

FLOOD RISK ASSESSMENT OF MAJOR RIVER BASINS IN THE PHILIPPINES

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ABSTRACT: Disaster risk management is vital in strengthening the resilience to and reduction of losses brought by natural disasters. In Philippines where typhoons frequently occur, flood risk maps are essential for the protection of communities and ecosystems in watersheds. This study created flood inundation maps with climate change considerations under 2020 A1B1 and 2050 A1B1 scenarios for four major river basins in the Philippines: the Agno, Cagayan, Mindanao, and Buayan-Malungon River Basins. From these maps, the most vulnerable areas for each basin are identified using GIS mapping software. Sixteen inundation risk maps were generated, four for each river basin, in terms of built-up areas, roads, bridges, and dams. Results showed that the northern part of Cagayan River Basin and the central parts of the Agno and Mindanao River Basins are the most flood-prone areas, while the Buayan-Malungon River Basin will have no significant inundation problems. Suitable adaptation and mitigation options were provided for each river basin.

Keywords: Disaster risk reduction, Climate change adaption, Inundation, Risk Mapping

1. INTRODUCTION

Disaster risk reduction is the systematic analysis of factors causing disasters, reduction of exposure and damage to life and property, and preparation for future disasters [1]. Part of disaster risk assessment is the analysis of flood inundation maps to locate key vulnerable areas and determine appropriate strategies for mitigation and prevention of disasters.

At present, there is a need to put climate change adaptation into consideration when planning disaster risk reduction. Especially in the Philippines, global greenhouse gas emissions play a huge part in influencing local climate, causing increased mean temperatures throughout the country. The recent decade has observed an increase in both drought and flooding intensity in the country [2]. Hence, including climate change adaptation is crucial to increase the effectivity of disaster risk reduction and management.

The relationship between these two approaches, disaster risk assessment and climate change adaptation, has been widely acknowledged yet rarely practiced [3]. These two areas of study use similar terms that serve different meanings in their respective fields [4].

Disaster risk is defined as potential losses due to disaster in various areas including health, work, and the general community [1]. Three factors that contribute to the disaster risk of an area are a hazard, vulnerability to the hazard, and coping capacity [5]. Risk can be mathematically computed by multiplying hazard with vulnerability [4].

A hazard can be either natural or anthropogenic, or an association between the two. For instance, a natural hazard can trigger a disaster due to anthropogenic malpractices such as improper land use [5]. However, while disaster risk reduction defines hazards as instantaneous and intense (e.g., extreme weather events and earthquakes) climate change adaptation defines hazards as slow or gradual changes (e.g., increase in global mean temperature and sea-level rise) [4].

Vulnerability is defined as the characteristics of an area that make it more susceptible to hazards [1]. UNESCO-IHE defines vulnerability as susceptibility. Climate change adaptation, on the other hand, defines vulnerability as the characteristics or conditions of a society that allow them to handle changing environmental conditions, again focusing on long-term effects rather than extreme events [4].

The Philippines is a country frequently ravaged by natural disasters, ranking third in the World Risk Index with a risk percentage of 27.98%. It is also the third most exposed country to natural disasters [6]. Tropical cyclones and flash floods are the two worst disasters in the country, affecting a total of around 132 million citizens [7]. These two phenomena are often connected, as typhoons often bring heavy rainfall resulting in flash floods. An example of this is Typhoon Ketsana in 2009, which brought severe flooding and caused up to PhP 11 billion damage to infrastructure and agriculture [8]. These disasters will only increase, as it was predicted that heavy rains and typhoon intensity

could intensify due to global warming [9].

An average of 20 tropical cyclones enters the Philippine Area of Responsibility (PAR) annually, which is greater than any other part of the world. Of these 20 tropical cyclones, eight to nine make landfall on the Philippine islands, and five are potentially disastrous [10]. This prevalence of typhoons in the country solidifies the need for disaster risk reduction and management on both local and national levels.

Watersheds makeup 70% of the country's total land area, and are home to the country's major natural forests. Due to the richness of these ecosystems, human communities establish and increase in these areas. Due to poor land-use planning and deforestation, however, watersheds have become extremely susceptible to climate change [11].

The Agno and Cagayan River Basins are both located on Luzon, the largest island of the Philippine archipelago. The Agno River Basin is the fifth largest basin in the country and is shared by eight provinces. Aside from its agricultural significance to the country, it has three major dams that supply energy to most of Luzon [12]. The Cagayan River Basin, located in northeastern Luzon, is the largest river basin in the country and is shared by 11 provinces. Compared to other regions of the Philippines (from 2001 to 2009), the regions of Cagayan are economically underdeveloped. However, this area contains one of the last remaining primary forests in the country [13]. Both river basins receive frequent typhoons, and flooding is a major problem in the surrounding low-lying areas [12,13].

The Mindanao and Buayan-Malungon River Basins are both located on Mindanao, the second largest island in the Philippines. The Mindanao River Basin is the second largest river basin in the country, covering nine provinces with mineral resources such as chromite, copper and gold. The Buayan-Malungon River Basin is a small basin adjacent to the Mindanao River and covers four provinces. The island of Mindanao, located in the southern Philippines, is rarely hit with typhoons unlike Luzon and Visayas in the northern and central regions. However, climate change has caused a shift in these trends, with typhoon landfalls becoming more frequent in Mindanao in the past decade [14]. When typhoons do reach these areas, massive flooding ensues due to ecological and social unpreparedness to this type of disaster [15]. To protect the river basins and their associated communities, important steps must be taken to reduce the impact of disasters.

This study aims to assess disaster risk using inundation maps that take climate change into account. Flooding (or inundation) as defined in this study is the overflow of a body of water or

collection of water in areas that are usually dry [16]. The information obtained from this study can be used in combination with other studies such as socio-economic and environmental studies to better forecast each location's vulnerability.

2. INUNDATION RISK ASSESSMENT

For the risk assessment, Quantum Graphic Information System (QGIS) software v.2.16 "Nødebo" was utilized to map areas of interest (roads, irrigation, bridges and built-up areas), and river basin land-use area maps were used to create the inundation maps for each river basin.

2.1 Extraction of Vulnerability Information

The inundation map subjected to risk assessment generated from previous studies using the 2020 and 2050 A1B1 climate change scenarios is shown in Fig. 1 [17,18].

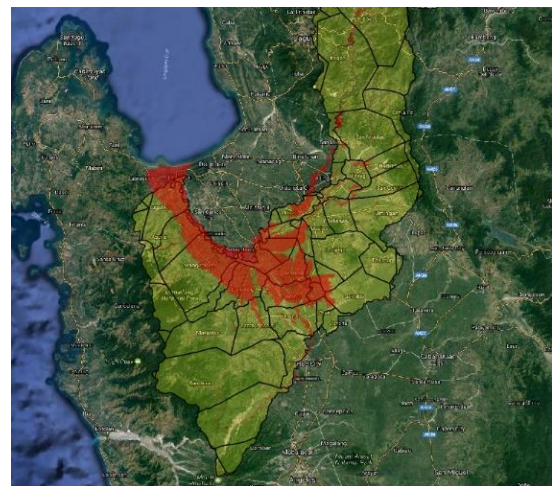


Fig.1 Inundation map (red) of the Agno River Basin (yellow)

The A1B1 is a climate scenario defined by rapid economic growth, a mid-century population peak, and social, cultural, and economic convergence in regions. The B1 part of the scenario describes the use of clean and efficient technology and reduced material use. Global solutions are made for economic, environmental and social sustainability [17]. In generating the risk maps, only the 2050 A1B1 inundation was used, while the 2020 A1B1 results were used to compare the changes in risk between the two time periods. It should be noted that A1B1 is a description for a climate change scenario and that the 2020 A1B1 scenario would mean a shorter return period and only useful for

short term prediction while 2050 A1B1 scenario used longer return period and thus predicts flooding for a farther time in the future. Due to the study's interest in long term development and climate change effects, the 2050 A1B1 period was considered in generating risk map.

While most flood studies previously used higher return periods for their inundation maps such as 10, 50, or 100 years [19, 20], this study explored the possible effects of weather disturbance within a shorter return period of two years. Due to the Philippines' location in the typhoon belt and annual occurrence of at least 20 tropical cyclones [10], enough data can be generated with just a two-year return period. The risk maps were then prepared with a high chance of occurrence in the year 2050 and have a 50% chance of exceedance.

To obtain the area of each flooded portion, the inundation maps for each river basin were overlaid with their corresponding built-up area maps. The resulting combined map file was then analyzed, obtaining the areas corresponding to each time scenario. This process was repeated for the maps of land-use areas and other areas of exposure.

Built-up areas were included due to high population densities in these areas. Dams were also included due to their importance to surrounding areas for both agriculture and flood control.

Roads and bridges determine the accessibility to transportation and goods and services, including relief operations during calamities. For roads, the inundation maps were overlaid with the corresponding roads for each river basin. The inundated road portions were obtained by utilizing the "sum line lengths" analysis tool using the road line vector with the flood inundation map.

For bridges, each inundated bridge was counted as exposed. Irrigation was also counted as exposed if it was within the inundation area. The number of points inundated was obtained and counted using the "Points in Polygon" tool.

2.2 Vulnerability Assessment

Vulnerability is the susceptibility of a system to floods due to exposure while accounting for its ability or inability to cope or adapt. The vulnerability of an area can be measured by subtracting resilience from exposure and susceptibility [21]. In this equation, resilience is the capability of the system to resist flooding or another hazard; exposure is the tendency of an area or system to be affected by flooding due to its location, and susceptibility is the specific parts of the system

that will be affected by the flooding.

This study adapted methods used in risk assessment by reference adapting the risk matrix and its style of color coding to generate risk maps [22] and the vulnerability assessment in North Central Vietnam by reference, overlapping exposure and inundation maps to generate vulnerability [23]. This study focused on the exposure of the four river basins, concentrating on land use areas (specifically built-up areas and roads) and return periods. The matrix used for the risk maps is shown in Table 1. The flood risk matrix measures exposure chance, which is defined as the likelihood that a road, bridge, or building is exposed or inundated at a given return period.

Table 1 Flood risk matrix

		Exposure chance							
		Very Low (1) 0-20%	Low (2) 21-40%	Moderate (3) 41-60%	High (4) 61-80%	Very High (5) 81-100%			
0-	10	20	30	40	50	60	70	80	90-
1	-	-	-	-	-	-	-	-	10
0	20	30	40	50	60	70	80	90	0

2.3 Risk Map Generation

Four risk categories were analyzed for each inundation map: built-up areas, roads, dams, and bridges. For buildings or built-up areas (BA), building exposure chance (BSC) was calculated using the following formula:

$$BSC (\%) = \frac{\text{Total Inundated BA (km}^2\text{)}}{\text{Total BA (km}^2\text{)}} * 100 \quad (1)$$

Road length (RL) was used to measure road exposure chance (REC) using Eq. (2).

$$REC (\%) = \frac{\text{Total Inundated RL (km)}}{\text{Total RL (km)}} * 100 \quad (2)$$

The exposure of bridges and irrigation structures, defined by point exposure chance (PEC), is given by Eq. (3),

$$PEC (\%) = \frac{\text{Total Inundated Points}}{\text{Total Points}} * 100 \quad (3)$$

where points are equal to locations of interest, marking susceptible infrastructures such as bridges or irrigation structures.

These factors were treated separately in the prioritization of each area, as each exposure factor requires different interventions.

From the results, engineering-based interventions were proposed. Ongoing and

suggested projects in each river basin were consolidated. Adaptation options used in past climate change and disaster risk management studies and projects were obtained. Adaptation options were proposed depending on factors such as cost, technical feasibility and benefits. Site prioritization also depended on the vulnerability data obtained. A schedule for the proposed adaptation options was created, with short- to long-term planning taken into consideration.

3. RESULTS AND DISCUSSION

Two climate scenarios for the flood inundation maps were used for this project: 2020 A1B1 and 2050 A1B1. A base return period of two years was used for these inundation maps. Sixteen risk maps were generated, four for each river basin.

3.1 Inundation Risk Maps

3.1.1 Agno River Basin

The inundation map for built-up areas in the Agno River Basin is shown in Fig.2. The analysis showed a total of 60.44 km² built-up area out of the 176.87 km² total river basin area is inundated. There are several municipalities (towns) in the Agno that have high risk in terms of built-up inundation. Of the 72 total municipalities located in the area, 13 municipalities have an inundation risk percentage of 50% or higher.

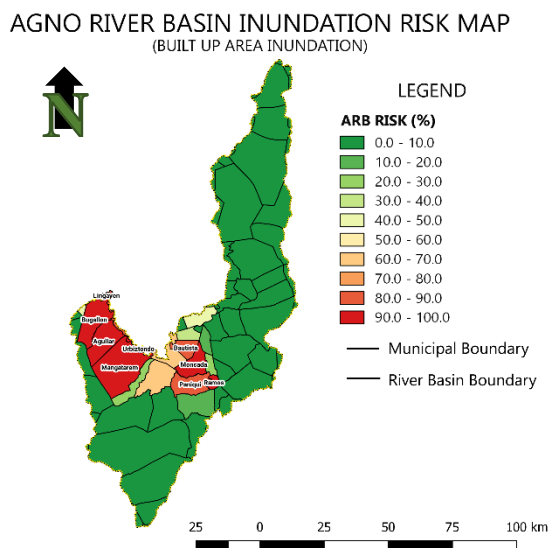


Fig.2 Agno River Basin built-up area risk map

The river basin faces problems in areas around its main river, the Agno River, where most of the high-risk towns are located. An increase in inundation risk can also be observed from 2020 to

2050, with most towns experiencing increased built-up inundation and road inundation (Table 2). The total inundated built-up area risk in the Agno River Basin increased by 16.71%, while the total inundated road risk increased by 24.69%. Though there was only one dam in the Camiling municipality that would get inundated by 2050 compared to the 2020 flood map, bridges showed a 26.83% increase in inundation risk. In total, 40 out of the 72 municipalities are at risk of flooding.

Table 2 Overall flood risk assessment of the Agno River Basin in the A1B1 scenarios

Category	Risk (%)	
	The year 2020	The year 2050
Built-Up	29.28	34.17
Roads	15.52	19.36
Dams	17.19	18.75
Bridges	25.79	32.70

3.1.2 Cagayan River Basin

In the Cagayan River Basin, a total of 122 municipalities were analyzed for inundation in the four risk categories. Results showed that out of the 470.05 km² watershed area, 42.27 km² of the built-up area is inundated (Fig.3).

CAGAYAN RIVER BASIN INUNDATION RISK MAP (BUILT UP AREA INUNDATION)

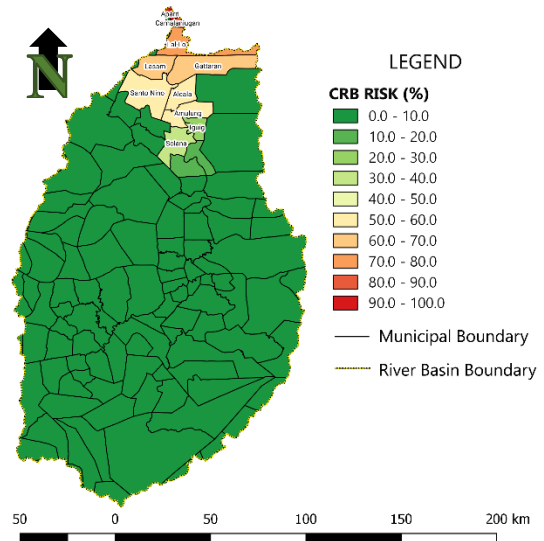


Fig.3 Cagayan River Basin built-up area risk map

Flooding is mainly observed in the northern sections of the Cagayan River and two of its tributaries, the Chico and Dummun Rivers. The river basin is projected to decrease in inundation from 2020 to 2050 (Table 3).

Table 3 Overall flood risk assessment of the Cagayan River Basin in the A1B1 scenarios

Category	Risk (%)	
	The year 2020	The year 2050
Built-Up	12.84	8.99
Roads	7.63	6.69
Dams	2.96	2.22
Bridges	14.85	11.51

By 2050, inundation risk is expected to decrease by 30% in built-up areas, 12.33% in roads, 22.54% in bridges, and one less dam. Overall, 81 out of 122 municipalities in the Cagayan River Basin are at risk of flooding.

3.1.3 Mindanao River Basin

A total of 104 municipalities were analyzed in the Mindanao River Basin. The analysis showed that 8.97 km² of built-up area out of 316.26 km² is inundated.

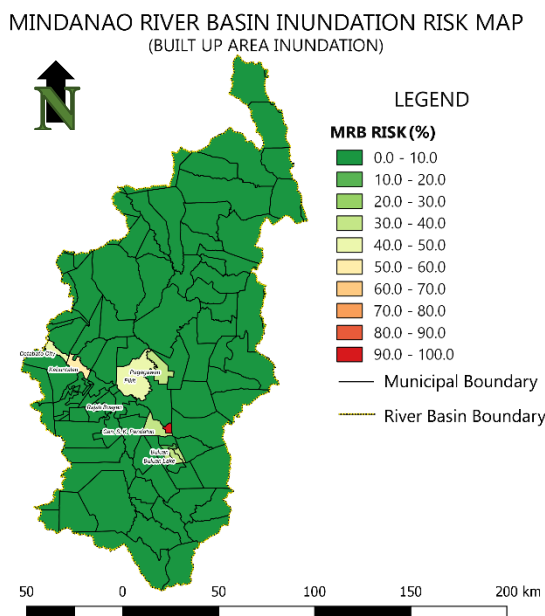


Fig.4 Mindanao River Basin built-up area risk map

The river basin’s flooding can be seen in the Tamontaka River, Mindanao River, and Buluan River. Like the Cagayan River Basin, the Mindanao River Basin will experience a decrease in inundation from 2020 to 2050. Inundation risk will decrease by 1.85% in built-up areas and 1.72% inroads. The number of inundated dams and bridges will remain the same in both years (Table 4). Compared to the Cagayan, the changes are smaller and less noticeable on the inundation map.

Table 4 Overall flood risk assessment of the Mindanao River Basin in the A1B1 scenario

Category	Risk (%)	
	The year 2020	The year 2050
Built-Up	2.89	2.84
Roads	1.10	1.08
Dams	3.57	3.57
Bridges	4.02	4.02

Overall, 65 out of 104 municipalities in the river basin are at risk of flooding.

3.1.4 Buayan-Malungon River Basin

In the BRB a total of 8 municipalities were analyzed for inundation in the four categories. Results showed 0.01 km² of the built-up area out of 9.6 km² in the river basin is inundated.

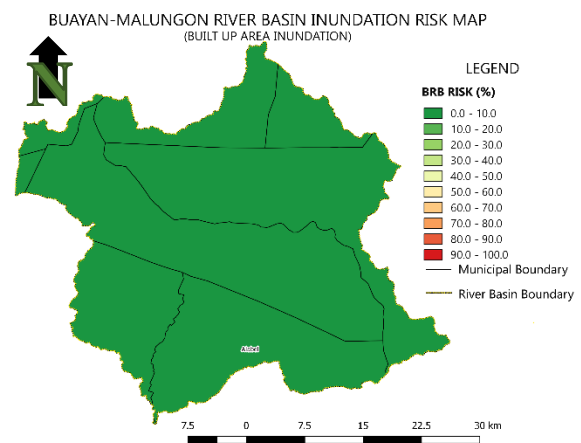


Fig.5 Buayan-Malungon River Basin built-up area risk map

Inundation risk in the BRB will be unnoticeable from 2020 to 2050, with its total inundated area risk decreasing by 0.64%, having no effect on any of the risk categories examined. Overall, 4 out of 8 municipalities in the area are at risk of flooding.

Table 5 Overall flood risk assessment of the Buayan-Malungon River Basin in the A1B1 scenario

Category	Risk (%)	
	The year 2020	The year 2050
Built-Up	0.11	0.11
Roads	0.29	0.29
Dams	0	0
Bridges	0	0

3.2 Adaptation Strategies

3.2.1 Infrastructure maintenance

To reduce flooding and damage in each river basin, proper maintenance of infrastructure must be done to ensure that structures are at their optimal capacity. This will be beneficial not only in extreme events, but also in the “business-as-usual” scenario [8].

For transportation infrastructure, basic maintenance practices should include sealing of cracked or distressed areas, removal of roadside foliage, and grass-cutting. Planting certain species of flora can also prevent soil erosion and stabilize roadsides [23]. A total of 122.81 km, 125.6 km, and 13.31 km of road length is suggested for maintenance and retrofitting in Agno, Cagayan, and Mindanao River Basins, respectively.

Proper drainage maintenance is also necessary to prevent flooding, especially in urban areas. Watercourses must be inspected regularly, and debris must be cleared from drains and culverts to allow proper flow. Outfalls for subsurface drainage systems should also be inspected [23].

3.2.2 Improvement of construction standards

Building concrete-sided buildings instead of metal are recommended since concrete is more resistant to corrosion and wind [8]. Changing the concrete and mortar mix used in adaptation to climate change is also an option. Several improvements can also be done to the drainage systems, such as increasing cross drainage structures, installing hume pipes with larger capacities, and utilizing slab or box culvert cross drains instead of catchpits [24].

3.2.3 Construction of river groynes

Groynes are firm hydraulic structures constructed at an angle to riverbanks, where they limit water velocity to prevent sedimentation and erosion [25]. Siltation and erosion are a major problem in three of the river basins studied (Agno, Cagayan, and Mindanao River Basins) [12-14]. In the Agno, it is recommended to establish a 21.34-km series of groynes in the upstream segments of the Agno River. In the Cagayan River Basin, groynes should be placed upstream of the Magat Dam along the Magat River in the municipalities of Diadi, Bagabag, Lagawe, and Lamut. A total of 33.58 km river length is suggested for construction. In the Mindanao River Basin, groynes may alleviate the siltation of the Liguasan Marsh. A total of 60.71

km of groynes can be constructed in the marsh’s tributaries, including the municipalities of Pagalungan, Pikit and Pagagawan.

3.2.4 Construction of gabions

Gabions reinforce riverbanks and easements by controlling flood or river flow. Their porous nature allows efficient water drainage and silt filtration while preventing erosion [26]. Additionally, gabions are advantageous for their ease of handling, transport, and construction.

Gabions are also a popular choice in existing management plans for the river basins in this study. In the Agno River Basin, a total of 4,400 cubic meters of gabions were planned to be constructed across its river systems, with more than half of the bulk to be erected in the province of Pangasinan [12]. Gabions have also been mentioned in management plans for the Cagayan and Mindanao River Basin [13,14].

3.2.5 Utilization of rainwater harvesting systems

The most direct method of flood alleviation is the construction or installation of rainwater harvesting systems. These projects may be utilized by the whole community or by individual buildings or households. Rainwater harvesting mechanisms have the additional advantage of addressing drought and energy problems.

Small water impounding systems (SWIS) or small water impounding projects (SWIP) are structures used to retain rainfall and runoff, allowing them to be harvested for agricultural or municipal use [27]. To mitigate flooding, SWIS can be constructed at upland areas surrounding the major rivers in each river basin: the Agno River, Tamontaka River, Cagayan River, and Buayan River. The Cagayan region will find the use of SWIS advantageous, as it has been noted that there will be a decrease in rainfall during the months of March, April, and May [2].

Pumped hydroelectric energy storage (PHES) systems are impounding systems that utilize the collected water to generate electricity. PHES obtains electricity by releasing water from a reservoir through turbines. The water can be pumped back up into the reservoir if demand is low [28]. PHES is a good adaptation for climate change, as it handles both flooding and drought by being able to store and release water as required. During typhoon seasons, reservoirs can collect excess rainwater that would otherwise flood into towns.

At smaller scales, the use of rainwater tanks offers several advantages. In Australia, small tanks

(5,000L) provide effective means of storing non-potable water for households, while large tanks are effective for stormwater retention, reducing the strain on groundwater extraction [29]. This makes the installation of rainwater tanks useful in both times of flooding and drought.

3.2.6 Emergency plans

Emergency plans for disaster response in most at-risk areas using the generated risk maps must be formulated and should involve five elements: alerts, evacuations, emergency medical assistance, protection of people and assets, and food and water supply [30].

4. CONCLUSION

The study utilized QGIS to analyze the A1B1 2020 and 2050 inundation maps, and generated risk maps for four river basins in the Philippines (Agno, Cagayan, Mindanao, and Buayan-Malungon River Basins) under four categories: built-up areas, roads, dams, and bridges. The inundation was analyzed by the municipality. This study demonstrates another example of the capability of QGIS to analyze substantial amounts of information using batch processing.

Inundation with a return period of two years was considered. Using other return periods and climate change flood maps could create more options in planning, such as using 50- or 100-year return periods to prepare for strong typhoons and heavy precipitation. This study utilized exposure to generate risk maps. However, including other factors such as susceptibility or resilience can greatly enhance the quality of the resulting risk maps.

It was observed that the Agno, Cagayan, and Mindanao River Basins had problems with inundation around their main rivers. Riverside municipalities, especially those located on river mouths, experience the heaviest inundation.

With the risk maps and areas taken into consideration, several strategies were suggested to mitigate flooding in the four river basins. Possible locations and lengths were given for the construction of gabions, river groynes, SWIS, and road maintenance.

Strategies specifically designed for each municipality, can be gleaned from the results of this study, with focus on the more heavily-inundated key areas.

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