



**THE COMBINATION FLOOD LAKE CHARACTERISTICS AND SIH3
(HYDROLOGY, HYDROMETEOROLOGY, HYDROGEOLOGY
INFORMATION SYSTEM) TO BUILD AN EARLY WARNING MODEL
FRAMEWORK**

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Abstract

The plains of the Mahakam Cascading Lakes (MCL) are prone to annual flooding during the rainy season. One of the first steps in disaster risk reduction planning is to analyse the flood characteristics (FCs) of lakes and building of a model framework for an early warning system (EWS). As such, this study examined efforts to build a framework for a flood EWS by combining the FCs of the MCL with the Hydrology, Hydrometeorology, and Hydrogeology Information System (SIH3). A spatial descriptive approach was employed to analyse the FCs of the lakes using topographical data of the lake and the area surrounding the central Mahakam watershed as well as data on the lake drainage system. The EWS was analysed using the SIH3 based on an automatic water level recorder (AWLR) and automatic weather system (AWS). This system was also combined with the FCs of lakes and community experiences with lake floods. According to a topographical analysis, a bottleneck exists in the southeastern part of the central Mahakam area, which is causing the waters of the Mahakam, Belayan, Kedang Kepala, and Kedang Rantau rivers to be retained in the central Mahakam basin area, thereby causing flooding in the lake. In addition, the hydrographic model and community knowledge indicate that there is a backflow of water due to the presence of a bottleneck. The integration of the change in the water level system from the AWLR and precipitation fluctuations from the AWS at all the gauges in the upper central Mahakam, lower central Mahakam, and Mahakam tributaries can form a framework for an EWS connected to the Disaster Management Agency (BPBD). The EWS can help the community prepare for disaster mitigation and reduce the risk of lake flood disasters.

Keywords: Cascade Mahakam, Disaster Risk Reduction, Early Warning Framework, Flood Plain Lake, Flood

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INTRODUCTION

The Mahakam Cascading Lakes (MCL) flood almost every year. Extreme floods, such as those that occurred in 2005 and 2007, have been documented since 1989 due to variations in high water levels (Dam & Lake Work Unit, 2021). Lake water dynamics also affect the lake area, which is only about 30000 Ha under normal circumstances, but reached 115000 Ha during the 2005 flood and 213000 Ha during the 2007 flood (BWS Kalimantan IV, 2019). Extreme floods often caused losses to the community, especially those living in the Kota Bangun District area, which is the second most populous urban area in Kutai Kartanegara Regency. Based on data from the BNPB, the 2007 flood submerged 213576 houses, 4563 educational facilities, and 547 health facilities (BNPB, 2024).

The MCL are susceptible to flooding even in the absence of precipitation due to the influence of adjacent rivers on variations in the water levels of the lakes. Factors in the hydrological network connecting the rivers and lakes have a major impact on floods in the floodplains of the lake areas (Baker, 1994). Studies on flood characteristics (FCs) have mostly only looked at this issue mathematically (Bachri et al., 2021; Lei et al., 2020; Wang, 2021) together with the evolving lake shape (Papaioannou et al., 2021). Apart from that, studies still need to be carried out on the FCs of floods that occur in the floodplains of the lakes in terms of the morphology of the lake area and the water flow system in the lake. The FCs of lakes can be the basis for the building of an early warning system (EWS).

East Kalimantan started developing the Hydrology, Hydrometeorology, and Hydrogeology Information System (SIH3) in 2023. One of the priorities of this system was to build an EWS for floods. The SIH3 has the most recent data on water levels, groundwater conditions, and climatology (precipitation, temperature, wind speed, relative humidity, and solar radiation). An EWS for floods, such as for the MCL, can be determined using climatological and water level data. However, an EWS for lake floods influenced by inlets and backflows does not exist as yet, and so, there is a need to develop for an EWS framework for floods that accommodates these conditions.

Meanwhile, the flood EWS that pays attention to backflows is still rarely used, especially for floods in the lake floodplains. Indonesia has the Indonesian National Standard (SNI) 8840-3:2022 Flood Early Warning System for flood disasters, but the SNI only provides standard early warnings for upstream sources (inlets) (Rosya et al., 2022). Thus, the system is less suitable for lake floodplains that receive water from inlets and outlets during floods, which can be challenging because flooding does not only occur due to the inlet but the outlet as well. Therefore, it is necessary to create a new framework for an EWS for flooding in lake areas. This can provide new insights regarding an EWS, where water sources from inlets and outlets contribute to flooding. Therefore, this

study examined efforts to build a flood EWS framework by combining the FCs of the MCL with the SIH3.

LITERATURE REVIEW

Flood Characteristics (FCs)

Understanding the FCs is crucial for reducing the risk of floods since they reveal the dynamics of the flood system (Irawan et al., 2020). Knowledge of the risk of floods, which contributes to the creation of flood information and models for lakes, includes FCs (J. Chen et al., 2021; Irawan et al., 2024). Flooding in flood-prone lake areas is influenced by the hydrological network between rivers and lakes (Baker, 1994). The connectivity between floodplain lakes and main rivers plays an essential role in determining the characteristics of the overall ecosystem (Hamerlynck et al., 2011). The FCs of floodplain lakes are influenced by: (a) fluctuations in the water level of the main river, which are a determining factor in the waterlogging pattern of floodplain lakes (Schiemer et al., 2006); (b) the hydrological network between the lake and the main river, which is a necessary process that influences the flow of water into the lake (Hamerlynck et al., 2011); and (c) the capacity of the lake affects the amount of water that it can contain. When this capacity is exceeded, it causes flooding (Bachri et al., 2020; Schiemer et al., 2006).

Flood characteristics (FCs) can provide information on how an area can be inundated (Riadi et al., 2018). In fact, through the FCs, the causes, impacts, and flood risk reduction strategies that can be implemented can be identified (Irawan et al., 2022; Son et al., 2015). Knowing these FCs can help in disaster risk reduction scenarios (Worowirasmi et al., 2015), especially when building an EWS.

Early warning system (EWS)

It is necessary to build an EWS to reduce the risk of flooding because flooding is an unpredictable tragedy that can occur at any time (Fang et al., 2021). In order to enable communities, governments, business communities, and other stakeholders take prompt action to lower the risk of disasters, an EWS is expected to be an integrated system that involves monitoring, hazard estimations and predictions, disaster risk assessments, communication processes, and preparedness (Idfi et al., 2021). The goal of developing an EWS framework is to put in place a plan to lessen Indonesia's vulnerability to flooding. The development of this system mainly involves the use of a single input system, such as for floods that originate from one river (Mdegela et al., 2023), and sometimes there are already several dam or reservoir buildings that can easily provide warnings about flooding (Thomas et al., 2020).

RESEARCH METHODOLOGY

Study Location

The MCL, located in East Kalimantan Province, are the largest lakes on the island of Borneo (Figure 1). These lakes are in West Kutai and Kutai Kartanegara districts, which are divided into eight sub-districts and 17 villages. The two sub-district city centres, namely Kota Bangun and Muara Muntai, have quite a high population density. A population of more than 60000 people live around these lakes, mostly above the lakes.

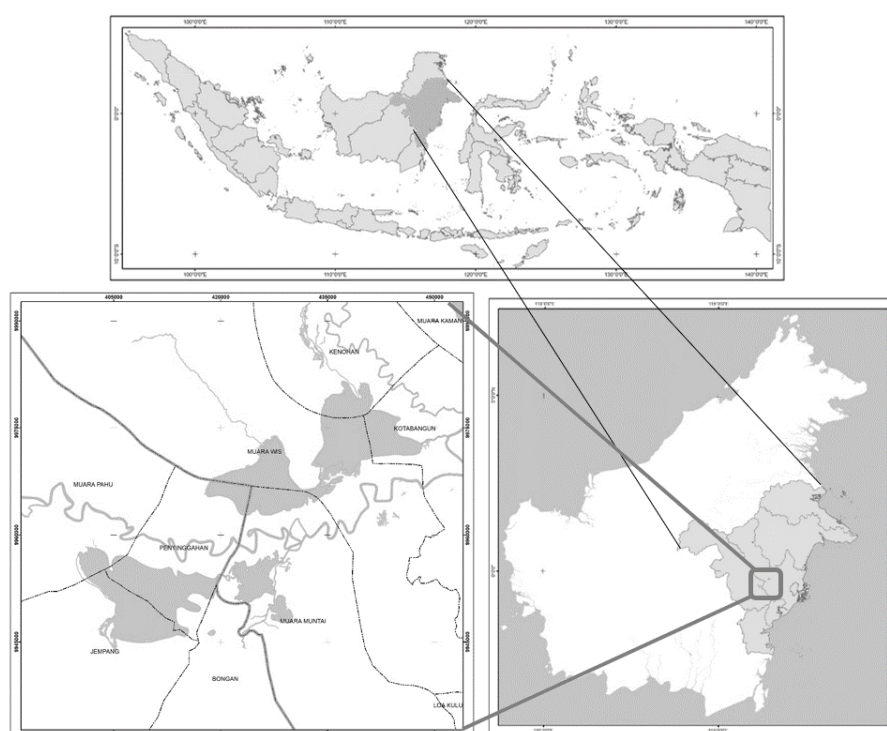


Figure 1: The Location of the MCL

Data Collection and Sources

The following research data was needed to determine the FCs of the lakes and to build an EWS for the floods (Table 1).

Table 1: The Research Data

No	Data	Source
1	Contour topography and bathymetry	BWS Kalimantan IV
2	Water level records of the lake	BWS Kalimantan IV
3	Fluctuative flow models of the MCL	BWS Kalimantan IV
4	Experience with lake floods: - Model of water flows into the lake during normal conditions and flood conditions - Model of changes (increases) in water levels at the lake - Method of predicting floods (EWS of the community) - Method of disseminating flood warnings	In-depth interviews with the community and head/staff of the village

Data Analysis

A descriptive approach was used to develop the FCs of the MCL from the topography analysis and lake drainage systems as well as from the experiences of the community living around the MCL. The topography analysis used Digital Elevation Model (DEM) data (Okolie & Smit, 2022) built from the contour data and 1-meter bathymetry. The lake topography was used to determine the shape of the lakes and the topographical causes of flooding. The data on the inputs and outputs of the rivers leading to the lakes were used to analyse the flow paths to the lakes, which would help to improve the flow model of the MCL from the BWS Kalimantan IV. In addition, the data from the community interviews also served to reinforce the observations of the water flow characteristics in the lakes during normal conditions, normal floods, and extreme floods. Meanwhile, the data on the water levels of the lakes were used to observe the duration and frequency of the floods each year.

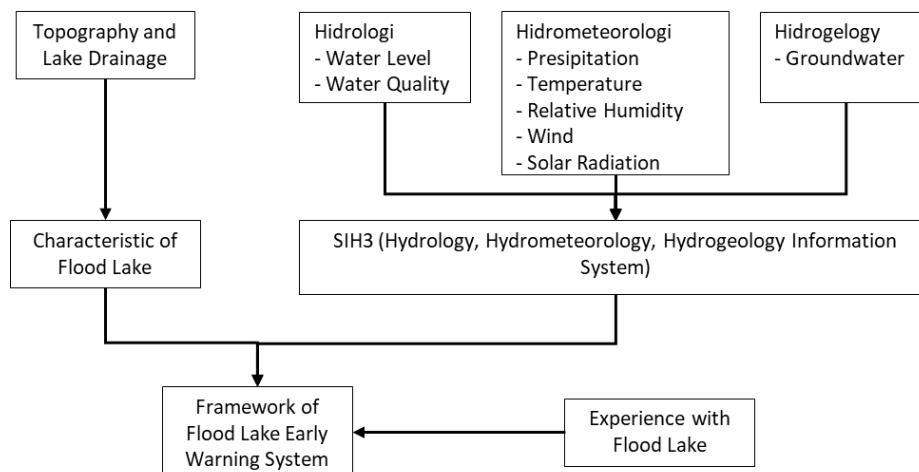


Figure 2: A Diagram of the Flow of the EWS Framework

The Hydrology, Hydrometeorology, and Hydrogeology Information System (SIH3) is one of the actual information systems related to hydrological, hydro-climatological, and hydrogeological conditions. The information provided includes water level conditions, water quality, current climatological data (precipitation, temperature, wind velocity, relative humidity, and solar radiation), and groundwater conditions. Its primary function is to provide data for the management of water resources. Water resource management also pays attention to reducing the risk of water resource-related disasters. One of the efforts to reduce disaster risks is to create a flood EWS framework by combining the FCs of lakes with the SIH3. The steps in compiling this flood early warning framework are shown in Figure 2.

The combination of the FCs of lakes and the SIH3 still needs to be integrated with the experiences of the community with regard to lake floods so that EWS scenarios and dissemination of early warning information can be formulated. This is because people understand the conditions of their environment better and are aware of the flood disasters that occur. With the combination of the FCs of lakes and the SIH3, an accurate EWS framework model can be built according to the conditions of the lakes.

ANALYSIS AND DISCUSSION

Lake Flood Characteristics (FCs)

Flood Durations and Frequencies

The data on the water level from the Pela-Sangkuliman Lake Gauge from 1989-2023 showed that floods occurred at the MCL almost every year (Table 2). Normal floods occurred every year, and the longest duration of normal floods occurred in 2022 (198 days). Although extreme floods did not occur every year, they sometimes occurred for a long duration. The worst extreme flood occurred in 2007, lasting 55 days. The highest frequency of floods occurred in 2017 and 2001. This condition is caused by water fluctuations in the MCL, which causes floods to occur several times a year.

Table 2: The Durations and Frequencies of Floods at the MCL

Year	Flood Category		Frequency	Year	Flood Category		Frequency
	Normal (>3.9-5m) (Day)	Extreme (>5m) (Day)			Normal (>3.9-5m) (Day)	Extreme (>5m) (Day)	
1989	30		3	2005	82	30	2
1991	61		1	2006	79		2
1992	33		1	2007	70	55	2
1993	39	5	3	2009	40		2

Year	Flood Category		Frequency	Year	Flood Category		Frequency
	Normal (>3.9-5m) (Day)	Extreme (>5m) (Day)			Normal (>3.9-5m) (Day)	Extreme (>5m) (Day)	
1994	106		3	2010	157		3
1995	45	1	1	2011	61		2
1996	112	7	3	2013	90		3
1997	16		1	2014	25		2
1998	90		3	2015	81	2	2
1999	108		2	2016	44		3
2000	25		1	2017	92	46	4
2001	104	3	4	2021	81		3
2002	146		2	2022	198	34	3
2004	80		3	2023	26		3

Source: BWS Kalimantan IV

Topography

The MCL area is a basin located around small hills in the middle of the Mahakam watershed (Figure 3), with water input from the Mahakam River and other rivers flowing into the lakes. A $\pm 186\text{m}$ -wide bottleneck, that obstructs the flow of the Mahakam River, was also discovered. Globally, a bottleneck often inhibits water flow and causes backflows (Stevaux et al., 2020). It also widens water bodies during floods (Harrison et al., 2022).

Before the bottleneck in the Mahakam River, three large rivers; namely, the Belaya ($\pm 105\text{m}$ wide), Kedang Kepala ($\pm 130\text{m}$ wide), and Kedang Rantau ($\pm 102\text{m}$ wide) rivers; flow into it. The total amount of water that flows from these three rivers into the Mahakam River exceed the Mahakam River's capacity at the bottleneck during floods.

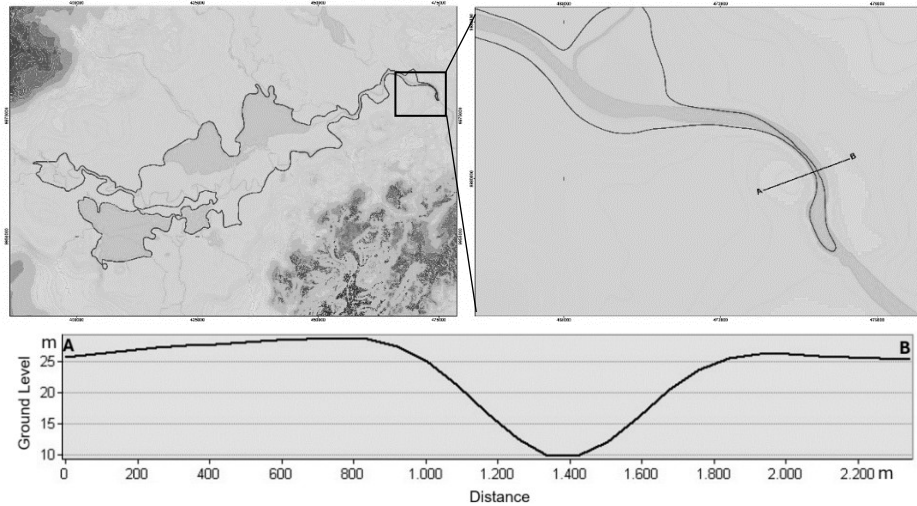


Figure 3: A Topographical Map of the MCL

Drainage System

According to the findings of the BWS Kalimantan IV study, under normal conditions, no water flows from the Blimbingan and N. N. Rivers into the MCL (BWS Kalimantan IV, 2019). However, under normal flood conditions, water from the Blimbingan, N. N., Belayan, and Mahakam River flow into the MCL. Under extreme flood conditions, in addition to the water from these four rivers, the flow of water at the MCL's outlets reverses and flows back into it instead (Figure 4) (BWS Kalimantan IV, 2019). This backflow is caused by the dynamics of the water flow in the floodplain area due to the bottleneck (Stevaux et al., 2020). Apart from that, the width of the Mahakam River's water channel widens, even to the low riparian areas, and appears to almost merge with the lake. This generally occurs in flood plain areas, which are often connected to river networks (X. Chen et al., 2020). Extreme floods also change the area of the lakes, whereby all the lakes appear to merge into a single lake. These changes around the lakes are a geomorphological response to the floodplain area (Yihan et al., 2022), which holds water and will make the waters between the lakes merge into a single body.

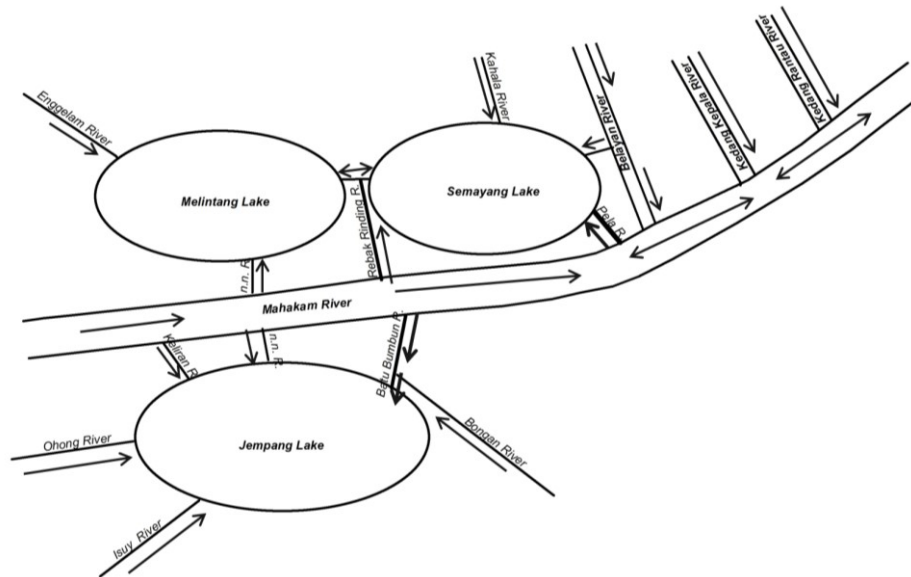


Figure 4: The MCL's Drainage System in an Extreme Flood Condition

Lake Flood Early Warning System (EWS) Framework

Based on the topography of the lakes, it can be seen that the lakes form a bottleneck that causes the water to flow backwards and back into the lakes. Waterlogging in flood-prone areas occurs when the river capacity is exceeded (Zhao & Shao, 2015). The characteristic conditions of the MCL, which have inputs from both upstream and downstream, define the water flow in the lake complex. The initial step for predicting floods is to determine the criteria for safe, alert, and warning/danger status (Antwi-Agyakwa et al., 2023), where the criteria for the water height limit are adjusted to the water height limit of each automatic water level recorder (AWLR) gauge which affects the lake input. The criteria for the water height at each existing AWLR gauge is shown in Table 3. In addition, in predicting the flood duration, it can be seen from the prediction of rainfall combined with the water level that the accuracy of flood duration prediction is higher. To help determine the flood early warning scenario, it is necessary to determine the following rainfall criteria:

- Advisory: >150 - <200mm
- Alert: >200 - <300mm
- Warning: >300mm

Table 3: The Alert Levels of Every Gauge at the MCL

Alert Level	Gauge AWLR (m)				
	Melak	Penyinggahan Ulu	Kota Bangun	Pela-Sangkuliman (Outlet Melintang & Smayang Lake)	Muara Kaman (Near Bottleneck of Mahakam River)
Normal	<10.7	<8.7	<4.0	<3.4	<3.2
Watch	10.7-11.2	8.7-9.2	4.0-4.5	3.4-3.9	3.2-3.7
Warning	>11.2	>9.2	>4.5	>3.9	>3.7

Source: SIH3 East Kalimantan

To build an effective early warning framework for lake floods, it is necessary to understand the community's knowledge of the characteristics of lake floods and flood prediction techniques commonly used by the community. The community's knowledge of floods is fundamental to building a practical and applicable EWS (Kuller et al., 2021). Based on the results of interviews with the community and village government in the MCL, it was learned that they predicted the occurrence of floods and prepared for floods by paying attention to the weather in the hilly areas in the upper reaches of the Mahakam and Belayan Rivers as well as information received by short messaging service (SMS) and phone calls from relatives living along the upper streams of the Mahakam and Belayan Rivers. This information was in line with the results of the interviews of the Melintang Village respondents:

"Usually, we determine if a flood will occur by calling family in Melak to get information about the water level of the Mahakam River there. We also call family in Kembang Janggut to ask about the water level of the Belayan River."

Apart from that, according to Mr. Aji of Tubuhan Village:

"To determine if a flood will occur, we determine the frequency of the rain in the mountains, which can be seen from Lake, and we also call family in upstream areas, such as in Long Iram, Kembang Janggut, to get information about the water level of the Mahakam River or Belayan River there."

However, flood predictions by the community are still far from accurate. This lack of accuracy is due to the limited information with which to predict floods (Macherera & Chimbari, 2016), as the community has not taken into account the discharge from the Kedang Kepala and Kedang Rantau rivers, which blocks the flow of the Mahakam River and causes a backflow. This was

also reinforced by the interview results of the BWS Kalimantan IV study to determine the boundaries of the MCL. According to Mr. Alimin and Mr. Dhani:

"During the floods, water flows from the Pela River and enters the lake, especially when the Mahakam and Belayan rivers rise."

"During severe flooding, the water from the lake no longer flows into the Batu Bumbun River. The water from the Batu Bumbun River enters the lake instead. So much so that the lake seems to merge with the Mahakam River as a lot of water from the Mahakam River enters the lake, too."

From the community's knowledge of FCs, it is quite clear that the floods are not only influenced by the water inputted into the lakes from upstream but are also caused by the backflow of the Mahakam River into the lakes. Although the community already knows how to predict floods, their system still lacks accuracy and the information is spread only by word of mouth. Based on the interview results, most of the people failed to take action when the water began to rise and inundate their homes, and they did not know how high the water would rise and how long the floods would last. The loudspeakers of the mosque are used to disseminate information to the people in the village. The information dissemination tools commonly used by the community can also be used for early warning notifications of floods in the future, since the Internet network in the lake villages is unreliable and some people do not have mobile phones or smartphones. Hence, the most effective way to disseminate information is through the use of loudspeakers and sirens. However, with the continuous development of information technology in the remote areas, this can be brought about in the future through the use of cellular networks and the Internet. The most effective way to develop a flood EWS is to base it on the community's knowledge and experience (Pham et al., 2024). A flood early warning framework was designed, as shown in Figure 5, based on the FCs, the availability of the SIH3, and the results of the interviews with the community.

The AWLR and automatic weather system (AWS) gauges were integrated with the Hydrology, Hydrometeorology, and Hydrogeology Information System (SIH3) in East Kalimantan. The primary purpose of establishing a flood EWS is to help the community improve their adaptation and reduce casualties and damage to property (Fakhruddin et al., 2015). In the SIH3, warning status criteria were determined from the AWLR and AWS. The combination of AWLR, AWS, and the community's knowledge was used to create a lake flood prediction scenario.

The flood prediction scenario was based on the water level conditions in the Mahakam River, the rivers flowing close to the bottleneck, and the AWS status from all the gauges. The AWLR gauges for the rivers close to the

bottleneck were available as yet, so for the time being, the EWS for floods from the rivers near the bottleneck was through direct observation predictions combined with the height of the Muara Kaman AWLR gauge. Meanwhile, the Melak, Penyinggahan Ulu, and Kota Bangun gauges were used to determine the warning status from the Mahakam River input. Meanwhile, the Pela-Sangkuliman gauge was able to determine the warning status at the Semayang-Melintang Lake outlet. The flood scenario was obtained when the water levels in the Mahakam River or rivers close to the bottleneck were in warning status simultaneously or only one of the AWS (from the Mahakam watershed or rivers close to the bottleneck watershed) recorded high rainfall at most gauges.

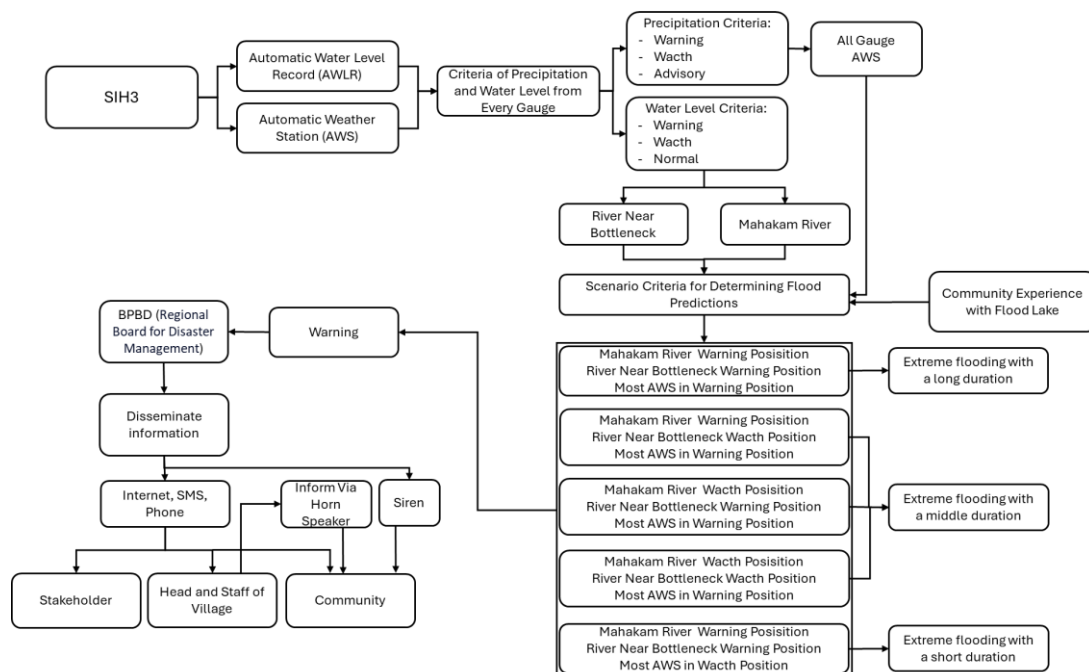


Figure 5: The Design of the Early Warning Framework for the MCL

The MCL flood early warning scenario was divided into three scenarios. The first was the Long Duration Extreme Flood Scenario, where extreme flooding would occur when all the AWLR gauges at the Mahakam River and rivers close to the bottleneck were in the “warning” status, and all the AWS gauges were also in the “warning” status. The second was the Moderate Duration Extreme Flood Scenario, where extreme flooding would occur if one or both of the AWLR gauges from both the Mahakam River and rivers close to the bottleneck were in the “watch” status, but all the AWS gauges were in “warning” status. The third scenario was a Short Duration Extreme Flood Scenario, where

extreme flooding would occur when the AWLR gauges at the Mahakam River and rivers close to the bottleneck were in the “warning” status, but all the AWS gauges were in the “watch” status. When a flood is predicted, the information will be forwarded to the Disaster Management Agency (BPBD) and disseminated.

The early warning information will be communicated to the community, the village government, and stakeholders to determine the best disaster management actions together with the BPBD. This information should be shared with the community through SMS, chats, loudspeakers, or sirens. The broadcast system should work in tandem with cellular providers to deliver SMSs in flood-prone areas so that all communities in the flood-prone buffer area can directly receive early warnings. It should also be combined with siren and loudspeaker system to ensure that the community is aware of the danger. It is hoped that an effective EWS will be able to help lake communities prepare for floods, especially extreme floods, to save property and reduce the number of casualties.

CONCLUSION

This study showed that the MCL have the characteristics of lakes that are prone to floods, where the input and output of the lakes contribute to the inundation of residential areas and productive land around the lakes. During a flood, the outlet of the MCL turns into a water inlet of the Mahakam River. This condition is caused by the retention of water from the Mahakam River due to the simultaneous overflow of the Belayan, Kedang Kepala, and Kedang Rantau rivers at the bottleneck at the Mahakam River. Therefore, to determine the design of the EWS framework, it was necessary to combine the FCs of the lake and the SIH3, while strengthening it with public knowledge about the lake floods.

Combining the FCs of the lakes with the SIH3 was able to help in the construction of a flood early warning framework. It was discovered that the FCs, which were influenced by input from the upper stream (Mahakam River) and downstream (rivers close to the bottleneck), can create backflows. The SIH3 can be used to build an early warning scenario through information from the AWLR and AWS from the upper stream and downstream of the lakes. This scenario would provide predictive information for extreme floods in the lake for long, moderate, and short durations. Therefore, this design could help the BPBD provide early flood warnings in the MCL.

Improvements to this system may include the placement of additional equipment, AWLRs in rivers close to the bottleneck, and AWS measurement instruments that are more evenly distributed throughout the sub-watershed. Moreover, it is necessary to calculate the amount of time that it takes the water to travel between the AWLR gauges to accurately estimate when a flood may occur.

The main limitation of this study was the lack of adequate AWS and AWLR gauges in each sub-watershed. As such, the early warning scenarios could not be tested. Therefore, further research is needed to test the effectiveness of this EWS framework, if all the necessary measurement instruments are in place.

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