6100Y_{4,17} + 5800Y_{4,19} + 4300Y_{4,21} + 3200Y_{4,23} + 2800Y_{4,24} + 1500Y_{4,25} + 6700Y_{4,26} + 100Y_{4,27} + 7200Y_{4,28} + 8000Y_{4,29} + 1800Y_{5,2} + 900Y_{5,4} + 2000Y_{5,5} + 950Y_{5,6} + 2000Y_{5,8} + 3700Y_{5,9} + 2600Y_{5,12} + 3200Y_{5,13} + 3200Y_{5,16} + 4400Y_{5,17} + 4800Y_{5,19} + 5700Y_{5,21} + 4100Y_{5,23} + 6000Y_{5,24} + 800Y_{5,26} + 2600Y_{5,27} + 3100Y_{5,28} + 3300Y_{5,29} + 7100Y_{6,2} + 7100Y_{6,4} + 8800Y_{6,5} + 5800Y_{6,6} + 7000Y_{6,8} + 4300Y_{6,9} + 4400Y_{6,12} + 3800Y_{6,13} + 5900Y_{6,16} + 3100Y_{6,17} + 3400Y_{6,19} + 4300Y_{6,21} + 5500Y_{6,23} + 6900Y_{6,24} + 7400Y_{6,25} + 1000Y_{6,26} + 11000Y_{6,27} + 11000Y_{6,28} + 11000Y_{6,29} + 12000Y_{7,2} + 13000Y_{7,4} + 9900Y_{7,5} + 11000Y_{7,6} + 12000Y_{7,8} + 9700Y_{7,9} + 9900Y_{7,12} + 9200Y_{7,13} + 6200Y_{7,16} + 8500Y_{7,17} + 8800Y_{7,19} + 6800Y_{7,21} + 5800Y_{7,23} + 5300Y_{7,24} + 4100Y_{7,25} + 9300Y_{7,26} + 9700Y_{7,27} + 9700Y_{7,28} + 11000Y_{7,29} \quad (45)$$

subject to:

$$Y_{1,2} + Y_{1,4} + Y_{1,5} + Y_{1,6} + Y_{1,8} + Y_{1,9} + Y_{1,12} + Y_{1,13} + Y_{1,16} + Y_{1,17} + Y_{1,19} + Y_{1,21} + Y_{1,23} + Y_{1,24} + Y_{1,25} + Y_{1,26} + Y_{1,27} + Y_{1,28} + Y_{1,29} = 1 \quad (46)$$

$$Y_{2,2} + Y_{2,4} + Y_{2,5} + Y_{2,6} + Y_{2,8} + Y_{2,9} + Y_{2,12} + Y_{2,13} + Y_{2,16} + Y_{2,17} + Y_{2,19} + Y_{2,21} + Y_{2,23} + Y_{2,24} + Y_{2,25} + Y_{2,26} + Y_{2,27} + Y_{2,28} + Y_{2,29} = 1 \quad (47)$$

$$Y_{3,2} + Y_{3,4} + Y_{3,5} + Y_{3,6} + Y_{3,8} + Y_{3,9} + Y_{3,12} + Y_{3,13} + Y_{3,16} + Y_{3,17} + Y_{3,19} + Y_{3,21} + Y_{3,23} + Y_{3,24} + Y_{3,25} + Y_{3,26} + Y_{3,27} + Y_{3,28} + Y_{3,29} = 1 \quad (48)$$

$$Y_{4,2} + Y_{4,4} + Y_{4,5} + Y_{4,6} + Y_{4,8} + Y_{4,9} + Y_{4,12} + Y_{4,13} + Y_{4,16} + Y_{4,17} + Y_{4,19} + Y_{4,21} + Y_{4,23} + Y_{4,24} + Y_{4,25} + Y_{4,26} + Y_{4,27} + Y_{4,28} + Y_{4,29} = 1 \quad (49)$$

$$Y_{5,2} + Y_{5,4} + Y_{5,5} + Y_{5,6} + Y_{5,8} + Y_{5,9} + Y_{5,12} + Y_{5,13} + Y_{5,16} + Y_{5,17} + Y_{5,19} + Y_{5,21} + Y_{5,23} + Y_{5,24} + Y_{5,25} + Y_{5,26} + Y_{5,27} + Y_{5,28} + Y_{5,29} = 1 \quad (50)$$

$$Y_{6,2} + Y_{6,4} + Y_{6,5} + Y_{6,6} + Y_{6,8} + Y_{6,9} + Y_{6,12} + Y_{6,13} + Y_{6,16} + Y_{6,17} + Y_{6,19} + Y_{6,21} + Y_{6,23} + Y_{6,24} + Y_{6,19} + Y_{6,21} + Y_{6,23} + Y_{6,24} + Y_{6,25} + Y_{6,26} + Y_{6,27} + Y_{6,28} + Y_{6,29} = 1 \quad (51)$$

$$Y_{7,2} + Y_{7,4} + Y_{7,5} + Y_{7,6} + Y_{7,8} + Y_{7,9} + Y_{7,12} + Y_{7,13} + Y_{7,16} + Y_{7,17} + Y_{7,19} + Y_{7,21} + Y_{7,23} + Y_{7,24} + Y_{7,25} + Y_{7,26} + Y_{7,27} + Y_{7,28} + Y_{7,29} = 1 \quad (52)$$

$$X_2 + X_4 + X_5 + X_6 + X_8 + X_9 + X_{12} + X_{13} + X_{16} + X_{17} + X_{19} + X_{21} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + x_{28} + x_{29} = 19 \quad (53)$$

$$Y_{1,2} + Y_{2,2} + Y_{3,2} + Y_{4,2} + Y_{5,2} + Y_{6,2} + Y_{7,2} \leq X_2 \quad (54)$$

$$Y_{1,4} + Y_{2,4} + Y_{3,4} + Y_{4,4} + Y_{5,4} + Y_{6,4} + Y_{7,4} \leq X_4 \quad (55)$$

$$Y_{1,5} + Y_{2,5} + Y_{3,5} + Y_{4,5} + Y_{5,5} + Y_{6,5} + Y_{7,5} \leq X_5 \quad (56)$$

$$Y_{1,6} + Y_{2,6} + Y_{3,6} + Y_{4,6} + Y_{5,6} + Y_{6,6} + Y_{7,6} \leq X_6 \quad (57)$$

$$Y_{1,8} + Y_{2,8} + Y_{3,8} + Y_{4,8} + Y_{5,8} + Y_{6,8} + Y_{7,8} \leq X_8 \quad (58)$$

$$Y_{1,9} + Y_{2,9} + Y_{3,9} + Y_{4,9} + Y_{5,9} + Y_{6,9} + Y_{7,9} \leq X_9 \quad (59)$$

$$Y_{1,12} + Y_{2,12} + Y_{3,12} + Y_{4,12} + Y_{5,12} + Y_{6,12} + Y_{7,12} \leq X_{12} \quad (60)$$

$$Y_{1,13} + Y_{2,13} + Y_{3,13} + Y_{4,13} + Y_{5,13} + Y_{6,13} + Y_{7,13} \leq X_{13} \quad (61)$$

$$Y_{1,16} + Y_{2,16} + Y_{3,16} + Y_{4,16} + Y_{5,16} + Y_{6,16} + Y_{7,16} \leq X_{16} \quad (62)$$

$$Y_{1,17} + Y_{2,17} + Y_{3,17} + Y_{4,17} + Y_{5,17} + Y_{6,17} + Y_{7,17} \leq X_{17} \quad (63)$$

$$Y_{1,19} + Y_{2,19} + Y_{3,19} + Y_{4,19} + Y_{5,19} + Y_{6,19} + Y_{7,19} \leq X_{19} \quad (64)$$

$$Y_{1,21} + Y_{2,21} + Y_{3,21} + Y_{4,21} + Y_{5,21} + Y_{6,21} + Y_{7,21} \leq X_{21} \quad (65)$$

$$Y_{1,23} + Y_{2,23} + Y_{3,23} + Y_{4,23} + Y_{5,23} + Y_{6,23} + Y_{7,23} \leq X_{23} \quad (66)$$

$$Y_{1,24} + Y_{2,24} + Y_{3,24} + Y_{4,24} + Y_{5,24} + Y_{6,24} + Y_{7,24} \leq X_{24} \quad (67)$$

$$Y_{1,25} + Y_{2,25} + Y_{3,25} + Y_{4,25} + Y_{5,25} + Y_{6,25} + Y_{7,25} \leq X_{25} \quad (68)$$

$$Y_{1,26} + Y_{2,26} + Y_{3,26} + Y_{4,26} + Y_{5,26} + Y_{6,26} + Y_{7,26} \leq X_{26} \quad (69)$$

$$Y_{1,27} + Y_{2,27} + Y_{3,27} + Y_{4,27} + Y_{5,27} + Y_{6,27} + Y_{7,27} \leq X_{27} \quad (70)$$

$$Y_{1,28} + Y_{2,28} + Y_{3,28} + Y_{4,28} + Y_{5,28} + Y_{6,28} + Y_{7,28} \leq X_{28} \quad (71)$$

$$Y_{1,29} + Y_{2,29} + Y_{3,29} + Y_{4,29} + Y_{5,29} + Y_{6,29} + Y_{7,29} \leq X_{29} \quad (72)$$

$$Y_{i,j} \in \{0,1\},\ i = 1,2,\dots,7 \text{ and } j = 2,4,5,6,8,9,12,13,16,17,19,21,23,24,25,26,27,28,29 \quad (73)$$

$$X_j \in \{0,1\},\ j = 2,4,5,6,8,9,12,13,16,17,19,21,23,24,25,26,27,28,29 \quad (74)$$

By using GAMS, the optimal solutions of the p-median problem model are: the demand in the Sukabangun village will be located at TWDS Sukabangun 1 Street (Chinese Grave), the demand in the Sukarami village will be located at TWDS Kolonel H Burlian Street in front of Mitra Bangunan bus stop, the demand in the Kebun Bunga village will be located at TWDS Bambu Kuning Street, the demand in the Talang Jambe village (Y_4) will be located at TWDS Gotong Royong IV Street, the demand in the Sukajaya village will be located at TWDS Sukabangun 1 Street (Chinese Grave), the demand in the Sukodadi village will be located at TWDS Illegal Perjuangan Street, and the demand in the Talang Betutu village will be located at TWDS Sukabangun 2 Street (Chinese Grave).

3.3. Bender's decomposition model in solving SCP

The Bender's decomposition model uses data from the location of TWDS and demand locations in Sukarami Subdistrict. The location of the facilities used is the location obtained from solving the previous SCLP model.

Primal SP

$$\hat{Y} = \sum_{n=24}^{29} Y_n \quad (75)$$

$$\text{Minimize } \sum_{j=1}^{23} X_j + \hat{Y} \quad (76)$$

subject to:
constraints (19) to (43)

$$X_j \in \{0,1\}, j = 1,2,\dots,23 \quad (77)$$

$$Y_n \in \{0,1\}, n = 24, 25, \dots, 29 \quad (78)$$

Dual SP

$$\text{Maximize } \sum_{j=1}^{23} X_j + \hat{Y} \quad (79)$$

subject to:

$$X_1 + X_2 \leq 1 \quad (80)$$

$$X_3 + X_6 \leq 1 \quad (81)$$

$$X_4 \leq 1 \quad (82)$$

$$X_5 \leq 1 \quad (83)$$

$$X_3 + X_6 + X_7 \leq 1 \quad (84)$$

$$X_6 + X_7 \leq 1 \quad (85)$$

$$X_8 + X_{10} \leq 1 \quad (86)$$

$$X_9 \leq 1 \quad (87)$$

$$X_8 + X_{10} + X_{11} \leq 1 \quad (88)$$

$$X_{10} + X_{11} + X_{12} \leq 1 \quad (89)$$

$$X_{11} + X_{12} \leq 1 \quad (90)$$

$$X_{13} \leq 1 X_{13} \leq 1 \quad (91)$$

$$X_{14} + X_{15} + X_{17} \leq 1 \quad (92)$$

$$X_{16} \leq 1 \quad (93)$$

$$X_{18} + X_{19} \leq 1 \quad (94)$$

$$X_{18} + X_{19} + X_{20} \leq 1 \quad (95)$$

$$X_{19} + X_{20} \leq 1 \quad (96)$$

$$X_{21} \leq 1 \quad (97)$$

$$X_{22} + X_{23} \leq 1 \quad (98)$$

$$Y_{24} \leq 1 \quad (99)$$

$$Y_{25} \leq 1 \quad (100)$$

$$Y_{26} \leq 1 \quad (101)$$

$$Y_{27} \leq 1 \quad (102)$$

$$Y_{28} \leq 1 \quad (103)$$

$$Y_{29} \leq 1 \quad (104)$$

$$X_j \in \{0,1\}, j = 1,2, \dots ,23 \quad (105)$$

$$Y_n \in \{0,1\}, n = 24, 25, \dots , 29 \quad (106)$$

Bender’s reformulation

$$\text{Maximize } Z \quad (107)$$

subject to:

$$Z \geq X_2 + X_3 + X_4 + X_5 + X_8 + X_9 + X_{12} + X_{13} + X_{16} + X_{17} + X_{18} + X_{21} + X_{23} \quad (108)$$

constraints (80) to (106).

The optimal solutions and variables of Bender's reformulation model using GAMS are TWDS KM 5 Market (Palimo) Basement, TWDS Sukabangun 1 Street (Chinese Grave), TWDS Sukabangun 2 Street (Chinese Grave), TWDS Kolonel H Burlian Street Sukamaju Road Intersection, TWDS Batu Jajar Street, TWDS Kolonel H Burlian Street beside Dharma Agung Hotel Lane. TWDS Kolonel H Burlian Street SMPN 40 Palembang Intersection, TWDS Kolonel H Burlian beside Trakindo Lane, TWDS Kolonel H Burlian Perindustrian Road Intersection (Kebun Bunga A bus stop), TWDS Lubuk Kawah Street behind Auto 2000 TAA, TWDS Letjen Harun Sohar Street in front of Mosque, TWDS Letjen Harun Sohar Street Talang Kedondong, TWDS Letjen Harun Sohar Street Honda Dealer, TWDS Bambu Kuning Street, TWDS Talang Jambe Street, TWDS Sukawinatan Market, TWDS Bima Lane, TWDS Gotong Royong IV, and TWDS Talang Kerikil Grave. The final results of the SCLP, p-Median problem, and Bender's decomposition models using GAMS yielded a variety of optimal TWDS. The SCLP and Bender's decomposition models yielded 19 optimal locations, while the p-median problem model yielded 7 optimal TWDS. This study's findings advocate for implementing the solution derived from the Bender's decomposition model, as it can address the comprehensive array of demands present within the administrative region of the Sukarami Subdistrict. The optimal solution identified in this research is delineated in Table 5 and Figure 1.

Table 5. Optimal TWDS in the Sukarami Subdistrict

Name of Villages	Name of TWDS	Coordinate point
Sukabangun	TWDS KM 5 Market (Palimo) Basement	-2.953310805305508, 104.73533825244395
	TWDS Sukabangun 1 Street (Chinese Grave)	-2.942268,104.738020
	TWDS Sukabangun 2 Street (Chinese Grave)	-2.9387204847172312, 104.73068397943067
	TWDS Kolonel H Burlian Street Sukamaju Road Intersection	-2.942996806239465, 104.72883268327489
Sukarami	TWDS Batu Jajar Street	-2.927012,104.732415
	TWDS Kolonel H Burlian Street beside Dharma Agung Hotel Lane	-2.938209013581986, 104.72094474215639
	TWDS Kolonel H Burlian Street SMPN 40 Palembang Intersection	-2.937631435577897, 104.72035556978825
	TWDS Kolonel H Burlian beside Trakindo Lane	-2.931239,104.717431
Kebun Bunga	TWDS Kolonel H Burlian Perindustrian Road Intersection (Kebun Bunga A bus stop)	-2.9257365705977625, 104.71402040180891
	TWDS Lubuk Kawah Street behind Auto 2000 TAA	-2.908032,104.724538
	TWDS Letjen Harun Sohar Street in front of Mosque	-2.917599,104.711909
	TWDS Letjen Harun Sohar Street Talang Kedondong	-2.9097607220020087, 104.71491239477257
	TWDS Letjen Harun Sohar Street Honda Dealer	-2.9084365459834394, 104.72263615302286
	TWDS Bambu Kuning Street	-2.8987144422339934, 104.72584516471169
Talang Jambe	TWDS Talang Jambe Street	-2.896005,104.722895
Sukajaya	TWDS Sukawinatan Market	-2.923844434410053, 104.75129543928927
	TWDS Bima Lane	-2.9291229193941226, 104.75083623277754
	TWDS Gotong Royong IV	-2.9144626553521795, 104.73818642642625
	TWDS Talang Kerikil Grave	-2.934100649668788, 104.7545833363388

Figure 1 shows the distribution of optimal TWDS in five villages in the Sukarami Subdistrict. As shown in Figure 1, Sukabangun village, Sukarami village, and Sukajaya village have 4 optimal TWDS each. Kebun Bungan village has the most optimal TWDS. There are 6 TWDS in this village, which are TWDS Kolonel H Burlian Perindustrian Road Intersection (Kebun Bunga A bus stop), TWDS Lubuk Kawah Street behind Auto 2000 TAA, TWDS Letjen Harun Sohar Street in front of Mosque, TWDS Letjen Harun Sohar Street Talang Kedondong, TWDS Letjen Harin Sohar Street Honda Dealer, and. TWDS Bambu Kuning Street. Talang Jambe village has only one TWDS namely TWDS Talang Jambe Street. The distribution of the number of TWDS remains imbalanced across all villages. This research suggests the implementation of additional TWDS, particularly in Talang Jambe Village, which currently has only one TWDS. This recommendation is based on the observation that Talang Jambe Village is comparatively large in relation to other villages within the Sukarami Subdistrict.

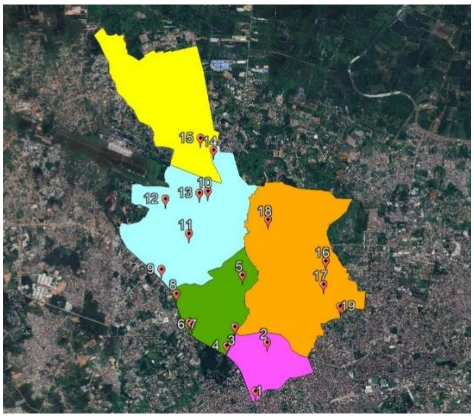

Figure 1. Map of optimal TWDS in Sukarami Subdistrict

Description:
: Sukabangun Village
: Sukarami Village
: Kebun Bunga Village
: Talang Jambe Village
: Sukajaya Village
1 : TWDS KM 5 Market (Palimo) Basement.
2 : TWDS Sukabangun 1 Street (Chinese Grave).
3 : TWDS Sukabangun 2 Street (Chinese Grave).
4 : TWDS Kolonel H Burlian Street Sukamaju Road Intersection.
5 : TWDS Batu Jajar Street.
6 : TWDS Kolonel H Burlian Street beside Dharma Agung Hotel Lane.
7 : TWDS Kolonel H Burlian Street SMPN 40 Palembang Intersection.
8 : TWDS Kolonel H Burlian beside Trakindo Lane.
9 : TWDS Kolonel H Burlian Perindustrian Road Intersection (Kebun Bunga A bus stop).
10 : TWDS Lubuk Kawah Street behind Auto 2000 TAA.
11 : TWDS Letjen Harun Sohar Street in front of Mosque.
12 : TWDS Letjen Harun Sohar Street Talang Kedondong.
13 : TWDS Letjen Harun Sohar Street Honda Dealer.
14 : TWDS Bambu Kuning Street.
15 : TWDS Talang Jambe Street.
16 : TWDS Sukawinatan Market.
17 : TWDS Bima Lane.
18 : TWDS Gotong Royong IV.
19 : TWDS Talang Kerikil Grave.

4. CONCLUSION

A comprehensive analysis of the results and discussion about determining the optimal TWDS in Sukarami Subdistrict has been conducted. The formulation of the SCP and Bender's decomposition models facilitated this analysis. The ensuing conclusion, derived from this analysis, asserts that the SCLP model yielded 19 optimal TWDS that the community in the Sukarami Subdistrict can utilize. In comparison, the p-median problem model obtained 7 TWDS to meet the demand of 7 villages in the Sukarami Subdistrict. This study recommends adding TWDS in Sukodadi and Talang Betutu Villages, which previously lacked TWDS, to be placed at the location of the nearest facility so that all demands are met. The Bender's decomposition model yielded 19 optimal TWDS, though these differed from the locations obtained from the SCP model. The findings of this study advocate for the utilization of the Bender's decomposition model outcomes, as the optimal solution for the placement of TWDS in the Sukarami Subdistrict.

In comparison with the research conducted by Octarina *et al.* [26], this study has yielded a more optimal TWDS, which can be submitted to the DEH of Palembang City as a consideration in determining the location of TWDS and waste transportation routes in the Sukarami Subdistrict. The optimal location for a

TWDS is of paramount importance in the fields of environmental management and waste management. The study's findings indicated that Bender's decomposition model was a highly utilized tool for identifying the location of TWDS.

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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