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Decision Support System for flood management in Batang Arau river basin

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Abstract. Flood is one of the most vulnerable disasters in Indonesia. Batang Arau river basin is located in the West Sumatra province, which is one of the areas that often experience the flood. Since 1894, a number of measures have been taken to control flooding in the Batang Arau river basin. However, until now, the incidence of flooding is still not appropriately resolved. The aim of this study is to identify the areas that had the worst impact due to flood events in the Batang Arau river basin over the past 10 years and then identify the leading causes of the flood event. After that, the Decision Support System (DSS) was carried out using the Analytical Hierarchy Process (AHP) method to determine the suitable measures both structural and no structural for flood control in the Batang Arau. In order to achieve these objectives, data was taken in the form of; the historical flood event over past 10 years, the factors causing flood events based on field observations and review studies, and Measures to control flood events according to experts. So that the results of this study will be able to describe short-term and long-term for flood management, which are adaptable for future flood management strategy.

1 Introduction

Batang Arau river, West Sumatra is one of the most flood-prone areas. It can be seen on the following map, which Fig.s out the new situation in the Batang Arau river basin and other river basins in Padang city. The factors which can cause flooding in this basin, are not only due to heavy rains, but also triggered by increasing the population growth, the climate, and the land-use change and others. However, this combination of factors leads to flooding occurs.

Batang Arau river basin has an area of 174.5 km square. Geographically, the Batang Arau river basin is located at 0º48 "- 0º56" LS and 100º21 "- 100º33" BT with elevations from 0 - 1,210 m above sea level. The upstream part is in Lubuk Kilangan Subdistrict. Geographically, Lubuk Kilangan Subdistrict is located between 0 ° 58 '4 " LS and 100 ° 21 '11 " East Longitude, altitude 25-1,853 m above sea level, with an area of 85.99 km2. Air temperature ranges from 24º C - 31.5ºC with humidity ranging from 50% - 75%. Batang Arau River has a river length of ± 29.72 km from upstream to downstream. Batang Arau topography is dominated by steep to very steep slopes. This is because the degree of slope of the river basin slopes is getting more upstream, so the surface water flow velocity will be higher towards the river basins. The Batang Arau river basin is slightly oval in shape. The upstream river basin of the Batang Arau river basin is similar to the bird feather pattern, which means that water flowing from the tributaries enters the main river, but the flood discharge is small because the time of arrival of the streams varies.

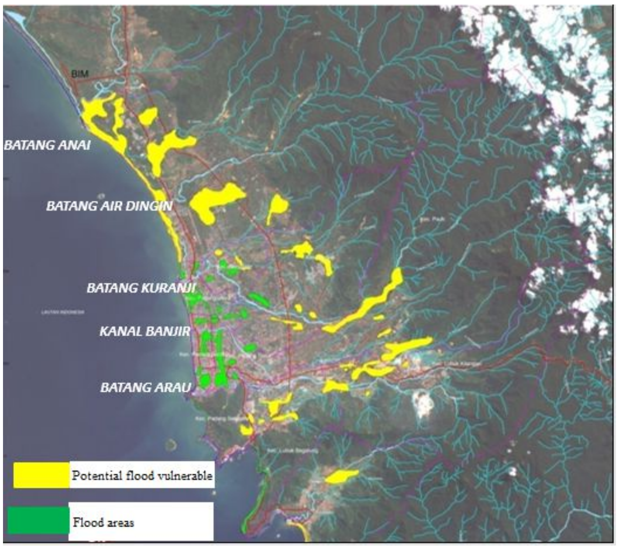

Fig. 1. Flood vulnerable areas.

On last November 2nd, 2018, there was a flash flood occurred in the Batang Arau river basin. It caused two fatalities, one bridge was broken, and one house was washed away, during heavy rain. This event was the worst event from the last 10 years, which create fatalities and damage in infrastructures. Based on this phenomena, the study is aimed to identify and analysis of Decision Support System using Analytical Hierarchy Process (AHP) method for integrated flood management in the Batang Arau river basin which can be implemented in the near future.

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This study aims to identify the worst affected areas of the flood along the Batang Arau river basin, to identify the causes of flooding that have threatened the Batang Arau river basin lately, to inventory current flood control and evaluate compliance with existing conditions, and to develop a flood measures strategy with the AHP decision making system.

The result of the research is beneficial as information and consideration for the Padang City government in planning the direction of spatial use, as information on flood disaster management models in the Batang Arau river basin and as information for future research.

2 Decision Support System

Decision Support System (DSS) is proposed to help the decision-makers in recognizing problems and then formulating supporting data for the purposes of problem analysis. The action taking DSS to facilitate one or all phases of decision making regarding the process runs effectively and efficiently (Sozer, Kocaman, Nefeslioglu, Firat, & Gokceoglu, 2018). DSS is expected to assist management in decisions making strategic on flood management in the Batang Arau river basin.

A method that can be used as a supporter of DSS is the Analytical Hierarchy Process (AHP) method, where the AHP is a decision support model developed by Thomas L. Saaty (Saaty, 1990). This decision support model will describe multi-factor problems or complex multi-criteria into a hierarchy (Saaty & Ergu, 2015). According to Saaty, hierarchy is defined as a representation of a complicated issue in a multi-level structure where the first level is a goal, followed by a factor level, criteria, sub-criteria, and on the last level of the alternative. With hierarchy, a complex problem can be broken down into groups which are then organized into a hierarchical form so that the problem will appear to be more structured and systematic. In the AHP method, the problem will be described in the form of a hierarchy as follows:

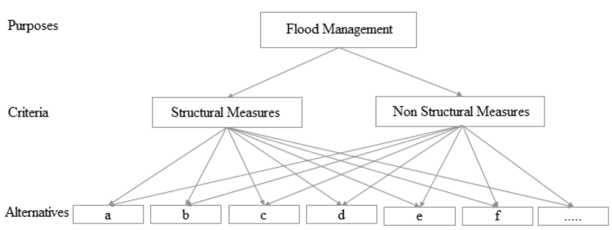

Fig. 1. Hierarchy AHP chart.

By using the decision-making system of the AHP method, a strategy that is a priority for the short-term and long-term floods will be obtained in the Batang Arau river basin. The steps in using the AHP method are as follows (Kadarsah Suryadi, Ali Ramdani, 1998; Aznur, 2017):

1. Defining the Problem. In this stage, it was tried to determine the problem that will be solved clearly, in detail, and easily understood. From the problem, it was attempted to establish a solution that might be suitable for the challenge. Solutions for issues could be more than one. Furthermore, it will be developed these solutions for the next stage.

2. Making a hierarchical structure. After arranging the main goal as the top level, a hierarchy level will be organized below that which is the appropriate criteria to consider or assess the alternatives it is provided and determined the other options. Each approach has a different intensity. The hierarchy is followed by sub-criteria (if possible).

3. Create a Pairwise Comparison Matrix. The advantage of the AHP method is its ability to combine qualitative and quantitative elements. Quantitative things that are qualitative in nature are carried out by providing a perception of comparison scaled in pairs (pairwise comparisons scale). A person who will deliver these perceptions must understand thoroughly the elements that are compared and their relevance to the intended purpose.

According to Saaty, the scale of the comparison can be seen in the following table:

Table 1. Comparison Scale According to Saaty

Intensity of Interest	Information
1	Both elements are equally important. Two factors have the same effect
3	One element is a little more important than the other aspects, Experience and judgment support a single part slightly compared to the other elements
5	One element is more important than the other, Experience and judgment actively support one aspect compared to the other
7	One element is clearly more important than other factors, one strong factor that is supported and dominant is seen in practice
9	One element is absolutely essential than the other aspects, Evidence that supports one issue against another has the highest degree of affirmation that might strengthen
2,4,6,8	Values between two values are contiguous considerations; This value is given if there are two compromises between the 2 reverse choices = If for the activity i get one number compared to activity j, then j has the opposite value compared to i

Calculation of Element Weight

The calculation process is done using a paired matrix, as seen in table 2. Filling a_{12} values uses the following rules:

• If $a_{12} = \alpha$, then $a_{21} = 1 / \alpha$

• If between operating elements A_1 and A_2 have the same level of importance, the value of $a_{12} = a_{21} = 1$.

• Value of $a_{12} = 1$ for 1 = 2 (diagonal matrix has a value of 1).

Table 2. Preference comparison matrix

	A_1	A_2	....	A_n
A_1	1	a_{12}	....	a_{1n}
A_2	$1/a_{12}$	1		a_{2n}
....	....	....	1	....
A_n	$1/a_{1n}$	$1/a_{2n}$	....	1

Consistency and Priority Vector Calculations.
This calculation is analyzed using the following equation:

$$CI = \frac{\lambda\ maks - n}{n - 1}$$

Where: max λ = maximum eigenvalue N = matrix size The Consistency Index (CI) in the equation written above is a random matrix with a rating scale of 9 (1 to 9) along with the opposite as a random index (RI). RI has the values specified in table 3 depending on the number of matrix sizes compared (Taylor, 1999)

Table 3. Random Index Value RI (Taylor,1999)

Matrix	Index of Random/RI (Inconsistency)
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

The comparison between CI and RI for a matrix is defined as a Consistency Ratio (CR), as the following equation:

$$CR = \frac{CI}{RI}$$

For the AHP model, a comparison matrix is accepted if the value of the consistency ratio is < 0,1.

3 Research Methodology

The research methodology begins with the identification of problems according to determined data. Data collection is divided into two; primary data from questionnaires which filled out with direct interviews with respondents. This interview was conducted on two parties experts related to water disaster and management, and communities who are living in Baringin, Lubuk Kilangan Sub-district. Secondary data, data on flood events obtained different resources from the local and national governments *(BAPPEDA, BWS, and PSDA*), i.e., Rainfall, discharge, land use, map, historic flood event. The flood events were evaluated using suitable flood management indicators, and give the value on each sign as AHP essential reference. Primary data were taken from local societies who directly impacted by flood on last November 2nd, 2018, and also from a number of experts in flood management.

4 Result and Discussion

4.1 Historical of flooding

After collecting information from the number of resources, flood events along the Batang Arau river basin can be presented as follows in table 4.

Table 4. Historical flood events

No	Date	Impacted areas (district)	Damages
1	November 2nd, 2018	Lubuk Kilangan Lubuk Begalung Padang Selatan Padang Timur Padang Barat Teluk Bayur	2 bridges destroyed 37 houses inundated 1 fatality Flood reach up to 150cm
2	September 26th, 2018	Padang Selatan	Flood reach up to 80 cm
3	September 09th , 2017	Lubuk Kilangan Lubuk Begalung Padang Selatan Padang Timur Padang Barat	Flood reach up to 60 cm
4	May 31st, 2017	Lubuk Kilangan Lubuk Begalung	2 bridge destroyed Landslide 2 houses destroyed Cemetery destroyed 200 homes inundated
5	May 21st , 2017	Padang Selatan	6 sub-districts inundated Flood reach up to 150 cm
6	June 17th, 2016	Lubuk Begalung Padang Selatan Padang Timur Padang Barat Teluk Bayur	Electricity destroyed Flood reach up to 140 cm Public services
7	November 21st, 2015	Lubuk Begalung	Flood reach up to 100 cm
8	November 12th, 2015	Lubuk Kilangan Lubuk Begalung Padang Selatan	92 houses inundated 1 house destroyed by a landslide
9	October 19th, 2013	Lubuk Kilangan Lubuk Begalung Padang Selatan Padang Timur Padang Barat	1500 houses inundated Flood reach up to 150 cm
10	July 24th 2012	Lubuk Kilangan Lubuk Begalung	Flash flood and land slide
11	March 26th , 2010	Lubuk Begalung Padang Timur	Flood reach up to 70 cm

According to the history of flood events from the last 15 years, the Batang Arau river basin belongs to the flood-prone areas. Lubuk Kilangan is the most and frequent affected by flash floods. The flood caused, fatalities, injuries, destroyed of the public facilities, disturbed the public services including the local transportation. The worst situation has been found the highest level of flood reached up till 150 cm. A number of structural and no structural measures have been taken to mitigate the flood risk. However, flood still occurs in almost every year.

4.2 The causes of flood

1. Land use

The land uses in Batang Arau river basin are classified into 6 such as forest, plantation, agriculture, land clearing including bushes, settlement, and mining. Identification of change in land use starts from 2000 until 2016. Based on the following table 5, a significant change has been found in the forest, from 5162 ha decrease to 3024 ha. Meanwhile, the settlement has a substantial change within 15 years from 42 ha increase

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to 3076 ha, plantation and agriculture also increase significantly.

Table 5. Changes in Arau Basin Land Use Code

Land uses	**Area (Ha)**				**Total change, Ha**
	2000	2006	2009	2016	
Forest	5162	4699	2462	3024	-2138
Plantation	346	724	5598	2262	1916
Agriculture	305	266	1377	1990	1685
Land clearing	83	191	21	194	111
Settlement	42	86	2319	3076	3034
Mining	170,6	181,8	106,4	189,2	18,6

4.2 Flood Measures

By comparing the results of interviews and references from books (J. Kadoatie, 2005), the primary indicators are determined to be a factor for flood control. After matching the suitability of the control effort to the circumstances that occur, the data obtained are as follows:

Table 6. Flood Measures

No.	Measures
a	Carry out emergency response evaluations
b	Record damage to facilities and infrastructure, water resources, environmental destruction, loss of life, and estimated losses incurred
c	Plan and implement recovery programs
d	Evaluate flood characteristics for adjusting future flood predictions
e	Prioritized development implementation
f	Widening and dredging of rivers
g	Making flood control buildings
h	Operation and maintenance of flood control buildings
i	Review of forest management systems upstream and land use
j	Throw garbage in its place
k	Forest planting again
l	Performs arrangements for areas around the river
m	Mapping areas prone to flooding and landslides
n	Training and education for the community are ready to flood
o	Evaluate with local residents regarding flood events
p	Prepare the evacuation process through education
q	Coordinate with the local area to plan the actions needed in flood control

Furthermore, based on the listed data, from the data on flood management for the short and long term is grouped again into structural and non-structural measures. After that, the weighting is carried out for each of them to determine the priority measures of each group using the AHP method. Which can be seen in the following table:

a. From the previous weighting data, we do the calculation of each paired matrix alternatively

Table 7. The paired matrix of short-term flood management based on the non-structural measure.

		a	b	c	j	m	o
		6	5	8	4	9	7
a	6	6/6	6/5	6/8	6/4	6/9	6/7
b	5	5/6	5/5	5/8	5/4	5/9	5/7
c	8	8/6	8/5	8/8	8/4	8/9	8/7
j	4	4/6	4/5	4/8	4/4	4/9	4/7
m	9	9/6	9/5	9/8	9/4	9/9	9/7
o	7	7/6	7/5	7/8	7/4	7/9	7/7

Table 8. The paired matrix of long-term flood management based on the non-structural measure.

Alterna - tives		d	h	i	k	l	n	p	q
	Weight value	8	2	6	1	7	5	7	9
d	8	1,0	4,0	1,3	8,0	1,1	1,6	1,1	0,9
h	2	0,3	1,0	0,3	2,0	0,3	0,4	0,3	0,2
i	6	0,8	3,0	1,0	6,0	0,9	1,2	0,9	0,7
k	1	0,1	0,5	0,2	1,0	0,1	0,2	0,1	0,1
l	7	0,9	3,5	0,3	7,0	1,0	1,4	1,0	0,8
n	5	0,6	2,5	0,8	5,0	0,7	1,0	0,7	0,6
p	7	0,9	3,5	1,8	7,0	1,0	1,4	1,0	0,8
q	9	1,1	4,5	1,5	9,0	1,3	1,8	1,3	1,0
Total		5,6	23	6,7	45	6,4	9,0	6,4	5,0

Table 9. The paired matrix of long-term flood management based on the structural measure.

Alternatives		f	g
	Weight value	3	4
f	3	1,00	0,75
g	4	1,33	1,00
Total		2,33	1,75

b. Normalization Calculations and Average Normalization of the Criteria Matrix

Table 10. Normalization of short-term flood management based on the non-structural measure.

Alternative Matrix							**Mean of alternative matrix**
	0,6	0,2	0,2	0,2	0,2	0,2	0,15
	0,1	0,1	0,1	0,1	0,1	0,1	0,13
	0,2	0,2	0,2	0,2	0,2	0,2	0,21
	0,1	0,1	0,1	0,1	0,1	0,1	0,10
	0,2	0,2	0,2	0,2	0,2	0,2	0,23
	0,2	0,2	0,2	0,2	0,2	0,2	0,18
or	1,0	0,8	1,3	0,7	1,5	1,2	
	0,2	0,1	0,2	0,1	0,2	0,2	

Table 11 Normalization of long-term flood management based on the non-structural measure.

Alterna-tive Matrix									**Mean of alternative matrix**
	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,16
	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,1
	0,1	0,1	0,2	0,1	0,1	0,1	0,1	0,1	0,14
	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,02
	0,2	0,2	0,1	0,2	0,2	0,2	0,2	0,2	0,14
	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,11
	0,2	0,2	0,2	0,2	0,2	0,2	0,1	0,2	0,16
	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,20
or	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	
	0,2	0,1	0,1	0,0	0,1	0,1	0,2	0,2	

Table 12 Normalization of long-term flood management based on the structural measure.

Alternative matrix			**Mean of Alternative matrix**
	0,43	0,43	0,43
	0,57	0,57	0,57
or	1,00	1,33	
	0,43	0,57	

c. Consistency Value of Random Index (RI)

In this discussion, a test of the highest concentration value is carried out in one matrix table, because if the method is the same, then the resulting consistency value will be the same. The following is the calculation of the value of consistency for short-term flood control in the form of non-structural handling.

- First, the weight values of each alternative are multiplied by the average normalized matrix

Table 13. The weight values of each alternative multiplied by the normalization matrix

Alternative	a	b	c	j	m	o	Sum
a	0.15	0.18	0.11	0.23	0.1	0.13	0.90
b	0.11	0.13	0.08	0.16	0.07	0.09	0.65
c	0.28	0.34	0.21	0.42	0.19	0.24	1.67
j	0.07	0.08	0.05	0.1	0.04	0.06	0.40
m	0.35	0.41	0.26	0.52	0.23	0.3	2.06
o	0.21	0.25	0.16	0.32	0.14	0.18	1.25

- Calculate the value of consistency by comparing the amount with the average value of the alternative matrix normalization

Table 14. Consistency value

Alternative	Weight of priority	Consistency value
a	0,90/0,15	6.00
b	0,65/0,13	5.00
c	1,67/0,21	7.95
j	0,40/0,10	4.00
m	2,06/0,23	8.96
o	1,25/0,18	6.94
Mean of consistency (λ)		6.48

- Calculate the CI value

$$CI = \frac{\lambda maks - n}{n - 1}$$

$$CI = \frac{6,48 - 6}{6 - 1}$$

$$CI = 0,096$$

Calculate the CR value as Known RI = 1,24

$$CR = \frac{CI}{RI}$$

$$CR = \frac{0,096}{R1,24}$$

$$CR = 0,08$$

$0,08 \leq 0,1$ then a consistent value can be received so that the results of matrix normalization can be used.

If the value is consistent > 0.1, it is necessary to do a re-evaluation when performing a paired matrix calculation.

d. Ranking of Flood management on Priority Scale

Table 15. Priority scales for short-term flood management for non-structural measure

Alternative	Weight	Description
m	0,23	Mapping areas prone to flooding and landslides
c	0,21	Plan and implement recovery programs
o	0,18	Evaluate with local residents regarding flood events
a	0,15	Carry out emergency response evaluations
b	0,13	Record damage to facilities and infrastructure, water resources, environmental destruction, loss of life, and estimated losses incurred
j	0,10	Throw garbage in its place

Table 16. Priority scales for long-term flood management for non-structural measure

Alternative	Weight	Description
q	0,20	Coordinate with the local area to plan the actions needed in flood control
d	0,18	Evaluate flood characteristics for adjusting future flood predictions
p	0,16	Prepare the evacuation process through education
i	0,14	Review of forest management systems upstream and land use
l	0,14	Performs arrangements for areas around the river
n	0,11	Training and education for the community are ready to flood
h	0,05	Operation and maintenance of flood control buildings
k	0,02	Forest planting again

Table 17. Priority scales for long-term flood management for structural measure

Alternative	Weight	Description
g	0,57	Making flood control buildings
f	0,43	Widening and dredging of rivers

From each of the ranking results of the flood management on the priority scale, it can be seen that the priority of each flood measure is:

a. Priority scales for short-term flood management for non-structural action is to create the maps for flood-prone areas and landslides

b. Priority scales for short flood management for the structural measure is the prioritized implementation of development

c. Priority scales for long-term flood management for the non-structural measure is to coordinate with the local area to plan the actions needed in flood control.

d. Priority scales for long-term flood management for the structural measure is to construct the flood protection buildings, e.g., dike

5. Conclusion

From the DSS study of the AHP method for management of the Batang Arau river basin, conclusions can be drawn as follows:

1. Based on flood events, it can be seen that the area along the Batang Arau river basin is prone to experiencing flood events. However, the Lubuk Kilangan area became the most affected area of floods in the last 10 years, with a total of 5 flood events and losses of broken bridges due to 3 floods.
2. The results of the analysis of land use data in the Batang Arau river basin area, it can be seen that the most significant land change occurred in the decrease in the field of Forest land by -2137.60 Ha. From the calculation of the 10-year return period flood discharge, the Q10 value is 768.94 m^3/s. Meanwhile, based on the data on November 02, 2018, the flood discharge that occurred has exceeded the Q_{10} discharge rate, Q = 1421,8 m^3/s.
3. Based on the existing flood control, there were 17 indicators been chosen as the priority for controlling the Batang Arau river basin against floods, which was then grouped based on short-term and long-term periods.
4. After conducting the DSS analysis using the AHP method, it is known that in the short term flood control, which is a priority in non-structural measures, it is a mapping of areas prone to flooding and landslides with a weighting of 23%. Whereas in the structural action, there is only one indicator that becomes a priority, i.e., the implementation of priority development. Then the priority for the long-term period of non-structural is coordination with the local area to plan the actions needed in flood control with a weighting of 20%, and non-structural handling is to create a flood protection building with an exciting weight of 57%.

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