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The decision making analysis of increasing storage capacity of sutami reservoir with Analytical Hierarchy Process (AHP) approach

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Abstract

Aim: This research aims to use the Analytical Hierarchy Process (AHP) technique, a form of multi-criteria decision-making, to rank the relative merits of potential courses of action. Through pairwise comparisons based on importance levels, AHP unites different individuals' qualitative, subjective evaluations into a collective evaluation of decision-making.
Method: In this study, we will draw from existing literature on water resource management and planning to establish our criteria and sub-criteria. Experts in a dam, reservoir, and water resource management use FGD to finalize criteria/sub-criteria because of a knowledge gap between the two sets of studies. After collecting data from the FGDs, the criteria and sub-criteria are used in an AHP to rank a set of potential solutions.
Findings: The following is the outcome of applying weights to the pairwise comparisons we conducted using the criteria of social, environmental, technical, and economic aspects: With 36.2% of the vote, the option of raising the dam body by 5 meters is deemed most important. In terms of alternatives, a 0.5-meter-higher spillway comes in second with a weight of 25.7%, while dredging sediments to the same depth as sediment inflow comes in third with a weight of 20.5%, and maintaining the current configuration receives the least amount of weight at 17.7%.
Implications/Novel Contribution: All stakeholders must back and contribute to the development of research aimed at extending the useful life of existing reservoirs. It is common knowledge that all reservoirs have a finite amount of time before they must be shut down. Old, inefficient reservoirs are expensive to keep up and close. However, a new dam will not come cheap, and finding a suitable site is uncertain.

Keywords: Decision Support System, Water Resources Management, Sutami Reservoir Dam, AHP

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INTRODUCTION

We couldn't survive without water. Future water demands will rise with the global population and technological advancements. What's more, the success of the food and energy industries is heavily dependent on the availability of water resources. These are the two domains that are crucial to all forms of life. Therefore, efforts made to preserve water resources to guarantee their availability are crucial to enhancing the well-being of the community as a whole. Water scarcity may emerge as one of the global warming's most pressing consequences in the years to come. We risk a water crisis in the dry season if we don't take preventative measures, and we risk flooding in the wet season if we don't. Artificial water storage, like that provided by dams, is crucial to the well-being of any sustainable society. That's because it's used in many different ways, from drinking to irrigation to power to industry. In addition to supplying water during the dry season and preventing floods during the wet season, dam reservoirs benefit tourism and freshwater fisheries.

Sedimentation is the most difficult problem to solve when it comes to managing reservoirs all over the world, according to Schleiss, Franca, Juez, and Giovanni (2016). Sedimentation is a major issue that has led to a decrease in the total amount of water stored in reservoirs, reducing their effectiveness as water sources, power plants, and flood controllers (Alemu, 2016). According to data provided by reservoir manager Perum. Jasa Tirta 1 (PJT1),

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eight (8) reservoirs were built along the Brantas River between 1970 and 2000 (Bening, 1981; Batuca & Jordaan Jr, 2000; Hidayat et al., 2018; Lahor, 2011). Because of sedimentation issues, the capacity of the existing reservoirs has drastically decreased. 2014 measurements showed that the sediment deposition rate in 1the eight reservoirs had reduced the initial total storage capacity from 647 million m^3 to 366 million m^3, or only about 56.5 percent of the initial total capacity. More effective and efficient efforts are needed to increase the longevity of the reservoir because of the high costs, limited availability of land, and lengthy process required to realize the construction of new dams.

Due to its strategic location (upstream in the Brantas River), large storage capacity, and high sedimentation rate, Sutami Reservoir was selected as the research case.

Sutami Reservoir

East Java Province, Indonesia, is home to Sutami Dam (Karangkates). It is in the Malang Regency. Beginning in 1972, this dam was used for hydroelectric production. In Figure 1, we see where the Sutami reservoir is situated. The dimensions of the Sutami dam are as follows: height: 100m; width: 13.7m; base width: 400m; peak length: 823.5m. The 2,050 km^2 catchment area of Sutami Reservoir provides many benefits to the local community, including freshwater fisheries, agriculture, plantations, and tourism. Furthermore, the existence of public settlements due to the Sutami reservoir also increases the economic environment around the community (offices, shops, schools, markets and other public facilities). Because of its positive effect on the local economy, the Sutami reservoir should be kept open.

Sedimentation of Sutami Reservoir

The reservoir capacity of the Sutami Reservoir has been diminished due to its very high level of sedimentation. Measuring results from 2016 indicated that reservoir capacity had decreased to 187,241 million m^3 or 54.6% from the original total storage capacity of 343 million m^3. Since the reservoir's operation began in 1972, sedimentation in the Sutami area has increased to 155.759 million m^3 or about 3.54 million m^3 per year. Both technical and non-technical measures have been taken to combat sedimentation upstream of the reservoir. Figure 1 displays a map of the Sutami reservoir's longitudinal profile, and Figure 2 displays the reservoir's longitudinal historical profile based on 2016 measurement data. These numbers show that sediment deposits impact reservoir performance in raw water supply and flood control because they are not just piled up in dead storage but are also spread out ineffective storage zones.

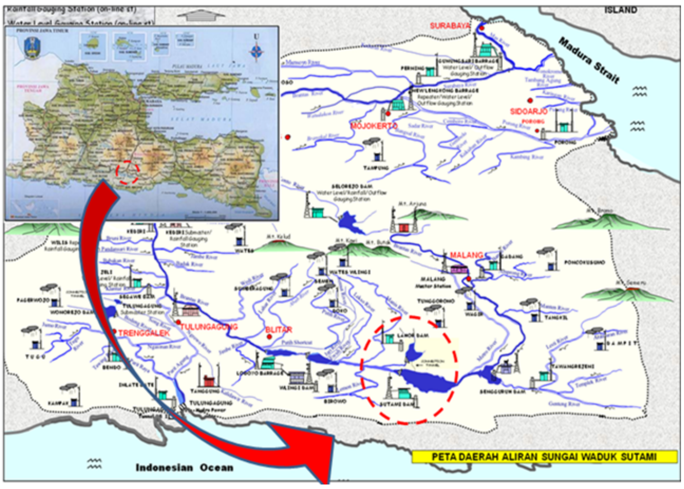

Figure 1. Location of the Sutami reservoir

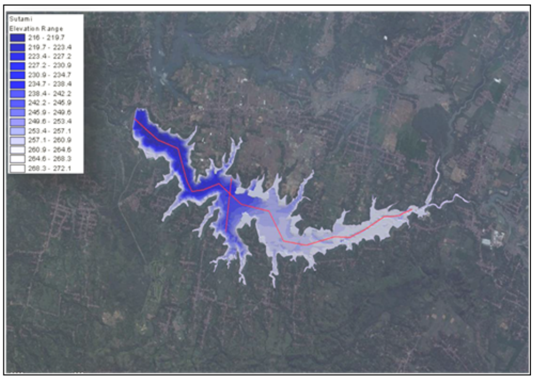

Figure 2. Longitudinal profile map of Sutami reservoir

Technically, the effort which has been done by PJT1 as the reservoir manager is dragging and flushing. Due to limited equipment, PJT1 can only dredge sediments of $\pm$ 0.4 million m^3/year, much smaller than the average sediment in the reservoir. This will affect the decrease of the storage capacity of the Sutami reservoir. Because of the limited area for sediment storage (spoil bank), other efforts need to be made to increase the Sutami Reservoir's capacity to extend its Sutami reservoir lifespan.

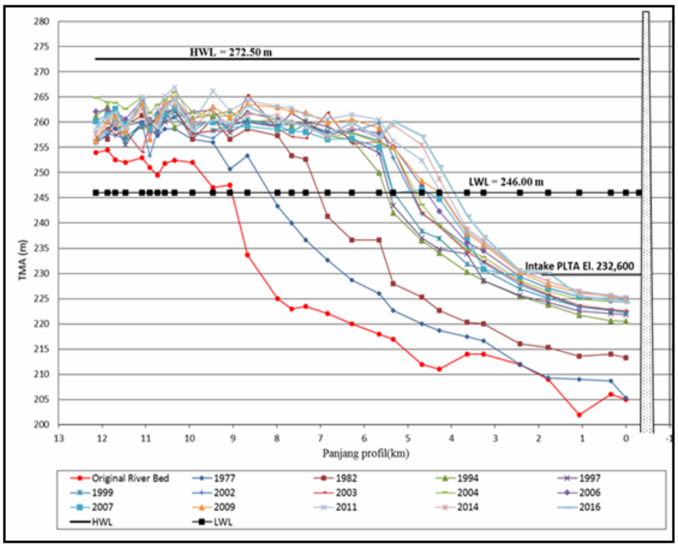

Figure 3. Longitudinal historical profile of the Sutami reservoir in 2016

In light of these issues, novel, quantifiable risk-taking is required to increase the storage capacity of the Sutami reservoir. Although various alternatives have been proposed, they remain a source of contention amongst experts due to their divergent evaluation criteria. Dam body heightening by 5 meters, spillway elevation by 0.5 meters, sediment dredging equal to inflow volume, status quo (sediment dredging around 0.4 million m^3 per year), and no action are the alternatives proposed. They used Social, Environmental, Technical, Economic, and Political criteria to make decisions about reservoirs, dams, and water resource management based on the outcomes of in-depth discussions with experts and stakeholders in these areas. According to Ciptomulyono (2010), Multiple Criteria Decision Making (MCDM) is a method for selecting the best possible course of action from among several potential courses of action, all of which must take into account more than one criterion simultaneously.

The AHP method is used in this research to rank alternatives in the context of a multi-criteria decision-making process. The AHP approach unites the subjective qualitative assessments of individuals into a group evaluation via pairwise comparisons of importance level. Simpler factors like AHP's ability to provide an evaluation mechanism for the consistency of results and its user-friendly software led to its selection. The fields of river basin planning, urban water planning, and water and environmental management are common examples of fields where AHP is used in decision-making. We will use the expert choice v.11 programs to do the math for this research.

LITERATURE STUDY

Multi Criteria Decision Making (MCDM)

Decision making is the study of identifying and selecting alternatives based on the values and preferences of decision makers. Those values and preferences are often influenced by the rules or corporate culture, law, best practices, etc (Harris, 2012; Masuo & Cheang, 2017). The decision-making process must be begun with the identification of decision makers and stakeholders, reducing the possibility of disagreement about problem definitions, requirements, goals, and criteria (Baker et al., 2002; Manager, 2017). Meanwhile, according to Ciptomulyono (2010), multicriteria decision making is an alternative selection process method to obtain optimal solutions from several decision alternatives which is considering into more than one criterias in the conflict situations.

Focus Group Disscusion (FGD)

FGD is a type of qualitative research methodology, which is defined as a structured and focused discussion with a small group of people, guided by a facilitator (moderator) to produce qualitative data through a series of open questions (Marczak & Sewell, 2007; Prince & Davies, 2001). FGD is an exploratory group discussion, which aims to develop and formulate a list of questions which are suitable for questionnaire surveys, especially in the absence of research on a particular topic and help in defining survey items clearly (Masadeh, 2012).

AHP

AHP is a method for decision making of various criteria, which is related to the way of someone resolves complex problems intuitively by deciphering them into simpler ones (Pwint, 2016; Saaty, 1980). AHP decision support model elaborate the complex multi-criteria problems into a hierarchy. Hierarchy is defined as a representation of a complex problem in a multi-level structure where the first level is a goal, then factor level, criteria, sub criteria, and the last level is an alternative. According to Ciptomulyono (2010), AHP has advantages, such as having the ability to synthesize the thoughts of various perspectives of respondent and able to calculate the consistency of the valuation which have been done in factors comparing to validate the decisions in addition, AHP also has the disadvantages, which is AHP must involves the people who have enough knowledge about the problem and about AHP itself. AHP cannot be applied to a very sharp or extreme difference in viewpoints among respondents.

Satty and Kearns (1985) provides a guide of steps to conduct AHP, which are: 1). Decomposition or hierarchical construction is to divide the problem into hierarchical manner. This step is to break down the problem into separate elements until the further solving is not possible, so we obtained several levels. 2). Comparative Judgment is to make an assessment of the relative importance of two elements at a certain level in relation to the upper level. Quantification of qualitative matters is done by providing a perception of comparisons scaled in pairs (pairwise comparison scale). Weighting a comparison matrix in pairs is using a comparison scale (fundamental scale) with a weight of 1 (equal importance) to 9 (absolutely very important). 3). Synthesis of Priority is each pairwise comparison matrix and search the Eigen vector to get the local priority. Because the pairwise comparison matrix is found at each level, then to get global priority it needs to be synthesized between local priorities. 4). Logical Consistency is the weighting of pairwise comparisons must meet the transitivity requirements.

Previous Researches

There are no specific previous studies discuss about the increase of reservoir volume. Several previous studies discussed about the planning and management of river basin in general. Research which has been conducted in the Brantas River Area (Japan Internation Cooperation Agency, 2017) states that the impacts which might occur as a result of increasing water supply in the Brantas River Basin, is related with the social environment, natural environment, and pollution. Azarnivand, Hashemi-Madani, and Banihabib (2015) in his research about water and environmental management set four criteria; economic, environmental, social, and technical. Xi and Poh (2015) in their research with the topic of sustainable water resources management in Singapore have established three criteria in the sustainability of water management in Singapore, which are water sufficiency, independence in water supply, and financing. Srdjevic and Medeiros (2008) in their research about assessment of water management plans have set five criteria, which are the impact of politics, economic issues, social issues, environmental, and technical criteria.

METHODOLOGY

The study of increasing storage volume in existing reservoir with a multi-criteria approach has not been proposed by other researchers yet. The previous literature mostly discuss about the study of water resources planning and management. In this research, the determination of criteria/sub-criteria will use the previous research about the planning and management of water resource. Because there was a gap between the previous research and current research, so the finalization of criteria/sub-criteria is conducted through the FGD by the experts in field of dam, reservoir and water resource management. AHP is used to determine the ranking of several proposed alternatives based on the criteria/sub-criteria of the FGD results. The steps of this research will be shown in Figure 3.

Preliminary Study

The preliminary study was intended to determine the current problems and conditions of the Sutami reservoir. The researcher conducted interviews and in-depth discussions with several experts of reservoirs, dams, and management of water resources.

Research Problems and Aims

The problem in this research is to determine the order of priorities for proposed alternative actions to increase the volume of storage of the Sutami Reservoir. The purpose of this study is to determine the priority order of proposed alternative actions in order to increase the volume of storage of the Sutami Reservoir.

Field Observation

Some steps are needed to collect the information related in this part. Those steps are a) Identification and Inventorying conditions of Sutami reservoir, and b) Identification and Inventorying of sediment handling.

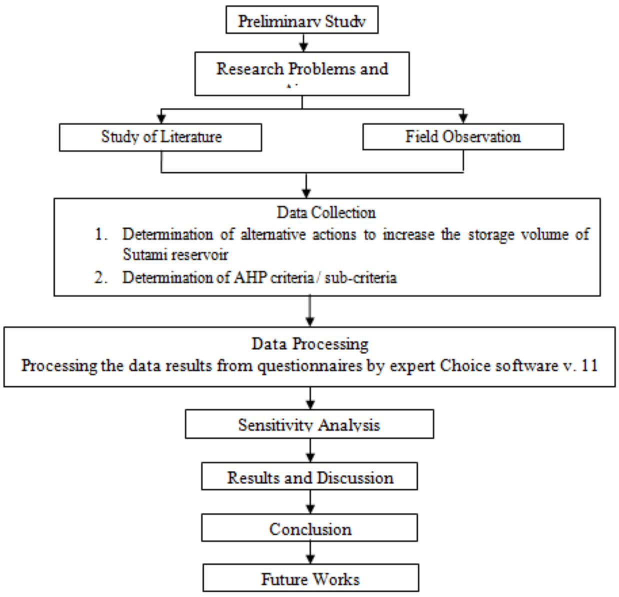

Figure 4. Research methodology

In this part, we conducted the identification of dam conditions, spill structure, and catchment area to assess the suitability of the proposed alternative actions. Next, is to identify the sediment handling methods, sediment disposal sites (spoilbank), and assessing the effectiveness of the handling which has been done so far.

RESULTS AND DISCUSSION

Based on the results of field observations, the existence of the Sutami reservoir has a positive impact on the livelihoods of the local population and increase the economic environment around community. Therefore, the existence of the Sutami reservoir needs to be maintained. Based on the observations in the environment of the Sutami dam and reservoir, the proposed of heightening of the dam body and spill structure is possible as long as the technical aspects are fullfilled. There will be an obstacle if the alternatives of dredging sediments conducted continuously in terms of limitation of the spoilbank area. Based on the results of in depth interviews with PJT1 experts, it was concluded that the estimated sediment inflow of Sutami reservoir will gradually increase from 2 million m^3/year to 4.85 million m^3/year.

Data Collection

Determination of alternative actions to increase the storage volume of Sutami reservoir

Based on the literature study and in depth interviews, proposed alternatives actions to increase the volume of Sutami reservoir are shown in Table 1 below.

Table 1: Alternative research

No.	Alternative	Definition	Reference
1	Heightening of the dam body	Heightening of the dam body by 5m with adjustments the overflow construction (spillway)	Japan International Cooperation Agency (2017)
2	Heightening the spillway	Heightening of the spillway by 0.5m (including the sluice gates and all of the equipment)	In depth Interview
3	Dredging the sediments	Dredging the sediments ± 2 million m^3/year to 4.85 million m^3/year (expectation of sediment inflow in reservoir)	Japan International Cooperation Agency (2017)
4	Status Quo	Dredging the sediments around ± 0.4 million m^3/year as currently doing by PJT1.	In depth Interview

Determination of AHP criteria/sub-criteria

Based on the results of previous studies (Azarnivand et al., 2015; Japan International Cooperation Agency, 2017; Srdjevic & Medeiros, 2008; Xi & Poh, 2015), we obtained 5 criterias and 32 sub-criterias. These results were further discussed by experts to FGD forum. The selection of FGD participants was based on purposive sampling of experts with a minimum education of Master Degrees and had at least 10 years experience in the fields of reservoirs, dams and water resources management. The forum with 10 experts decided to use criteria/sub criteria as summarized in the following Table 2.

Table 2: Criteria/sub kriteria of AHP

No	Criteria	No	Sub criteria
1	Social	S1	Community acceptance
		S2	Existing infrastructure and social services
		S3	Land use and location resources
		S4	Recreation facilities and tourism
2	Environment	L1	Preservation of cultural values
		L2	Flora, Fauna and Biodiversity
		L3	Pollution
		L4	Sediment waste

Table 2: Continue

No	Criteria	No	Sub criteria
3	Technical	T1	Clean Technology use
		T2	Simplicity of technology
		T3	Reliability of water supply
		T4	Ease of technical improvement
4	Economy	E1	Jobs and Occupation Availability
		E2	Intangible benefit/cost ratio
		E3	Simplicity of operation and maintenance
		E4	Ease of Financial

Weighting of criteria, sub-criteria, alternatives through AHP questionnaires

Assessment of criteria, sub criteria and alternative weights was obtained by conducting the questionnaires distribution survey to experts and stakeholders. Each respondent was asked to provide an assessment or perception of the importance of each element that compared by using the Saaty scale of 1 to 9. The selection of survey respondents was based on purposive sampling of experts and stakeholders. Based on the result of 15 questionnaires distribution directly or by email, 10 respondents returned the questionnaire according to the deadline, 2 respondents passed the deadline, and 3 respondents did not answer. Out of 10 respondents who returned the questionnaire on time, 4 respondents filled in according as required, but 6 respondents did not complete the questionnaire and/or did not meet the AHP transitivity requirements. Based on that result, the calculation in AHP data processing is only a questionnaire from 4 respondents with the following data:

• Respondent1: Master Degree of Civil Engineering Education, 16 years work experience in the field of Water Resources management, reservoirs, dams.

• Respondents 2: Masters Degree in Civil Engineering, 40 years of work experience in the field of water resources management, reservoirs, dams.

• Respondent 3: Masters Degree in Civil Engineering 23 years of work experience in the field of water resources management, reservoirs, dams.

• Respondents 4: Bachelor Degree of Mechanical Engineering 32 years work experience in field of civil construction, property development, water resources management supervision.

Data Processing

To avoid manual calculation errors, previous researchers used software to process data from the result of AHP pairwise comparisons (Erdogan, Šaparauskas, & Turskis, 2017). Maletič, Maletič, Lovrenčić, Al-Najjar, and Gomišček (2014) stated that Expert Choice software allows sensitivity analysis of very important results in decision making. In this research, the data processing of pairwise comparisons from questionnaire result has been conducted by using Expert Choice software v. 11 and the result shown in the Figure 5.

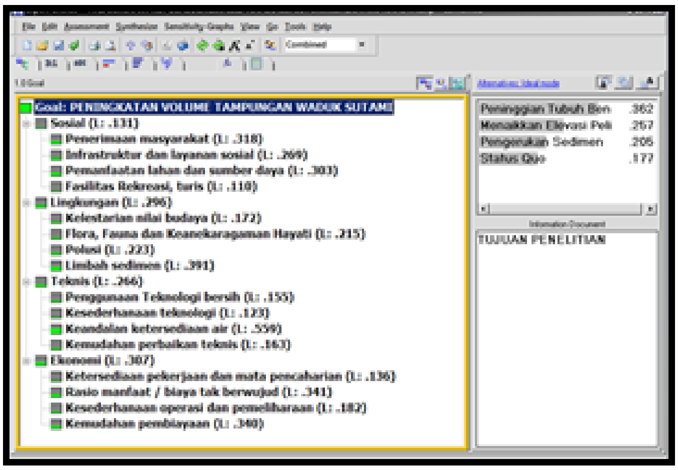

Figure 5. AHP weighting results

Weighting Criteria for Increasing the Storage Volume of Sutami Reservoir

Based on the Figure 6, we can see that the overall or aggregate weight of each criterion in order to increase the storage volume of Sutami reservoir as shown in Figure 6.

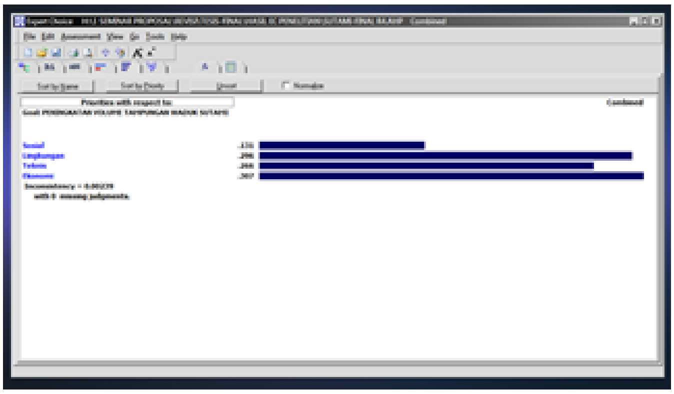

Figure 6. Research methodology

The consistency index of pairwise comparisons for each criteria is 0.003 or below 10%, which means it meets AHP transitivity requirements and is acceptable. The social criteria get a weight of 13.1%, Environmental criteria weight is 29.6%, while the Technical and Economic criteria weights are 26.6% and 30.7% respectively. Based on this result, the total weight of all criteria is 100%.

These results indicate that the assessment unity of the respondents considers the Economic criteria are the most influential in increasing the volume of storage of the Sutami reservoir with a weight of 30.7%.

The Order of Alternative Weights Increases the Storage of Sutami Reservoir

This part is the calculation of the overall weight or aggregate for each alternative from the results of weighting pairwise comparisons as shown in Figure 7.

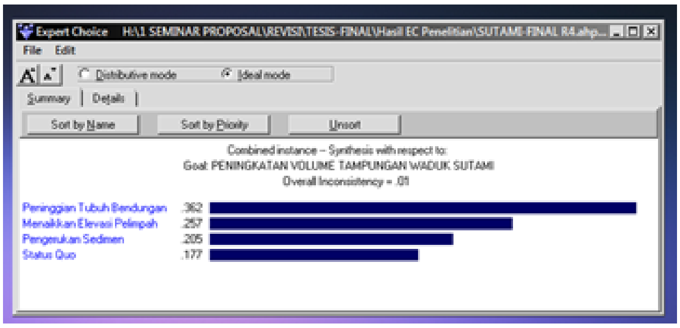

Figure 7. Weight of alternative AHP results

The consistency index of the pairwise comparisons for each alternative in Figure 7 is 0.01 or 1%, which means is good and acceptable. The alternative of heightening the dam body weight is 36.2%, the alternative of heightening the spillway weight is of 25.7%, while the alternative of dredging sediment and status quo are 20.5% and 17.7% respectively. Based on this result, the total weight all alternatives is 100%.

Sensitivity Analysis

Sensitivity analysis is to determine the sensitivity of the priority sequence chosen due to changing of the criteria. The researcher as a facilitator and stakeholder has the right to choose one of the criteria that is considered important as a test tool. The researcher chosed an economic criteria as a test tool with the consideration of having the greatest weight compared to the other criterias. Changes in the weight of economic criteria are shown in

Figure'8 to IV.4c respectively. In the initial conditions, heightening the dam body is the alternative with the highest priority order (36.2%). The weight of the economic criteria is 30.7% (Figure 8).

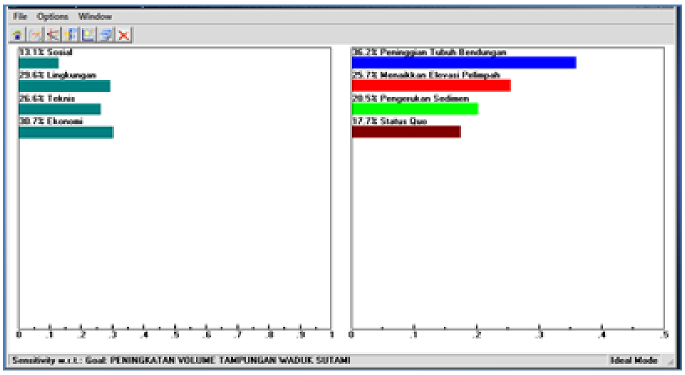

Figure 8. Sensitivity test for economic criteria

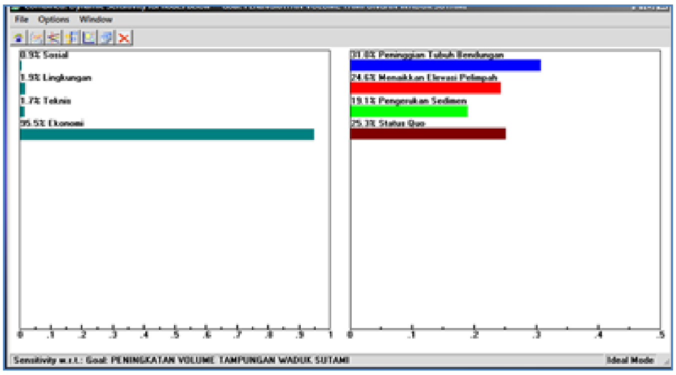

Figure 9. Sensitivity test for increasing the economic criteria

In Figure 9, the testing is done by increasing the economic criteria until approaching the maximum value of 95.5%. It turns out that heightening of the dam body alternative has decreased from 36.2% to 31% and the alternative of status quo has increased from 17.7% to 25.3%. The alternative of heightening the spillway and alternative of sediments dredging also decreased, but were not too significant.

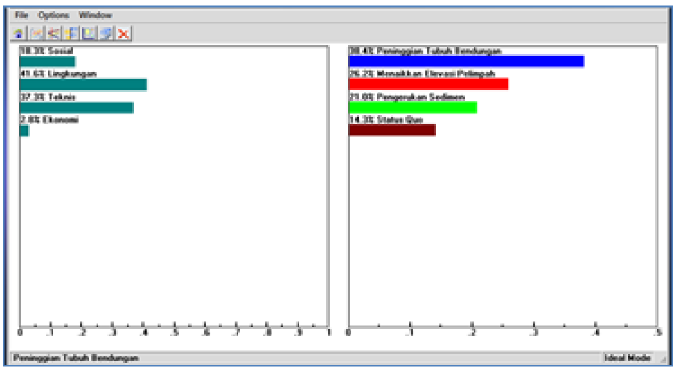

Figure 10. Sensitivity test for reducing the economic criteria

Next, by reducing the weight of economic criteria until approaching the minimum 2.8% (Figure 10), the alternative of heightening of the dam body increased from the original position of 36.2% to 38.4%. From various tests the position by increasing and decreasing of economic criteria weight apparently did not affected the order of alternative priority, which is the alternative of heightening of the dam body remained the highest position. Based on this result, it can be concluded that the order of priority of heightening of the dam body is insensitive with the changing of economic criteria weight both raised and lowered.

Alternative actions in order to increase the storage volume of Sutami reservoirs were obtained from literature study and in depth interviews with experts in reservoirs, dams, and management of water resources. The criteria/sub criteria for pairing comparisons are the results from the FGD consensus by experts based on previous research. Weighting data of pairwise comparison is obtained from the results of fill out the questionnaires by the experts and stakeholders then processed using expert choice v.11 software. Data processing consistency index is below 10%, which means good and acceptable. The results of the sensitivity analysis show that the weighting of economic criteria does not affected the order of alternative priorities. The sensitivity test of economic criteria can be interpreted as how much influence the economic criteria to the order of alternative priorities if there are an economic issues which make the decision makers change the weight of their assessment in economic criteria. Based on the results of processing the data above, we can summarize the global weight of the proposed alternative actions sorted by priority weights from the highest to the lowest as shown in Table 3.

Table 3: Global weight of each alternative

No	Altenative	Weight	Ranking
1	Heightening of the dam body by 5m	0.362	1
2	Heightening the spillway by 0.5m	0.257	2
3	Dredging the sediments as much as inflow volume	0.205	3
4	Status Quo	0.177	4

CONCLUSION, RECOMMENDATIONS AND IMPLICATIONS

The purpose of this study is to determine the best priority order for the proposed alternative actions to increase the storage capacity of Sutami reservoir. Economic criteria have the highest weight compared to Technical, Environmental and Social criterias. The order of results on alternative priority weights is not affected by the sensitivity test of economic criteria. The results showed that the alternative of heightening the dam body by 5m (36.2%) is a top priority compared to other alternatives. The alternatives heightening the spillway by 0.5m is the second priority (25.7%), alternative sediment dredging as much as sediment inflow volume is the third (20.5%) and the last priority is stastus quo (17.7%).

FUTURE WORKS

1. The research that aims to extend the lifespan of existing reservoirs needs to be supported by all parties and needs to be developed by other researchers. AS we known, all reservoirs will have a limited lifespan and eventually will be closed. The cost of closing and maintaining old reservoirs that does not work are not cheap. In the other hand, the cost of constructing new dam is also not cheap and uncertainly there are the locations which meet the requirements.
2. The number of criteria and sub-criteria used is kept to a minimum, as long as they cover important issues related to local problems. Too many criterias and sub-criterias (within certain limits) will cause respondents to be reluctant to fill out the questionnaire, the assessment will not focus, so the results do not meet the requirements.
3. Conclusion of this research was based on the results of the 4 valid questionnaires. In further research it is expected that more questionnaire results will be taken into account in ahp's calculations.

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