Analytical Hierarchy Process (AHP) to Determine the Sustainable Drainage System Used for Flood Management in Central Karanganyar Regency

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Abstract. A sustainable drainage system is one of the right methods in dealing with floods in cities, including in Karanganyar. The parameters of technology selection problems planned with the Analytic Hierarchy Process (AHP) are technical, economic, environmental, social/cultural, and technology: infiltration wells with drainage channels, rainwater harvesting with drainage channels, and dry swale. Rainfall data is used in this research. The area used is planning, budget planning, and AHP method steps with hierarchical compilation, pairwise comparisons, priority values, testing consistency, and data obtained from technology selection questionnaires filled with related institutions. The most influential criteria in the choice drainage system technology are environmental criteria 49%, technical 33%, economy 12%, and social/cultural 5%. The priority technology is rainwater harvesting with drainage channels with a percentage of 37.3%, infiltration wells with drainage channels 35.2%, and dry swale 27.4%.

1. Introduction

Karanganyar Regency is a district in Central Java consisting of 17 sub-districts with 77,378.64 ha or 2.38% of Central Java Province [1]. Administratively, Karanganyar Regency is bordered by Sragen Regency in the north, East Java Province in the east, Wonogiri Regency, and Sukoharjo Regency in the south Boyolali Regency and Surakarta City in the west.

Currently, the drainage in Karanganyar Regency still uses a conventional system. It is often found that the drainage system has multiple functions or is converted into an irrigation channel. Inadequate management of the drainage system and lack of public awareness to maintain and maintain the drainage also causes the drainage to function optimally. If this is allowed, it will cause environmental problems in Karanganyar Regency, such as flooding and inundation. The overflow of water from this channel can disrupt the daily activities of the surrounding community.

Several drainage system selection methods are applied in developed countries, such as the retention pond method, dry swale, wetlands, and rainwater harvesting [2]. Each of the above technologies has a different function. The retention pond functions as a temporary storage pond and absorbs runoff water before being discharged into a river or lake [3]. Rainwater harvesting serves as a water catchment area [4], while wetlands are places for clean water supply with a
large volume [5]. Determining the priority of sustainable drainage system technology must be done elaborately because many problems are influenced by various aspects [6]. Therefore, we need a method to analyze multiple influencing factors: the Analytical Hierarchy Process (AHP).

2. Analytical Hierarchy Process (AHP)

Prof Thomas L Saaty in 1970 [7] developed an analytical Hierarchy Process (AHP) to solve complex problems where data and information on the issues faced are very little. Decision-making model with multiple criteria. AHP is one of the methods considered appropriate to determine a benchmark. This method is used for measurement to obtain a ratio scale, both from discrete and continuous pair comparisons. AHP has particular concerns about deviations from consistency, measure, and dependence within and between groups of structural elements. There are several principles in solving problems using AHP: decomposition, comparative judgment, synthetic of priority, and logical consistency. Decomposition, which is a process of solving a whole problem into its elements [6].

In its development, AHP is not only used to determine the priority of choice options with many criteria, but its application has been widely used as an alternative method to solve various problems. As for the successful implementation of AHP, among others, the determination of the RI presidential candidate in the 2009 direct election, the selection of ships for the construction of a new tanker on Batam Island, the choice of project contractors at the Surabaya City PDAM auction, the determination of the provision of KPR financing at Bank Muamalat Indonesia, the Jakarta City Sub-Branch and others.

3. Research Methodology

AHP decision-making stages consist of defining the problem and determining the desired solution. Also, to create a hierarchical structure starting with the primary objective and then specifying the pairwise comparison assessment, reciprocal matrix, calculate eigenvalues and test the consistency. Repeat steps for all hierarchical levels and aspect criteria, and then sustainable drainage system technology associated with the multiplication of each standard’s priority vectors [8].

![Figure 1: Research hierarchical structure](image-url)

In solving a problem, AHP usually uses a hierarchical structure to simplify a complex problem to be solved. In this study, a hierarchical structure network begins with a general purpose and then followed by the criteria and options that want to be ranked. The network is created based on a structure related to the developed problem.
Table 1 shows that how to determination of the pairwise comparison scale assessment. Qualitative decisions are scaled in pairs into a quantitative assessment by assessing the importance of an element compared to other components.

### Table 1: Hierarchy Rating Scale

| Interest | Variable definitions          | Explanation                                      |
|----------|-------------------------------|--------------------------------------------------|
| 1        | Just as important             | The two elements have the same effect.           |
| 3        | A little bit more important   | Slightly siding with one of the elements         |
| 5        | More important                | Strongly siding with one element.                |
| 7        | Very important                | One element is very influential, and its         |
|          |                               | dominance is evident.                            |
| 9        | Absolutes are more important  | One of the more essential elements of the        |
|          |                               | partner is very clear                            |
| 2, 4, 6, 8| The middle value of the      | The value is given if there is doubt              |
|          | assessment above              | between the two options                          |
| Reciprocal|                               | The ratio between the elements i and j yields one of the values above, then the ratio between the elements j to i will produce the opposite value. |

The calculation uses a comparison matrix (reciprocal). That is, if $A_{ij}$ is a, then $A_{ji}$ is equal to $1/a$. If $A_i$ has the same importance as $A_j$, then $A_{ij}$ and $A_{ji}$ are equal to 1. However, for exceptional cases, $A_{ij}$ is equal to 1 for all $i$. The calculation process uses Formulas 7 to 10.

$$A = \begin{bmatrix} 1 & a(1,2) & a(1,n) \\ a/(a(1,2)) & 1 & a(2,n) \\ 1/(1,n) & 1/[a(2,n)] & 1 \end{bmatrix}$$ (1)

Reciprocal Matrix:

$$[b_{ij}] = \frac{b_j}{b_i}$$ (2)

Normalized Matrix:

$$[W_y] = [b_{m×n}]$$ (3)

Priority vector:

$$\{X_{n-y}\} = \sum_{n=1}^{l} b_{m×N}$$

$$= \hat{Y}_n$$ (4)

The consistency requirement is that the CR value is smaller, equal to 0.1. If more, the previous assessment process needs to be repeated. The consistency value can be calculated with formulas 5 to 9.

$$\{K_y\} = [B] \times \{\hat{Y}_n\}$$ (5)

Vector values:

$$E_y = [K_y]/\{\hat{X}_n\}$$ (6)

The maximum value of the principal eigenvalue:

$$\lambda_{max} = [\hat{E}_y]$$ (7)
Index consistency value:

\[ CI = (\lambda_{\text{max}} - n)/(n - 1) \]  

Test the consistency:

\[ CR = CI/RI \]  

with: \( CR = \text{consistency ratio}, CI = \text{consistency index} \) \( RI = \text{random index} \).

### Table 2: Values of RI

| Matrix Size (n) | 1.2 | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Random Index (RI) | 0.00 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 |

4. **Research Place**

This research was conducted in Karanganyar District, Karanganyar Regency. It consisted of housing complexes, offices, places of worship, educational areas, and green open spaces. In this study, several drainage problems were found in Karanganyar Regency, namely the capacity planning for the sustainable drainage system method, the criteria for selecting the sustainable drainage system method using the AHP method, and the priority setting the sustainable drainage system method using the AHP method. The issues that will be discussed later are obtaining research objectives, including planning the capacity of the sustainable drainage system method and then knowing the level of influence of the criteria for the selection of a sustainable drainage system method using the AHP. The priority of selecting a sustainable drainage system method that can be used in Karanganyar District.

5. **Analytic Hierarchy Process (AHP) Analysis Stages**

5.1. **Criteria selection**

The survey was conducted by distributing 29 questionnaires to the Karanganyar Regency Public Works Office’s Cipta Karya agency. The initial questionnaire data set was analyzed with a recapitulation of pairwise comparison assessments taken from the value of the intensity of importance of the questionnaire results, formed into a reciprocal matrix based on Formula 1. The survey results show that respondents are more social than technical, economic, and social-cultural, it is aimed at the third line. Because the environment itself has an important role model. The changes in land use are quite significant and cause a chain change in the land infiltration function [9]. The values are used to calculate the priority vector for each criterion using Formula 4, which results are:

| Criteria | Technical | Economy | Environment | Socio-cultural |
|----------|-----------|---------|-------------|----------------|
| Technical | 0.29      | 0.48    | 0.27        | 0.29           |
| Economy  | 0.06      | 0.1     | 0.13        | 0.18           |
| Environment | 0.59     | 0.39    | 0.53        | 0.47           |
| Socio-cultural | 0.06   | 0.03    | 0.07        | 0.06           |
| amount   | 1         | 1       | 1           | 1              |

The values are used to calculate the priority vector for each criterion using Formula 4, which results are:

- Technical: \( (0.29 + 0.48 + 0.27 + 0.29)/4 = 0.33 / (33\%) \)
- Economy: \( (0.06 + 0.10 + 0.13 + 0.18)/4 = 0.12 / (12\%) \)
- Environment: \( (0.59 + 0.39 + 0.53 + 0.47)/4 = 0.49 / (49\%) \)
- Socio-cultural: \( (0.06 + 0.03 + 0.07 + 0.06)/4 = 0.05 / (5\%) \)
The result gives information that the percentage for selecting criteria used in selecting technology to be used in sustainable drainage is environmental criteria, namely 49%, while for technical 33%, 12% for economic and social culture 5%. It supports the sustainability of life and the many developments that disregard the environmental impact of an action that covers green land and catchment areas. The land-use alteration reduces groundwater infiltration volume, increases the volume of runoff, and ultimately causes flooding at several points in this area. The environment is more important than other criteria [10].

5.2. Selection of technology based on the criteria

Selection of technology priorities uses the same steps as selecting the requirements for reasons with the formula 1,2,3,4,5,6,7,8,9: Table 4 shows the calculation of selection according to technical criteria. Due to infiltration, wells have been widely used, and people know more about making them. Infiltration wells have been done a lot in residential areas, so it is technically easy to work on for the community [10]. The table shows calculations based on economic criteria.

| IW+DC | RH+DC | Dry Swale | Vp | Scale (%) |
|-------|-------|-----------|----|-----------|
| 1.00  | 3.00  | 3.00      | 0.59 | 59 |
| 0.33  | 1.00  | 0.50      | 0.16 | 16 |
|       |       | 1.00      | 0.25 | 25 |

$\lambda_{max} = 3.07$  $CI = 0.035$  $RI = 0.58$  $CR = 0.061$

Since dry swale planning requires the least amount of money than the other two technologies, respondents choose dry swale into financial benchmarks. The selection of a drainage system in public places as dry swale is more economical than cost [11].

| IW+DC | RH+DC | Dry Swale | Vp | Scale (%) |
|-------|-------|-----------|----|-----------|
| 1.00  | 3.00  | 0.25      | 0.21 | 21 |
| 0.33  | 1.00  | 0.14      | 0.09 | 9 |
|       | 4.00  | 1.00      | 0.70 | 70 |

$\lambda_{max} = 3.05$  $CI = 0.026$  $RI = 0.58$  $CR = 0.046$

Table 6 shows that calculation according to environmental criteria. Rainwater harvesting is a technology whose water is stored and can be reused for daily needs. The selection of a drainage

| IW+DC | RH+DC | Dry Swale | Vp | Scale (%) |
|-------|-------|-----------|----|-----------|
| 1.00  | 0.33  | 2.00      | 0.25 | 25 |
| 3.00  | 1.00  | 3.00      | 0.59 | 59 |
| 0.50  | 0.33  | 1.00      | 0.16 | 16 |

$\lambda_{max} = 3.07$  $CI = 0.035$  $RI = 0.58$  $CR = 0.061$
system in public places as a runaway (low-cost apartment building) rainwater harvesting, the water is collected and can be used for spare parts. The manufacture is also on the ground [12].

Table 7 gives information that calculation with social criteria/cultural criteria. The manufacture of the dry swale in the open land can add aesthetic value to an area used in the garden. Dry swale adds aesthetic value to a place. Thus, it will positively impact either the area’s social and cultural site [13].

5.3. Combination of selection criteria with sustainable drainage technology
The priority criteria reason vector is connected with each technology’s priority vector to get the priority ranking for technology selection. The recapitulation results are presented in Table 8 and Table 9.

Table 7: Calculation of Selection of Social/Cultural Criteria

|              | IW+DC | RH+DC | Dry Swale | Vp  | Scale (%) |
|--------------|-------|-------|-----------|-----|-----------|
| IW+DC        | 1.00  | 0.25  | 0.25      | 0.11| 11        |
| RH+DC        | 4.00  | 1.00  | 0.50      | 0.35| 35        |
| Dry Swale    | 4.00  | 2.00  | 1.00      | 0.54| 54        |
| \( \lambda_{\text{max}} \) | 3.068 | 0.034 | 0.58      | 0.059|

Table 8: Recapitulation of Technology Selection based on Reason Criteria

| Technology                                      | Technical | Economy | Environment | Socio-cultural |
|-------------------------------------------------|-----------|---------|-------------|----------------|
| Infiltration well + drainage channel             | 0.59      | 0.21    | 0.25        | 0.11           |
| Rainwater harvesting with drainage channels      | 0.16      | 0.09    | 0.59        | 0.35           |
| Dry swale                                       | 0.25      | 0.70    | 0.16        | 0.54           |

Table 9: Vector Priority Criteria Reasons

| Criteria             | Priority vector value |
|----------------------|-----------------------|
| Technical (T)        | 0.33                  |
| Economy (Eco)        | 0.12                  |
| Environment (En)     | 0.49                  |
| Socio-cultural (SC)  | 0.05                  |

Table 8 shows that combination in every selection of reason criteria and technology will be used according to AHP. While Table 9 is a priority vector in selecting criteria that will then be combined with the calculation of technology. From the table above, the relationship between the requirements for reason and technology selection is obtained:

(i) Infiltration well + drainage channel = 0.59 T + 0.21 Eco + 0.25 En + 0.12 SC
(ii) Rainwater harvesting + drainage channel = 0.16 T + 0.09 Eco + 0.59 En + 0.35 SC
(iii) Dry swale = 0.25 T + 0.70 Eco + 0.16 En + 0.54 SC
Table 10: Priority Ranking for Technology Selection based on Criteria for Reason

| Rating | Technology                                      | Scale (%) |
|--------|-------------------------------------------------|-----------|
| 1      | Rainwater Harvesting and drainage channels      | 37.3      |
| 2      | Infiltration wells and drainage channels        | 35.2      |
| 3      | Dry Swale                                      | 27.4      |
| Total  |                                                 | 100       |

In AHP calculation, it was found that technology priority according to environmental criteria, respondents chose rainwater harvesting and drainage channels with percentage 37.3%, infiltration wells and drainage channels 35.2%, while dry swale 27.4%. So, the priority of selecting sustainable drainage system technology in Karanganyar Regency is rainwater harvesting and drainage channels. Also, rainwater harvesting can be used for simple wastewater treatment so the general public will understand that waste management can be applied easily to the community. It will have a good impact on the environment and minimize pollution [14].

Rainwater harvesting is an environmentally friendly and reusable water technology. It can be used as a reserve in daily needs that should be developed in a country that will have an economic impact in saving costs for using water [15].

6. Conclusion

Based on the data analysis, it is known that the level of influence of the criteria on the priority of selecting sustainable drainage system technology has research outputs in the form of 49% environmental, 33% technical, 12% economic, and 5% social/cultural criteria. From the analysis results, the success values for absorbing rainwater are as follows: 37.3% drainage channels, infiltration wells with 35.2% drainage channels, and 27.4% dry swales.

Acknowledgments

The authors express their gratitude to the Ministry of Education and Culture, Republik of Indonesia, for the research funding through the scheme of Penelitian Tesis Magister with research grant contract number: 133.61/A.3-III/LPPM/IV/2020.

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