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Dynamic System of Flood Disaster Management in Makassar City using the Analysis AHP Method

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Abstract

Flooding is one of the problems frequently faced by the people of Makassar City. This natural disaster is highly destructive and detrimental, affecting infrastructure, livelihoods, and the social conditions of the community. This study employs the Analytic Hierarchy Process (AHP) method to evaluate the criteria influencing flood management, focusing on population size and the role of stakeholders. Data were collected through questionnaires distributed to experts from various agencies, including the Meteorology, Climatology, and Geophysics Agency (BMKG) Region 4 Makassar, the Environmental Agency of Makassar City, the Public Works Agency of Makassar City, the Jeneberang River Basin Office, and the Regional Disaster Management Agency (BPBD) of Makassar City.The results of the study indicate that AHP data processing yields a comparison matrix value for flood disaster risk management and mitigation. The most dominant influencing criterion is the role of stakeholders, accounting for 54%, followed by population size at 27%, land development rate at 13%, and environmental quality at 6%. The analysis of the management dynamics model shows that the risk and impact of flooding have an interrelated relationship among the four categories. The role of stakeholders has the greatest contribution in influencing the categories of population size, land development rate, and environmental quality.

Keywords: Flood, AHP, Dynamic System

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1. Introduction

The rules written in Law Number 24 of 2007 state that flooding is a major threat that disrupts people's lives and livelihoods. Disasters can start from natural phenomena or human activities that cause casualties, environmental damage, property damage and psychological trauma. Changes in rainfall patterns, an increase in extreme weather events, changes in land use, and population growth are some of the causes contributing to increased flooding throughout the world (Sarmah and Das, 2018). The nature of water runoff can be significantly affected by increasing artificial surfaces, which can result in greater areas being submerged during floods. For developing countries, which often do not have the means to carry out recovery and restoration after natural disasters, changes in these natural processes cause considerable concern (Allafta and Opp, 2021).

Flooding has become one of the most prominent natural disasters globally, causing enormous social and economic damage (Chen et al. 2020). Natural disasters account for 40% of all socio-economic damage worldwide. Indeed, floods are most frequent and devastating, especially in Southeast Asian countries (Bui et al. 2019). Variations in flood risk are mostly caused by changes in land use, climate change, and other human activities. Urbanization, roads or other structures built across rivers, river banks, waterways, bridges of inappropriate dimensions, deforestation and the resulting erosion, land subsidence, and partial or complete closure of river courses are the most common anthropogenic consequences. These are evident on the region's flatlands due to human activities like excessive pumping, and more recently, changes or deviations in water paths (Green et al, 2000).

Natural disaster management or mitigation is a sustainable effort to reduce the impact of disasters on lives and the environment (Ahadi and Ulfah, 2024). Indonesia is highly vulnerable to flood disasters, which pose a significant risk that can result in property damage and substantial loss of life. Therefore, increasing prevention and knowledge in disaster preparedness among Indonesian society is very important (Ibrahim et al, 2020).

The capital and most populated city of South Sulawesi Province is Makassar. When it rains a lot or during the rainy season, many of Makassar City's major highways flood. The majority of the 72 flood-prone areas that the Makassar City Regional Disaster Management Agency identified in 2021 are found north to south of Makassar City. Due to comparatively highwater levels during the rainy season, 13 out of 72 locations including Jalan AP Pettarani, Minasa Upa region, Jalan Latimojong, Sungai Pareman, and Manggala were identified as having a substantial risk of flooding. Hundreds of people would have to leave Manggala District if the water level rose by up to 1.5 meters.

The significance of flood risk assessment components and the difficulties in combining different data sources for a more precise analysis (Mojaddadi et al., 2017). Several previous studies that used the AHP method often studied vulnerability in terms of physical, social or other geographical characteristics of an area, such as research conducted by Yanu et al., (2015), Andi (2015), and Heru et al., (2017) which uses the AHP method to determine a weighting system in determining the physical vulnerability of an area to flood disasters. Meanwhile, this research will provide data and information from the results of the AHP analysis to look at the criteria for managing flood disasters in terms of population, role of stakeholders, rate of land being developed, environmental quality which will later display system and dynamic relationship data from these criteria in managing risk, impacts, or detrimental things when flooding occurs in Makassar City

2. Method

With an area of 175.77 km^2 and 14 sub-districts, Makassar City is located on the west coast of southern South Sulawesi with coordinates 119°, 18', 27', 97'' East Longitude and 5°, 8', 6', 19'' South Latitude. The research location is shown in figure 3.1. Administratively, Makassar City has the following territorial boundaries: to the south it borders Gowa Regency, to the north it borders Pangkajene Islands Regency, to the east it borders Maros Regency, and to the west it borders the Makassar Strait. The research location can be seen in Figure 1. following:

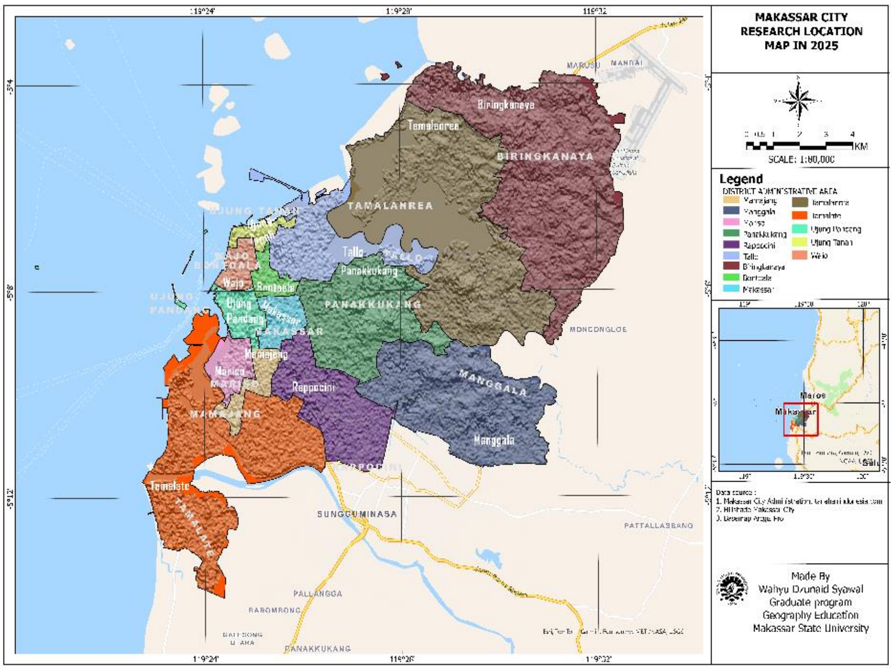

Figure 1. Research Location

In general, the terrain is coastal. Makassar City is at an altitude of between 0.5 and 10 meters above sea level. The area of Makassar City is 175.77 km^2, divided into 143 and 14 sub-districts. AHP is a decision making method that considers a number of goals and standards. To ascertain preferences among the possibilities, a pairwise comparison process is used. AHP uses absolute numbers on a scale to measure personal preferences or judgments.

The aim of this analysis is to measure the level of flood risk and vulnerability in an area. The total score of all factors that influence flooding is used to calculate an area's vulnerability to flooding. The analysis in this research uses the Analytical Hierarchy Process (AHP) method. Thomas L. Saaty (2008) explains hierarchy as a representation of complex problems in a multilevel structure where the first step is the goal, which follows the stages of criteria, sub-criteria, and so on. AHP It is often used as a procedure in decision making for the following reasons:

1) Hierarchical structure that descends to the most in-depth sub-criteria as a result of the selected criteria;
2) Tolerating contradictions among the many criteria and options selected;
3) Consider resilience or endurance.

The basic idea of AHP produces relative weight values between criteria and options in the table below using a pairwise comparison matrix. The importance of achieving the goals mentioned above is determined by comparing one criterion with another (saaty, 2008). Human perception serves as the main input for AHP, which uses functional hierarchy as its main tool. The existence of a hierarchy makes it possible to break down difficult or unstructured problems into smaller components and then arrange them hierarchically. This research uses a questionnaire to assess each role from the criteria in the form of population size, role of stakeholders, environmental quality and rate of land development in efforts to manage flood disasters in Makassar City which can be seen as in Figure 2 and Table 1 below.

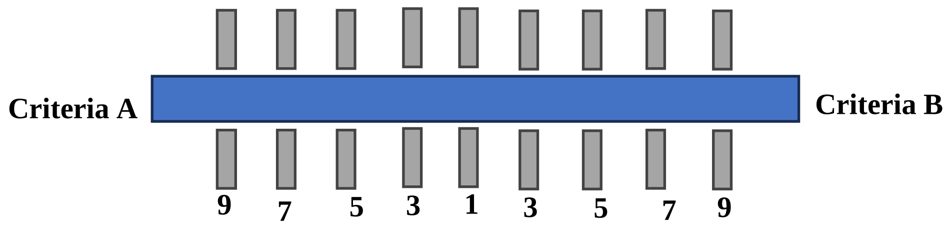

Figure 2. Questionnaire used in research

Table 1. Pairwise Comparison Scale

Importance Value	Importance Criteria
1	Two Criteria Are Equally Important
3	One criterion is Quite Important
5	One Criterion is Important from other criteria
7	One Criterion is Very Important than other criteria
9	One Criterion is More Important than Other Criteria

Source: Saaty, 2008

The results from using the AHP method must be constant for each pairwise comparison. Inconsistency arises because the evaluations used to compare one criterion with another are independent of each other.

The use of system dynamics in flood management can help evaluate more effective mitigation policies in flood-prone areas (Rahmandani and Yanuar, 2023). Based on the identification, there are several related stakeholders, namely: BPBD Makassar City and South Sulawesi Province, BMKG region 4 Makassar City, Public Works Department, Makassar City Government, Community, Environmental Service, River Region Hall, industrial and private companies, and others. Others include parties identified as stakeholders. Apart from that, all stakeholders must work together to deal with the flood disaster in Makassar City.

According to Farlow et al. (2002), a dynamic system is a system that develops simultaneously. along the time. The study of how system solutions behave near the equilibrium point is one of the main goals of dynamical systems. This research takes several criteria that will be factors influencing flood management in the city of Makassar, namely population size, the role of stakeholders, the rate at which land is built, and also environmental quality. All of these criteria will be analyzed using the AHP method in a questionnaire that will be distributed to experts in the relevant stakeholders, who will then see the dynamic relationship of each of the criteria based on the weights that have been calculated.

High population areas frequently have precarious social conditions, particularly in slums or densely inhabited settlements. The poor, who typically reside in disaster-prone areas, are more affected socially and economically when floods hit. Because they lack the money to construct homes that can withstand disasters or relocate to safer areas, this circumstance makes them more vulnerable to flooding (Shukla, 2021).

The role that stakeholders play in managing flooding has a significant impact on vulnerability in addition to environmental considerations. It is the duty of the government, society, business community, academia, and non-governmental organizations to collaborate in the development of suitable and efficient mitigation measures. Through more effective land use management, community capacity building, and the provision of disaster-resistant infrastructure, effective stakeholder collaboration can help lower susceptibility to floods (Smith et al., 2017).

Without careful planning, the rate of built-up land can increase, leading to infrastructure that is unable to handle significant amounts of rainfall. For instance, many towns construct buildings and roadways in low-lying or perhaps flood-prone locations without taking flood mitigation or drainage into account. This makes it more susceptible to flooding since poor infrastructure slows down water movement and frequently results in standing water that can turn into floods (Johnson et al., 2019).

Increased susceptibility to flooding is largely caused by poor environmental quality. Flood danger is increased by a number of factors, including pollution, poor resource management, deteriorating vegetation, inadequate infrastructure, and the effects of climate change. Thus, it is crucial to preserve and enhance environmental quality through pollution prevention, sustainable natural resource management, and the construction of infrastructure that aids in disaster mitigation in order to lessen vulnerability to flooding (Sharma et al., 2018).

3. Result and Discussion

A. Analytical Hierarchy Process

The process of filling out the questionnaire by 11 expert respondents in each relevant agency, with details of 2 respondents being climatology experts, 2 respondents being infrastructure experts, 3 respondents being hydrology experts, 2 being disaster mitigation experts, 2 being environmental experts.

Pairwise Comparison Matrix the geometric results of all respondents' answers to the questionnaire which was distributed to 11 experts can be seen in Table 2 as follows:

Table 2. Comparison Matrix Table

Criteria	Total Population	Developed Land Rate	Role of stakeholders	Environmental Quality
Total Population	1	3	0.33	5
Developed Land Rate	0.33	1	0.25	3
Role of stakeholders	3	4	1	7
Environmental Quality	0.2	0.33	0.14	1
Amount	4.53	8.33	1.72	16

Normalization Matrix based on the results of processing the geometry of the comparison matrix, the value of the sum of each column of criteria will be divided by the total column number of each criterion to obtain the eigenvalues of each criterion to obtain the results of the comparison matrix as in Table 3. below:

Table 3. Normalization Matrix Table

Criteria	Total Population	Developed Land Rate	Role of stakeholders	Environmental Quality
Total Population	0.220588235	0.360144058	0.191860465	0.3125
Developed Land Rate	0.073529412	0.120048019	0.145348837	0.1875
Role of stakeholders	0.661764706	0.480192077	0.581395349	0.4375

Environmental Quality	0.044117647	0.039615846	0.081395349	0.0625
Amount	1	1	1	1

Average value and weight of each criterion determining the average and weight of each criterion based on the normalization matrix value above can be seen in Table 4.

Table 4. Averages and Weights

Criteria	Rate-Rata	Weight
Total Population	0.27127319	27%
Developed Land Rate	0.131606567	13%
Role of stakeholders	0.540213033	54%
Environmental Quality	0.056907211	6%
Amount	1	100%

After getting the weight value for each criterion, the consistency index (CI) and consistency ratio (CR) tests are carried out as follows

$$CI = (\lambda max - n) / (n-1) \quad (1)$$

$$\lambda max = \sum (\text{Column Total x Criteria Weight})$$

$$\lambda max = (4.53 \text{ x } 0.27) + (8.33 \text{ x } 0.13) + (1.52 \text{ x } 0.54) + (16 \text{ x } 0.06) = 4.09$$

$$CI = (4.09-4) / (4-1) = 0.33$$

$$CR=CI/RI$$

Where RI for 4 Criteria (n) = 0.9

$$CR = 0.33 / 0.9 = 0.033$$

Because CR = 0.033 < 0.1, the comparison matrix is said to be consistent

Justification of Weighting Results The role of stakeholders is more important than population (3:1) because stakeholders determine the implementation of effective solutions. The role of stakeholders is more important than the rate of land built (4:1), because stakeholders have the power to regulate and control the rate of development. The role of stakeholders is much more important than environmental quality (7:1), because without stakeholder coordination, environmental quality is difficult to improve.

B. Dynamic System

The results of the analysis of calculations for managing flood-prone areas in Makassar City can be made into a diagram causal loop to model the dynamics of flood management in Makassar City using Vensim software, the following is a diagram of causal loop flood management in Makassar City. Which will be explained as in Figure 3 below:

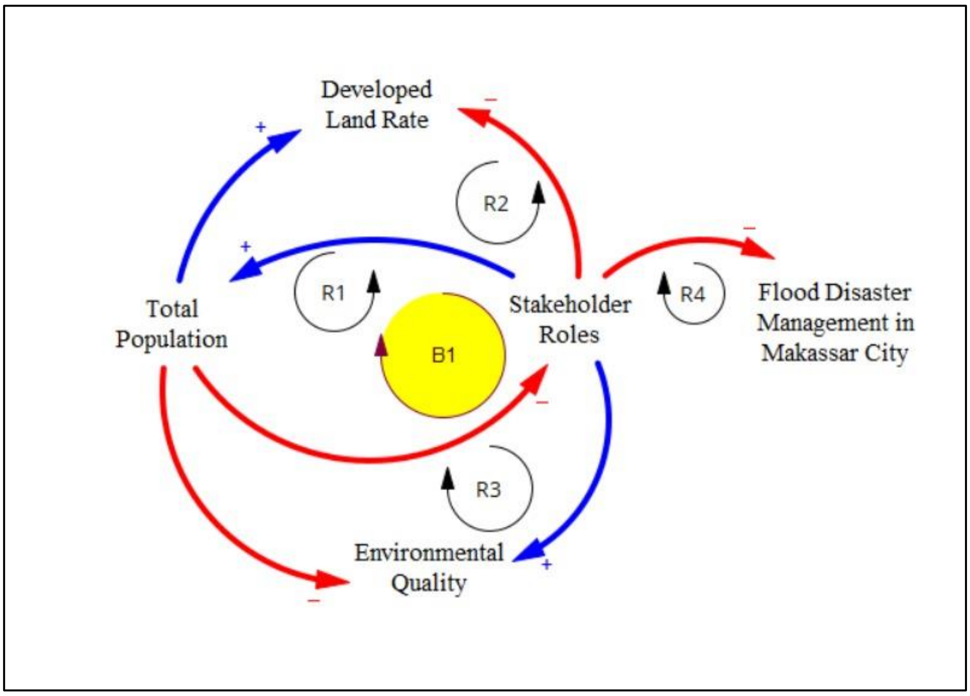

Figure 3. Diagram Causal Loop Risk and Impact Management

Diagram causal loop which describes the relationship between Stakeholder Roles, Population Number, Rate of Land Built, and Environmental Quality shows the existence of complex interaction dynamics in reducing flood risk in Makassar City. The role of stakeholders as a dominant factor plays an important role in influencing other factors directly or indirectly.

1) Relationship between Stakeholder Roles and population management (R1), effective stakeholders can control population growth through good city planning policies, such as controlling migration, planned development of new areas, and strengthening the spatial planning system. In this way, a controlled population will reduce pressure on infrastructure and the environment, thereby reducing the risk of flooding.
2) The role of stakeholders influences the management of the rate of land built up (R2), the role of stakeholders is also strongly related to controlling the rate of land conversion. Regulation and law enforcement related to the development of built areas, for example in policies providing green open space (RTH) and water catchment areas, to reduce environmental damage that worsens the potential for flooding. This relationship is positive reinforcement (reinforcing loop), where the greater the role of stakeholders, the better the land use management.
3) The Role of Stakeholders in Improving Environmental Quality (R3), stakeholders also influence environmental quality, such as waste management, drainage channel maintenance, and ecosystem rehabilitation programs. Improving environmental quality will support a significant reduction in flood risk, especially in areas with dense drainage systems.

4) The relationship between the three factors influenced by the role of stakeholders Number of Population, Rate of Land Built, Environmental Quality (B1) When the population increases, the need for residential land and infrastructure also increases, which can accelerate the rate of land conversion. Uncontrolled built-up land will reduce water absorption capacity and worsen environmental quality, creating a higher risk of flooding. However, a strong stakeholder role can break this negative cycle through better spatial planning and environmental management policies.
5) The role of stakeholders is to intervene in the form of overall policy in an effort to reduce the risk and impact of flooding (R4) as a dominant factor, stakeholders act as the main controller who can influence all factors. Decisions made by stakeholders in the form of policies, regulations and field actions can create broad positive impacts. For example, good spatial planning policies not only control the rate of land development but also improve environmental quality and improve the balance between population and infrastructure capacity.

C. Discussion

The results of the weighting analysis using the Analytical Hierarchy Process (AHP) method show that the Role of Stakeholders has the highest weight, namely 54%, followed by Number of Population with a weight of 27%, Rate of Land Built at 13%, and Environmental Quality at 6%.

The high weight in the Stakeholder Role criteria confirms that collaboration and active involvement from the government, community and private sector are the main keys in efforts to reduce flood risk in Makassar City. Stakeholders have a strategic role in formulating spatial planning policies, managing resources, and supervising the implementation of flood mitigation programs. With this dominant weight, the success of risk reduction is highly dependent on the effectiveness of coordination between parties and the implementation of policies based on data and local needs.

Population is in second place with a weight of 27%, which indicates that population pressure remains an important factor that needs to be considered. A large population increases the potential for vulnerability through uncontrolled land use, increased domestic waste, and higher infrastructure requirements, all of which contribute to increased flood risk. The built-up resistance rate criterion, with a weight of 13%, reflects that the conversion of land into built-up areas also influences the potential for flooding, especially in lowland areas and areas with minimal green space. Controlling land use is an important step that needs to be monitored by stakeholders, especially in maintaining a balance between development needs and environmental capacity.

Environmental quality has the lowest weight (6%), which shows that although the quality of environmental management such as waste management and drainage maintenance has an influence, its contribution is considered as a supporting factor in the context of flood mitigation. However, environmental quality must still be considered to increase the overall effectiveness of flood management.

The results of this weighting provide an illustration that flood risk reduction strategies in Makassar City must be focused on increasing stakeholder capacity in managing and coordinating various aspects of mitigation. This includes the preparation of spatial planning policies, strengthening land conversion regulations, as well as flood risk-based infrastructure management. With the support of a strong stakeholder role, the potential impact of other factors can be minimized, thereby creating more effective and sustainable flood risk management. The results of the AHP analysis which focuses on the role of stakeholders in this research are the same as research conducted by Kundzewicz et al (2014), which concluded the importance of stakeholder collaboration in facing the challenge of increasing flood risk due to climate change.

4. Conclusion

The results of AHP data processing show the comparison matrix value for flood disaster risk management and mitigation with the most dominant stakeholder influence criteria being 54%, for a population of 27%, the rate of built-up land getting a weight of 13% and environmental quality of 6% management dynamics system analysis. The risk and impact of flooding shows an interrelated relationship between the four categories, namely the role of stakeholders has the greatest contribution in influencing the categories of population size, land development rate, and environmental quality.

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