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# *Challenges and Solutions in Managing Flood Risk in the Bogowonto River Estuary to Support National Security*

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**Abstract— The Bogowonto River Estuary faces significant flood risks due to a confluence of factors, including heavy rainfall, sedimentation, and rising sea levels. This article comprehensively examines these challenges and proposes potential solutions for mitigating flood risk in the region. The research analyzes the hydrological factors contributing to flooding, evaluates the impact of sedimentation on river capacity, and assesses the influence of sea level rise on storm surge inundation. To address these challenges, the article explores various solutions, including improved watershed management practices, strategic dredging to maintain river depth, and the implementation of flood protection infrastructure such as dikes and levees. The effectiveness of each solution is evaluated, considering economic feasibility, environmental impact, and long-term sustainability. The article concludes by recommending a holistic approach that integrates these solutions to create a comprehensive flood risk management plan for the Bogowonto River Estuary.**

**Keywords— Flood; Bogowonto River Estuary; Sedimentation; Rainfall; Risk Management**

## I. Introduction

Indonesia is a tropical archipelago of islands connected by oceans. It is not surprising that the country is nicknamed the Equatorial Emerald because it has 17,589 islands. In addition, Indonesia is also known as a country that is very vulnerable to earthquakes and tsunamis (Suppasri et al., 2018). In line with this, the first pledge in the Independence of the Republic of Indonesia was to "Protect the entire Indonesian nation and all of Indonesia's blood". This idea is enshrined in Law No. 24/2007 on Disaster Management. At that time, Indonesia was relatively late in preparing a comprehensive disaster management system regulatory framework. The regulatory framework aims to respond to various disaster events in Indonesia by building a disaster management system that includes aspects of legislation, institutions, organization (pre-disaster, emergency response, and post-disaster), and budgeting. Law No. 24/2007 on Disaster Management was enacted by the government and Parliament to build a resilient disaster management system in Indonesia. Subsequently, a derivative regulation was issued in the form of Government Regulation No. 21/2008 on the Implementation of Disaster Management (Lasmono, L., Yusnaldi, H., & Saragih, 2016).

As the largest archipelago in the world, Indonesia faces various threats that can cause disasters in coastal areas, such as tsunamis, abrasion, sedimentation, high waves, rip currents, and various other problems due to geomorphological and hydrometeorological processes in coastal areas. One of the hydrometeorological disasters that often occur in Indonesia is flooding, which is influenced by atmospheric and climatic factors such as heavy rainfall, storms, and tidal waves. Flooding is a natural disaster that often occurs throughout the world, including in the Bogowonto River Estuary. A river is a large body of water that flows from a higher elevation downstream. Rivers have an important role in society as their presence or absence can pose serious risks to human survival. There are many benefits to living near a river, but when a river overflows, the surrounding area is in danger with significant damage, jeopardizing infrastructure, livelihoods and even lives (Pramita et al., 2021).

Some of the factors that increase the risk of flooding in the estuary are as follows. First, the region experiences high and intense rainfall, which dramatically increases river discharge and potentially exceeds its capacity. Secondly, the buildup of sedimentation within the river further reduces the width and depth of the river, reducing its ability to handle large volumes of water. In addition, rising sea levels due to climate change increase tidal waves, which exacerbate coastal flooding, including in the Bogowonto River Estuary. Given these challenges, this research seeks to comprehensively assess the barriers and potential solutions to effectively manage flood risk in the Bogowonto River estuary.


Figure 1. Bogowonto River Estuary Condition, (a) Before Jetty Installation and (b) After Jetty Installation

## II. Literature Review

### A. Definition Flood Disaster

Floods are events were water overflows into previously dry areas, often resulting in significant damage. Coastal areas, where seawater meets land, have dynamic hydrological and fluvial environments and are highly vulnerable to extreme weather such as storms and tidal waves, which can cause disasters to coastal infrastructure (Yasuhara et al., 2011). Different types of floods are often categorized, including coastal flooding, which occurs when sea water floods inland due to extreme weather or tides, and river flooding, which results from overflowing rivers due to extreme weather and other factors. Groundwater flooding, which occurs when the ground becomes gradually saturated, as well as sudden flash floods due to extreme weather or other events, are also common types of flooding. Overflow floods, caused by heavy rainfall exceeding drainage capacity, and sewage or drainage floods, when drains are blocked, are also examples of frequent flood disasters (Islam et al., 2016).

A flood disaster refers to a catastrophic event that occurs when water from a river, lake, sea, or other body of water overflows into normally dry land areas. This results in widespread inundation of previously unflooded areas, causing extensive damage to property, infrastructure, and loss of life. Floods can be triggered by a variety of factors such as heavy rains, snowmelt, storms, dam or levee failures, and rapid urban growth that alters natural water flow patterns. The severity of a flood disaster often depends on the intensity and duration of rainfall, the topography of the affected area, and the effectiveness of available flood control measures (Dixit, 2003). The process of recovering from a flood disaster generally involves emergency response, evacuation of affected populations, infrastructure repair, and long-term mitigation measures to reduce future risks.

### B. Rainfall

Rainfall is a fundamental meteorological phenomenon in which water vapor condensed in the atmosphere falls to the Earth's surface in the form of rain, either in the form of water or ice. This natural process plays an important role in supporting life and ecosystems, as well as influencing agricultural productivity, hydropower generation and regional climate formation. The occurrence of rainfall is triggered when air containing a lot of water vapor cools to the point where its ability to hold water vapor decreases, leading to condensation and the formation of droplets or ice crystals. These particles then grow large enough to overcome air resistance and fall downwards due to the force of gravity (Peters & Neelin, 2006).

In meteorology, rainfall is measured using devices such as rain gauges and weather radar systems, which provide important data for climate analysis and weather forecasting. The distribution and intensity of rainfall varies widely around the world, influenced by factors such as geographic location, dominant wind patterns, topography, and the annual climate cycle. Understanding rainfall patterns is crucial for evaluating water availability, managing natural resources, and reducing the impact of extreme weather events such as floods and droughts. With ongoing global climate change, monitoring rainfall trends is becoming increasingly important in predicting future environmental conditions and designing adaptation strategies to build resilience and sustainability (Monjo, R., & Martin-Vide, 2016).

### C. Sea Tides

The changes in sea water on coasts around the world, which rise and fall regularly, are called tides. These events are mainly influenced by the gravitational pull of the moon and, on a smaller scale, the sun. These two celestial bodies cause the water in Earth's oceans to move up and down in a predictable pattern within a certain time interval. Tides feature repeated variations in sea level, usually occurring twice a day in most locations, creating high and low points known as high and low tides. These cycles play an important role in shaping the geography and ecological characteristics of coasts, as well as affecting marine life, navigation, and ocean-related human activities (Douglas, 2001).

The tidal mechanism is closely related to celestial dynamics and gravitational interactions between celestial bodies. As the moon orbits the Earth, its attraction causes nearby water to bulge outward, resulting in high tides (Ogilvie, 2014). Conversely, areas affected by the moon's weaker gravity will experience a drop in sea level, called low tide. Influence from the sun also contributes albeit with lesser influence due to its greater distance from Earth. The combined tidal pull of the moon and sun results in a complex pattern of tidal cycles with variations in amplitude and frequency across the world's coasts.

## III. Research Methods

This research applies a descriptive qualitative method with the aim of describing and understanding complex social phenomena, particularly related to disaster management policies and implementation in Indonesia. This method was chosen because it allows researchers to investigate various aspects that affect disaster management in greater depth. Data collection was conducted through a comprehensive literature study and direct observation, with a focus on obtaining in-depth data to gain a holistic understanding of the phenomenon under study (Hall, S., & Liebenberg, 2024).

This research falls into the category of evaluation research, with an emphasis on understanding and describing the phenomena that influence disaster management policies, especially flooding in the Bogowonto River estuary on the border of Central Java and Special Region of Yogyakarta. Data was obtained from various literature sources and through direct study, with the hope that the data could complement each other and provide a more accurate understanding of the problem under study (Kim, H., Sefcik, J. S., & Bradway, 2017).

Various literature studies were conducted to explore methods and experiences in the implementation of disaster management in Indonesia, which were then used as lessons learned in the context of flood disaster management in the Bogowonto River estuary. Data analysis used a qualitative descriptive approach, which was adjusted to the conceptual framework of the disaster management system in Indonesia, to produce relevant conclusions regarding challenges and solutions in flood disaster management in the Bogowonto River estuary.

## IV. Results and Discussion

The disaster management system must be carried out comprehensively and is not only limited to certain aspects but covers all aspects of life. In the disaster management policy, it is stated that disaster is a shared responsibility of various parties. Therefore, a collective role is needed from the government, private sector, and the community to optimize flood disaster management efforts in the Bogowonto River estuary. The estuary has several characteristics that affect disaster management, such as the estuarine ecosystem, rainfall, tides, sedimentation, and other factors related to the challenges and efforts to mitigate flood disaster risk in the Bogowonto River estuary.

### A. Bogowonto River Estuary

The Bogowonto River estuary is in Jangkaran Village, Temon District, Kulon Progo Regency, Special Region og Yogyakarta. The estuary is the meeting point between the Bogowonto River and the Indian Ocean. Located on the border of Central Java and Special Region of Yogyakarta, the estuary has distinctive characteristics that affect the ecosystem and lives of the surrounding communities. Geomorphologically, the estuary was formed from a long process of sedimentation, where material from upstream was deposited when the water flow met the sea. This creates a fertile delta, often used for agriculture and plantations. However, continued sedimentation reduces the river's capacity to hold water, increasing the risk of flooding especially in the rainy season (Nugroho, M. O. B., Rizkianto, Y., Yuditama, R. R., Ryan, A., & Maulana, 2023).

The ecosystem around the Bogowonto River estuary consists of various habitats, including mangrove forests, seagrass beds, and coral reefs, which play an important role in maintaining environmental balance. Mangrove forests serve as natural fortresses that protect the land from erosion and tidal waves. They also serve as nesting and breeding grounds for various species of fish and birds. However, human activities such as mangrove cutting and unsustainable infrastructure development have damaged these ecosystems, reducing their natural capacity to deal with natural disasters such as floods and tidal waves.

The socioeconomics of the communities around the Bogowonto River estuary are also heavily influenced by the physical and ecological characteristics of this estuary. Most of the population depends on the agriculture, fisheries, and tourism sectors. The presence of the estuary with its natural wealth provides various sources of livelihood. However, with the increasing frequency of flooding and environmental degradation, the local economy has become vulnerable. Better conservation and environmental management efforts, including mangrove rehabilitation and sedimentation management, are urgently needed to ensure the sustainability of the ecosystem and the economic sustainability of local communities (Pawestri, M. T., & Sujono, 2016).

Table 1. Characteristics of Bogowonto River Estuary

| ***Aspect*** | ***Condition*** |
|---|---|
| Morphology | A 1 km long funnel-shaped estuary with an average diameter of 100 meters, an average depth of 2 meters, and an average water discharge 200 m³/detik.<br>Lowlands with sandy beaches.<br>There are sediment deposits in the estuary.<br>There are embankments and jetties on the west and east sides of the estuary. |
| Hydrology | River discharge varies depending on the season.<br>Tides affect the condition of the estuary.<br>Sedimentation occurs in the estuary, especially when water discharge is low.<br>Potential for flooding in the estuary and surrounding areas. |
| Socio-Economic | Used for fishing, pond and tourism activities.<br>There are human settlements around the estuary.<br>Potential conflict between water resource users. |
| Mangrove Forest Ecosystem | The mangrove forest covers about 100 hectares.<br>It consists of several types of mangroves, such as Rhizophora sp., Bruguiera sp., Avicennia sp., Sonneratia sp., Ceriops sp., Lumnitzera sp., Excoecaria sp.<br>Mangrove forest conditions vary, some are dense, and some are sparse.<br>Mangrove forests are threatened by sedimentation, coastal abrasion and pollution. |

| | |
|---|---|
| Biodiversity | There are various types of flora and fauna in the Bogowonto River estuary, including milkfish (Chanos chanos), snapper (Lutjanus sp.), mullet (Liza sp.), tilapia (Oreochromis niloticus), shrimp (Penaeus sp. ), crab (Scylla serrata), kingfisher (Portunus pelagicus), clam (Meretrix meretrix), stork (Ardea sp.), stork (Charadrius sp.), sea eagle (Haliaeetus sp.), gull (Larus sp.), pelican (Pelecanus sp.), and many more.<br><br>Biodiversity is threatened by pollution, sedimentation and land conversion. |

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### B. Rainfall Bogowonto Watershed

Rainfall in the Bogowonto watershed shows a complex pattern and variability with several important characteristics. Its spatial distribution is uneven; upstream areas receive more rainfall than downstream areas due to topographic factors such as altitude and slope. Upstream areas, which are generally higher and have steeper slopes, receive more rainfall, while lower and flatter downstream areas receive less rainfall (Chikalamo, E. E., Mavrouli, O. C., Ettema, J., van Westen, C. J., Muntohar, A. S., & Mustofa, 2020).

The temporal variability of rainfall in the Bogowonto watershed shows a clear seasonal pattern, with the peak rainfall occurring in the wet season (December-February) due to the west monsoon that brings water vapor from the Indian Ocean, and the lowest rainfall occurring in the dry season (June-August) due to the influence of the east monsoon that brings dry air from Australia. Rainfall intensity also varies, with an annual average of 1,500-2,000 mm. The highest intensity usually occurs in a short period of time and can cause flooding. Factors affecting rainfall intensity in the Bogowonto watershed include topography, vegetation, and temperature, where areas with steep slopes tend to have higher rainfall intensity, while dense vegetation can reduce it.

Rainfall trends in the Bogowonto watershed show a long-term increase attributed to climate change. This increase may be due to several factors such as rising global temperatures that increase ocean water evaporation and cloud formation, as well as changes in global wind patterns that alter rainfall patterns in different regions. Analysis of the long-term data suggests that these changes may continue, requiring an in-depth understanding and appropriate mitigation strategies to deal with the impacts, including potential increases in flood frequency and intensity in the region (Zwol, 2014).

In the Bogowonto watershed, two upstream rainfall observation stations, Padureso in Kebumen and Secang in Magelang, provide valuable data for understanding rainfall patterns and variability that impact river flow and flood risk. This discussion will analyze the rainfall data from these two observation stations to provide a comprehensive picture of the hydrological conditions in the upper Bogowonto watershed as shown in table 2 below:

Table 2. Rainfall Post Bogowonto Watershed

| **No** | **Rainfall Post** | **Probolo Hall Region (Progo, Bogowonto, Luk Ulo)** | | |
|---|---|---|---|---|
| | | ***Village*** | ***District*** | ***Regency*** |
| 1. | Merden | Merden | Padureso | Kebumen |
| 2. | Plered | Jambewangi | Secang | Magelang |

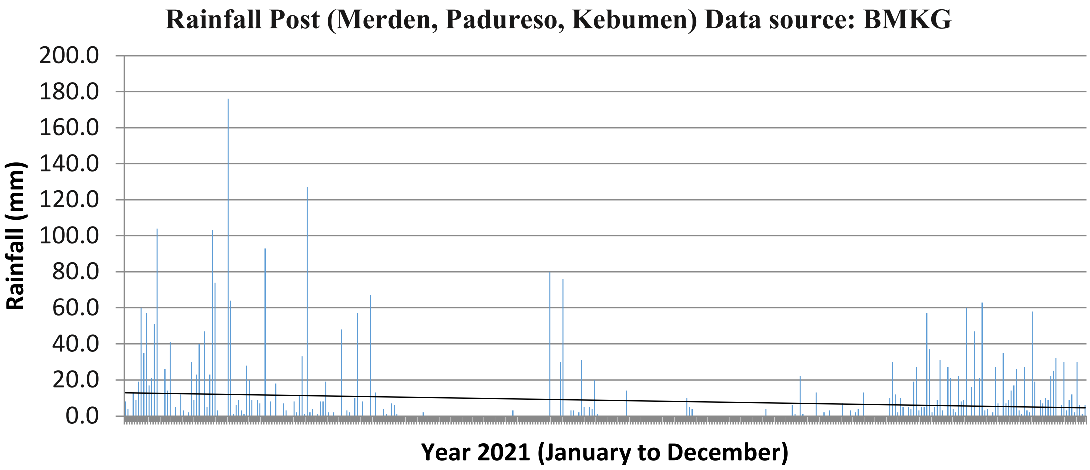


Figure 2. Rainfall Data at Padureso Observation Post Kebumen in 2021

Based on the graph above in Figure 2, Padureso observation post is in the upper reaches of the Bogowonto watershed in Kebumen, with a high topography and steep slopes. Rainfall data from Padureso shows that this area receives relatively high annual rainfall, averaging 3,218 mm per year. Rainfall in Padureso has a variable temporal distribution, with peaks occurring between December and February, following the rainy season in Indonesia which is influenced by the west monsoon.

The monthly variability of rainfall in Padureso is quite high, with some extreme rainfall events reaching more than 205 mm in a month. High rainfall intensity over a short period of time often increases surface flow and flood risk in downstream areas. The steep topography around Padureso also accelerates surface flow towards the river, rapidly increasing the volume of water and increasing the risk of flash flooding.

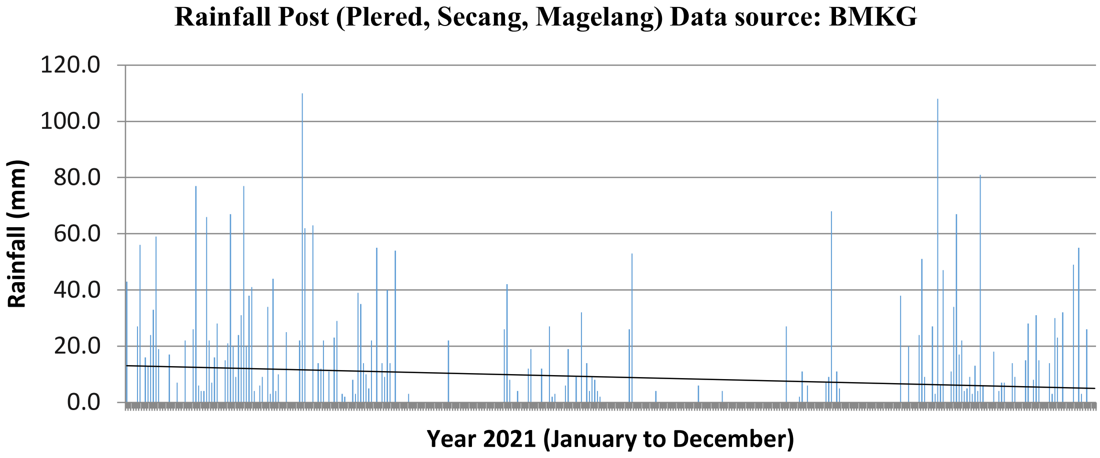


Figure 3. Rainfall Data at Padureso Observation Post Kebumen in 2021

Based on the graph above in Figure 3, Secang observation post in Magelang is also located in the upper Bogowonto watershed, with a similar topography to Padureso. Rainfall data from Secang shows a slightly higher annual average than Padureso, at 3,315 mm per year. The rainfall pattern in Secang also peaks in the rainy season (December to February), with high monthly rainfall, although the intensity is slightly lower compared to Padureso.

Rainfall in Secang has a more even distribution throughout the year and lower variability compared to Padureso. However, extreme rainfall events do occur, with some months recording more than 153 mm. The topography in Secang also accelerates surface runoff, but the surrounding denser vegetation helps to reduce flow rates and increase infiltration, reducing the risk of flash flooding compared to Padureso.

### C. Sea Tides on Bogowonto River Estuary

Sea tides at the Bogowonto River estuary are a complex natural phenomenon that has great importance to be studied in the context of coastal ecology and natural resource management. The Bogowonto River is located on the southern coast of Central Java, Indonesia, and acts as a link between the riverine and marine environments. The tidal phenomenon at the mouth of the river is influenced by the gravitational attraction of the moon and the sun as well as the topographic characteristics of the seabed, which periodically affect the sea water elevation (Chrysanti, A., Adityawan, M. B., Yakti, B. P., Nugroho, J., Zain, K., Haryanto, & Tanaka, 2019).

Tidal behavior at the Bogowonto River estuary shows significant variations during daily and monthly cycles. Daily tides are influenced by the Earth's rotation and the interaction between the gravitational pull of the moon and the sun, while monthly tides are influenced by the lunar cycle. This variability affects the hydrodynamic conditions in the estuary, which plays an important role in the distribution of nutrients, sediments, and biota in marine and river waters.

Table 3. Tidal Data in the Bogowonto River Estuary Area (Data source: BMKG)

| ***No*** | ***Month*** | ***2021 Year*** | | |
|---|---|---|---|---|
| | | ***Tide (High Highest Water Level) (m)*** | ***Tidal (Low Lowest Water Level) (m)*** | ***Difference (m)*** |
| 1. | January | 2,2 | 0,1 | 2,1 |
| 2. | February | 2,3 | 0,15 | 2,15 |
| 3. | March | 2,35 | 0,1 | 2,25 |
| 4. | April | 2,15 | 0,1 | 2,05 |

| | | | | |
|---|---|---|---|---|
| 5. | May | 2,1 | 0,2 | 1,9 |
| 6. | June | 2,1 | 0,2 | 1,9 |
| 7. | July | 2,05 | 0,25 | 1,8 |
| 8. | August | 2 | 0,25 | 1,75 |
| 9. | September | 2 | 0,3 | 1,7 |
| 10. | October | 2,1 | 0,2 | 1,9 |
| 11. | November | 2,15 | 0,2 | 1,95 |
| 12. | December | 2,2 | 0,1 | 2,1 |
| Average Tides | | 2,14 | 0,18 | 1,96 |

The study of 2021 tidal data around the Bogowonto River estuary provides valuable information on the changes in sea level dynamics during the year. This information is not only important for understanding scientifically complex natural phenomena, but also for recognizing long-term trends that may affect coastal ecology as well as the socio-economic life of local communities. During 2021, variations in tides around the Bogowonto River estuary recorded significant differences between the highest and lowest water levels. The highest tidal peaks occur during the rainy season, especially between November to March, with tidal elevation differences reaching about 2.25 meters. Heavy rainfall during this period increases the flow of rivers to the sea, thereby increasing the volume of water in the estuary and resulting in a marked rise in sea level in coastal areas. In contrast, the lowest tides generally occur during the dry season, particularly between June and September, with a difference in tidal elevation of about 1.7 meters. During this period, low rainfall reduces river flow to the sea, causing a decrease in sea water elevation at the Bogowonto River estuary.

### D. Estuary Sedimentation

River estuaries are transitional areas where freshwater from rivers meets seawater, often resulting in sediment buildup due to differences in flow velocity and water density. In the Bogowonto River estuary, sedimentation is influenced by several factors, such as river flow, ocean tides, human activities, and weather conditions. Excessive sediment buildup can result in silting of the estuary.


Figure 4. Bogowonto estuary surface silting due to sedimentation

Sedimentation in the Bogowonto River estuary is the result of the transportation of solid materials such as sand, mud, and small rocks by river flow which are then deposited in the estuary (Nugroho, M. O. B., Rizkianto, Y., Yuditama, R. R., Ryan, A., & Maulana, 2023). This phenomenon has significant impacts on estuarine landforms, water quality and coastal ecosystems. The main factors that cause sedimentation include high river discharge during the rainy season, soil erosion upstream from human activities such as agriculture and deforestation, and the flat topography and erodible geology characteristic of the estuary. Ocean currents from the Indian Ocean and ocean waves also contribute to sediment transport to the estuary. This accumulation of sediment results in changes to the morphology of the estuary, such as delta formation or closure of waterways, as well as degradation of seawater quality affecting coastal ecosystems.

### E. Challenges in Managing Flood Risk in the Bogowonto River Estuary

A study of flood risk management in the Bogowonto River Estuary revealed several challenges. One of the main difficulties is the region's vulnerability to climate change, which exacerbates the frequency and intensity of flooding. As a transitional area between the riverine environment and the marine ecosystem, the estuary faces complex hydrodynamic conditions. These conditions are influenced by tidal movements, sea level rise and increasing rainfall patterns. The combination of these factors complicates the prediction and management of flood events, making it difficult for local governments to implement effective mitigation strategies (Saleem Ashraf, M. L., Iftikhar, M., Ashraf, I., & Hassan, 2017).

Another significant challenge is the socio-economic context of the area. The Bogowonto River estuary is inhabited by communities that rely heavily on agriculture and fishing, both of which are highly vulnerable to the impacts of flooding. The socio-economic impacts of flooding are substantial, causing loss of livelihoods, displacement, and increased poverty. In addition, local infrastructure is often inadequate to cope with severe flood events, due to the lack of good drainage systems, flood barriers and early warning systems. These infrastructure deficiencies not only increase risk but also hamper emergency response and recovery efforts during and after flood events.

In addition, there are institutional and governance barriers that hinder effective flood risk management. Coordination between various government and non-government organizations is often weak, leading to fragmented and inefficient management practices. The lack of comprehensive and integrated flood management plans, as well as limited financial and technical resources, further exacerbates this problem. Effective flood risk management in the Bogowonto River Estuary requires robust data collection, ongoing monitoring, community engagement, and the implementation of adaptive and sustainable management practices. Addressing these challenges requires a multi-faceted approach that combines scientific research, socio-economic planning, and a strong institutional framework.

### F. Solutions in Managing Flood Risk in the Bogowonto River Estuary

Research on how to manage flood risk in the Bogowonto River Estuary emphasizes a holistic approach to deal with the complexities of the region. One important step is to develop and implement a sophisticated hydrological and meteorological monitoring system. These systems can provide real-time information on rainfall, river flow and tides, enabling more accurate predictions and early warnings of potential flooding. By leveraging technologies such as remote sensing and Geographic Information Systems (GIS), authorities can analyze and visualize flood risks more effectively, facilitating decision-making and strategic planning.

Another solution step is to strengthen local infrastructure to increase flood resilience. This includes building flood defenses such as embankments, flood retaining walls, and better drainage systems to reduce waterlogging and rapid runoff. The integration of green infrastructure solutions, such as wetland restoration and mangrove reforestation, can also help absorb excess floodwater and reduce its negative impact on inhabited areas, while providing additional benefits such as biodiversity preservation and improved water quality.

Community engagement and capacity building are important components of effective flood risk management in the Bogowonto River Estuary. Educating local communities on flood risks and preparedness measures can empower them to take proactive preventative measures. The establishment of local emergency response teams and the conduct of regular drills can improve community preparedness for floods. Community participation in the planning and implementation of flood management strategies is also important to ensure the inclusion of local knowledge and needs, resulting in more sustainable and community-acceptable solutions. Collaborative working between the government, non-governmental organizations and communities is key to creating a comprehensive and adaptive framework for managing flood risk in the Bogowonto River Estuary (Bhakty et al., 2021).

## V. Conclusion

Qualitative research on flood risk management challenges and solutions in the Bogowonto River Estuary concluded that effective flood risk management requires a multifaceted and integrated approach. The research highlighted the significant impacts of climate change, such as increased rainfall and rising sea levels, which exacerbate flood risk. Sedimentation and coastal erosion further compromise the capacity of estuaries to manage water flows and natural defenses, while rapid urbanization and deforestation upstream contribute to water runoff and sedimentation downstream. The research highlights that existing infrastructure is often inadequate, and financial and institutional constraints hamper effective flood management efforts. In addition, a lack of community awareness and preparedness increases their vulnerability to flooding. To address these challenges, this research advocates for a combination of structural measures, such as improving flood control systems, and non-structural strategies, including sustainable land use practices, afforestation, and community education and preparedness programs. Emphasizing nature-based solutions, improving institutional frameworks, and securing diverse funding sources are also critical. The study concludes that collaborative efforts between government, local communities and stakeholders are essential to develop adaptive, sustainable and contextually appropriate flood management strategies in the Bogowonto River Estuary.

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