 https://doi.org/10.1051/e3sconf/202560503001

Using AHP to prioritize flood mitigation measures in urban areas

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Abstract. This study explores the application of the Analytic Hierarchy Process (AHP) in prioritizing flood mitigation measures for urban areas. The research employs a waterfall method with a quantitative approach, integrating AHP into a comprehensive flood mitigation information system. Key criteria considered include rainfall, topography, water channel conditions, land cover, and population density. The study identifies and evaluates various flood mitigation alternatives, such as early warning systems, river normalization, and drainage system improvements. The AHP analysis yields a consistency ratio of 0.021, indicating reliable judgments in the pairwise comparisons. Results prioritize the construction of early warning systems (0.216), followed by embankment construction (0.151), and drainage system improvement (0.137) as the most effective flood mitigation strategies. The developed system successfully combines spatial data, flood risk analysis, and AHP-based decision-making processes, providing a structured approach to flood management in urban contexts. This research contributes to more informed and efficient flood mitigation planning, offering a valuable tool for urban planners and policymakers in addressing the complex challenges of urban flooding.

1 Introduction

Indonesia is one of the countries that is prone to experiencing hydrometeorological disasters, namely disasters caused by climate and weather changes [1]. Of the approximately 1,681 disasters that occurred, 259 people lost their lives, with the majority being victims of floods, especially in West Java Province [2]. Minister of Home Affairs Regulation no. 33 of 2006 emphasizes the importance of several aspects in disaster mitigation efforts, including the availability of information and disaster vulnerability maps, outreach to the community, understanding how to save oneself, as well as organizing and structuring disaster-prone areas [3]. In recent years, the increasing frequency and intensity of natural disasters requires serious attention, especially in

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disaster management and response. Residential infrastructure in disaster-prone areas needs special attention [4]. Lack of spatial planning and community knowledge about the steps to be taken when a disaster occurs further exacerbates the negative impacts [5]. Disaster management does not only involve government agencies, but also humanitarian agencies and community participation. Coordination in quick decision making is important, considering the complexity of disaster situations which often makes this process difficult to carry out optimally [6].

Urban flooding has become a serious threat to cities around the world, with increasing frequency and intensity due to climate change and rapid urbanization. The impact of flooding is not only limited to damage to infrastructure and property, but also threatens human life, disrupts economic activities, and damages ecosystems [7]. Therefore, flood mitigation has become a top priority in modern urban planning and management.

Flood mitigation efforts in urban areas involve a variety of actions, from building physical infrastructure such as embankments and drainage systems, to non-structural approaches such as land use planning and early warning systems [8]. However, given the limited resources and complexity of urban flooding problems, it is important to prioritize the most effective and efficient mitigation measures [9]. The main challenge in urban flood mitigation is determining priorities among the various mitigation measures available. This decision-making process is often complex because it involves multiple conflicting criteria, such as cost-effectiveness, environmental impact, and social acceptability. In addition, the diversity of geographic, socio-economic and environmental characteristics in various cities adds complexity to determining optimal mitigation strategies [10].

Several previous studies have tried to overcome this problem by using various multi-criteria decision-making methods. For example, Lu C (2019) used the TOPSIS method to evaluate flood mitigation options in the Mekong River Delta. This research considers various criteria such as risk reduction effectiveness, costs, and environmental impacts. The results show that ecosystem-based approaches, such as mangrove forest restoration, rank highest in the local context [11]. While Sun et al. (2020) applied the Fuzzy Delphi Method to prioritize flood adaptation measures in Shanghai. This method allows the integration of diverse expert opinions and addresses uncertainty in assessments. The study identified improving drainage systems and developing green infrastructure as key priorities for flood adaptation in the city [12].

Furthermore, Wu S. (2023) conducted a flood risk analysis in the Mekong River basin, Vietnam. Factors such as rainfall, land use, and infrastructure are evaluated. The results of this research are used to plan more effective and efficient mitigation actions in dealing with flood risks [13]. Another research was conducted by Tempa (2022) who evaluated flood vulnerability in Bhutan. This study based on various criteria such as rainfall, topography, and land use. The results show can provide detailed vulnerability maps and enable a more comprehensive and structured assessment of various flood risk factors, which is important for effective mitigation planning. Although these studies provide valuable insights, they are often limited to specific geographic contexts or take insufficient consideration of hierarchical complexity in decision making [14].

To overcome these limitations, this study proposes the use of the Analytic Hierarchy Process (AHP) to prioritize flood mitigation measures in urban areas. AHP, developed by

Thomas L. Saaty, offers a systematic approach to decomposing complex problems into simpler hierarchies, allowing pairwise comparisons between criteria and alternatives [15]. This method is very suitable for urban flood mitigation problems because of its ability to handle qualitative and quantitative criteria, as well as its flexibility in accommodating various stakeholder perspectives [16].

The main objective of this research is to develop and apply AHP based framework to prioritize flood mitigation measures in urban areas. Specifically, this research aims to identify and categorize various flood mitigation options that are relevant for the urban context; determine and evaluate key criteria that influence the effectiveness and feasibility of mitigation measures; apply the AHP method to weight criteria and assess mitigation alternatives systematically; develop a prioritization model that can be adapted to various city characteristics; and validating the framework through case studies in several cities with different geographical, socio-economic and environmental conditions [17]. Through achieving these goals, research is expected to produce robust and flexible decision-making tools, which can assist city planners and policy makers in formulating effective, efficient and sustainable flood mitigation strategies in various urban contexts.

2 Data and Methods

2.1 Research Stage

The method used in this research is the waterfall method with a quantitative approach, which focuses on system development and application of the Analytical Hierarchy Process (AHP) method. More details of the research steps can be seen in Fig. 1.

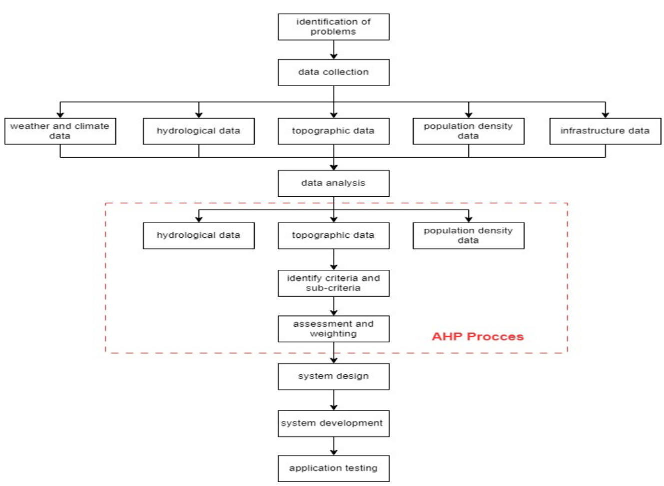

Fig. 1. Research flow.

The research begins with formulating the research topic and title, which in this case is about flood disaster mitigation systems. The next stage involves identifying the problem, followed by problem formulation. Based on the identified issues, the next step is data collection, conducted through observation, internal data gathering, and literature review. System requirements analysis is conducted to identify functional and nonfunctional requirements, as well as business process modelling. The system design includes system architecture design, database design, and user interface design.

The AHP method is applied to prioritize flood disaster mitigation measures. The AHP steps include determining flood mitigation criteria and sub-criteria, weighting the criteria, calculating consistency, and constructing the decision hierarchy [18]. The results from the AHP process are then integrated into an information system to support decision-making in flood disaster mitigation. System development is carried out by implementing the database, building the backend using PHP/Laravel, and developing the frontend with HTML, CSS, and JavaScript. System testing is conducted through several stages, including functional testing (black box testing), usability testing, and performance testing to ensure the system operates as expected. Evaluation and validation of the system are crucial stages in this research. The evaluation of the AHP method implementation is conducted to ensure accuracy and effectiveness in supporting decision-making. System validation involves BPBD to ensure alignment with operational needs. User feedback analysis is also performed to identify areas for improvement and further development.

2.2 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a method in decision support systems that optimizes criteria weights by selecting the best alternative options and is useful for resolving unstructured and complex problems into various components in a hierarchical arrangement, by providing subjective value regarding the important role of each variable and determining which variable has the highest priority in order to influence the results in that particular situation [8], [19]. The stages in the AHP method are as follows [20]

a. Defining the problem and determining the desired solution
b. Create a hierarchical structure that starts with a general objective, followed by criteria and alternative choices that you want to rank.
c. Form a pairwise comparison matrix that describes the relative contribution or influence of each element towards each goal or criterion at the level above.
d. Normalize data
e. Calculate the eigenvector values and test their consistency. If they are not consistent then data collection (preferences) needs to be repeated.
f. Repeat steps 3, 4, and 5 for all hierarchical levels.
g. Calculate the eigenvector of each pairwise comparison matrix.
h. Testing hierarchical consistency. If it does not meet the $CR < 0.100$ then the assessment must be repeated.

3 Result and Discussion

3.1 Data Collection

The case study for this research is the Indramayu district. The initial step in identifying the research object involved conducting interviews with relevant stakeholders, as well as field observations in flood-prone areas to gather information on the criteria and list of alternatives used for flood mitigation. The criteria data and alternative data collected will be used for designing the AHP process in the developed system. The criteria data include rainfall (CH), topography (T), condition of water channels (KSA), land cover (TL), and population density (KP). The alternative data include the construction of an early warning system (SPD), river normalization (NS), improvement of drainage systems (PSD), construction of embankments (PT), creation of infiltration wells (PSR), and relocation of residents (RP)

Table 1. Dataset and alternatif variable.

id	CH	T	KSA	TL	KP	Alternatif
1	1002	1	3	53	2931	NS
2	1335	4	1	58	2012	PSD
3	1170	2	1	78	2664	PT
4	1006	1	4	75	2081	PSR
5	971	5	3	60	1633	PSR
6	920	3	5	64	1512	PT
7	1021	4	3	62	2774	RP
8	1366	3	4	50	1801	NS
9	1114	3	4	61	2119	PSR
10	1002	1	3	53	2931	NS
…	…	…	…	…	…	…
…	…	…	…	…	…	…
100	927	2	5	38	2191	SPD

3.2 Data Processing

To obtain an overview of the recommendation system using the AHP method, it is necessary to design a hierarchical structure for the application. This hierarchy begins with the goal of recommending appropriate disaster prevention measures based on the user's regional conditions. It is followed by criteria that influence flood disasters and alternatives that represent the appropriate prevention or mitigation measures.

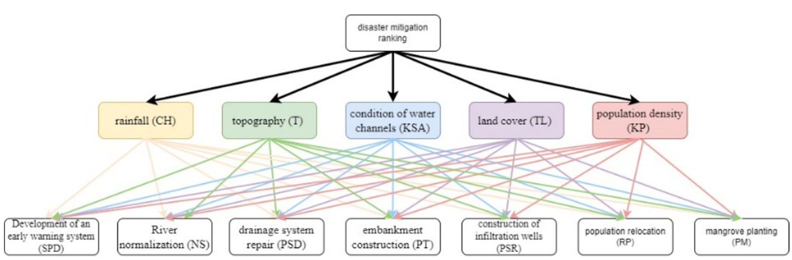

Fig. 2. AHP Hierarchical Structure.

The next step is to create a pairwise comparison matrix. Form a pairwise comparison matrix. Comparisons are made based on the choice or judgment of the decision maker by assessing the level of importance of one element compared to other elements.

Table 2. Pairwise comparison matrix.

	CH	T	KSA	TL	KP
CH	1	3	2	4	5

T	0.33	1	0.50	2	3
KSA	0.50	2	1	3	4
TL	0.25	0.50	0.33	1	2
KP	0.20	0.33	0.25	0.50	1
Total	2.283	6.833	4.083	10.5	15

The next step is to normalize the data by dividing the value of each matrix element in pairs by the total value of each column and calculating the eigen vector value

Table 3. Normalize matriks and Eigen vector value.

	CH	T	KSA	TL	KP
CH	0.438	0.439	0.490	0.381	0.333
T	0.146	0.146	0.122	0.190	0.200
KSA	0.219	0.293	0.245	0.286	0.267
TL	0.110	0.073	0.082	0.095	0.133
KP	0.088	0.049	0.061	0.048	0.067

Eigen vector
0.416
0.161
0.262
0.099
0.063

After that calculate the Consistency Ratio (CR) for the criteria and test their consistency. If they are not consistent then data collection (preferences) needs to be repeated.

Calculate λmax:

$$\lambda_{max} = (2.283 * 0.416) + (6.833 * 0.161) + (4.083 * 0.262) + (10.5 * 0.063) = 5.092 \quad (1)$$

Calculate Consistency Index (CI):

$$CI = (\lambda_{max} - n)/(n-1) = (5.092-5)/(5-1) = 0.023 \quad (2)$$

Calculate Consistency Ratio (CR):

CR = CI / RI, where RI for n = 5 is 1.12 (3)

CR = 0.023 / 1.12 = 0.021 (Because CR < 0.1, so consistency is acceptable.)

The next step is to create a pairwise comparison matrix for alternatives against each criterion. After obtaining an acceptable Consistency Ratio value for the alternative data (CR < 0.1), then carry out an assessment and weighting for the criteria and alternative data.

Table 4. Weighting and assessment.

	CH	T	KSA	TL	KP	Total
SPD	0.256	0.220	0.180	0.150	0.300	0.224
NS	0.172	0.250	0.220	0.180	0.150	0.198
PSD	0.108	0.180	0.250	0.220	0.180	0.173
PT	0.368	0.150	0.180	0.250	01.20	0.252
PSR	0.060	0.100	0.080	0.100	0.080	0.077
RP	0.036	0.060	0.050	0.060	0.120	0.049
PM	0.025	0.040	0.040	0.040	0.050	0.033
Weight	0.416	0.161	0.262	0.099	0.063	

3.3 System Design

System modeling is conducted using use cases in the Unified Modeling Language (UML). During this stage, the system's workflow is illustrated through a use case diagram. This diagram aids in comprehending the primary functions offered by the application and the interactions between each actor and the system.

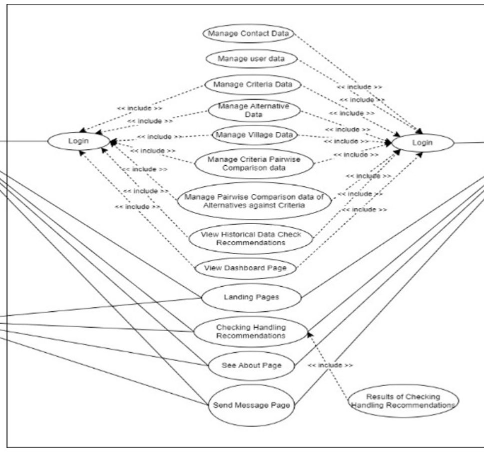

Fig. 3. Usecase diagram system.

Fig. 3 illustrates that the guest has access to four menu: landing page, recommendation check, about, and send message. Admin/expert can view the guest menus and additionally manage the criteria data, alternative data, village data, criteria pairwise comparisons, alternative pairwise comparisons, and recommendation check history menu.

3.4 Implementation System

This section offers a thorough overview of the flood mitigation system interface, describing the functionality of each component and how users interact with them. The system comprises several web page interfaces designed to be visually appealing and user-friendly, ensuring that users can operate the system quickly and easily. These web pages are categorized into two sections: the first is accessible to users (guests), and the second is restricted to access by admin or experts only.

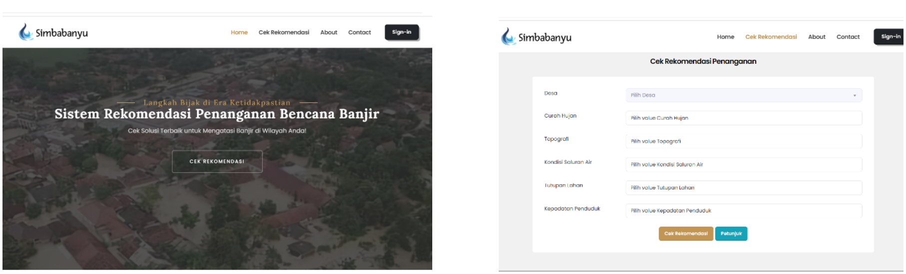

Fig. 4. Landing Page and Recommendation Check Page.

Fig.4 illustrates the user landing page interface. This page provides users with information about the system. It features a "check recommendation" menu, which users (guests) can utilize to obtain disaster mitigation recommendations processed using the AHP method. On this page, users are required to enter data according to predetermined criteria, and the system will process this information to generate disaster mitigation recommendations based on AHP rules.

Next, the website page accessed by the admin/expert is used to manage criteria data and the AHP process within the system. To access this page, the admin/expert must first enter a registered email and password. Upon successfully entering the correct email and password, the system will direct them to the main admin/expert menu page. Admin/expert will add the criteria data and alternative data to be used in the system's recommendation process. The system includes options to add, edit, or delete, allowing modifications to the criteria and alternatives according to the previously designed plan.

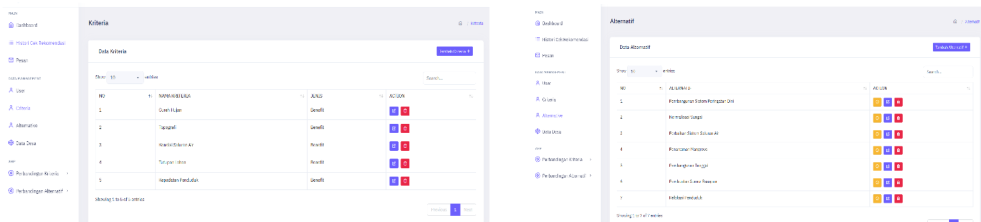

Fig. 5. Criteria and Alternatif Data.

Next, criteria comparisons are conducted to obtain the criteria pairwise matrix. The admin/expert can select the criteria comparison menu, choose pairwise comparisons, and calculate the criteria values, including maximum eigenvalue, CI, and CR values, in the criteria ranking menu. After that, they check if the CR value is acceptable (consistent) or not.

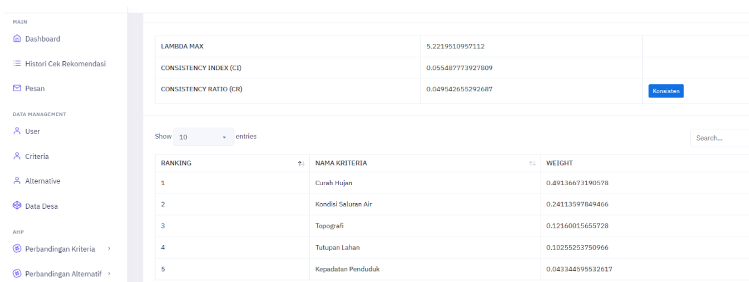

Fig. 6. Consistensy Ratio Criteria Value.

Lastly, the weights/priority vector page displays the weight values for each alternative data. From these weight values, the alternatives can be prioritized in order of the highest to lowest weight.

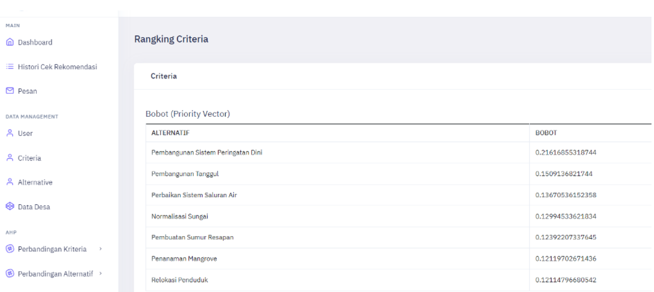

Fig. 7. Weights / Priority Vector.

 https://doi.org/10.1051/e3sconf/202560503001

Based on the results of the AHP analysis in fig. 7, the best alternative for flood management is early warning system (0.216), followed by construction of embankments (0.151) and improvement of drainage systems (0.137).

3.5 System Testing

After implementing the application, the next step is testing. The testing is conducted using black box testing, which focuses on evaluating the functionality of the system without examining its internal structures or workings. The details of the black box testing, including test cases, expected outcomes, and actual results can be seen in table 5.

Table 5. Blackbox Testing.

No	Information	
	System	**Testing**
1	Management of landing pages	In accordance
2	Managing the recommendation check page	In accordance
3	Login Validation	In accordance
4	User menu management	In accordance
5	Criteria menu management	In accordance
6	Alternative menu management	In accordance
7	Village data menu management	In accordance
8	Pairwise comparison menu management (criteria)	In accordance
9	Management of criteria ranking menu	In accordance
10	Pairwise comparison menu management (alternative)	In accordance
11	Management of alternative ranking menu	In accordance
12	Management of priority vector menu	In accordance

4 Conclusion

This research develops a natural disaster mitigation system that integrates the AHP method, successfully combining spatial data, flood risk analysis, and AHP-based decision-making processes into a comprehensive platform. The study yields a consistency ratio (CR) value of 0.021, which is acceptable (consistent) since it is below 0.1. The top alternative for flood management is the early warning system (0.216), followed by embankment construction (0.151), and drainage system improvement (0.137). This system has proven effective in providing accurate and structured information on flood-prone areas, risk levels, and mitigation recommendations. Implementing the AHP method enables objective weighting of various flood mitigation criteria, resulting in more targeted and efficient action priorities.

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