Flood Modelling of the Effect of Tide Fluctuations in Malusac, Sasmuan, Pampanga

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Abstract: - The Philippines' geographic location, which faces the Pacific Ocean and is part of the Pacific Ring of Fire, contributes to its vulnerability to natural catastrophes, particularly floods and other hydrological events. Every year, the country is hit with a lot of storms and rain, which can create flooding in a lot of places, especially around the shore. Rising sea levels increase the risk of flooding, and coastal communities must prepare for this increased risk [1]. Storm events that frequently flood many coastal communities are worsened by sea level rise and climate change. A crucial, but often ignored, aspect of the recurring floods these areas experience is the elevation of the groundwater table in these low-relief coastal cities [2]. In order to solve the growing problem of flooding in Malusac, Sasmuan, Pampanga, a model projecting the different flood effects by the varying tides was created in this study. Also, to be prepared and provide data that will aid the community in dealing with the coastal flood. The methods used were the collection of data including the elevation, boundary, location of the study area and maps, particularly the geologic, vicinity and land use map. All the data were obtained at the Municipality of Sasmuan, Pampanga, namely the Department of Engineering, Municipal Planning & Development Coordinator, and Municipal Disaster Risk Reduction and Management Office. The data gathered will be inputted into ArcScene and ArcMap to run and create the model. At the end of the study, the researchers will also provide a Flood Response Framework to help the community.

Key Words: — ***Groundwater, Sea Level Rise, Coastal Water, Tide Fluctuations, ArcScene, ArcMap.***

I. INTRODUCTION

One factor contributing to the Philippines' vulnerability to natural disasters is its geographic location, which faces the Pacific Ocean and is part of the Pacific Ring of Fire, floods, and other hydrological events in particular. Every year, the country encounters a great deal of storms and rain, which can cause flooding in many locations, particularly in coastal areas.

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Many individuals living in low-lying areas are expected to have substantial flooding-related issues in the next years, whilst those living in coastal towns and cities are likely to face various kinds of difficulties. Some Asian metropolises, in particular, are expected to have greatly increased geographical flooding vulnerability, major increases in the number of flooding episodes, significant damage to buildings and infrastructure, and significant financial costs associated with such disasters [3].

According to [4], ice sheets and glaciers are melting, which is causing coastal dangers and the sea level to rise as a result of the changing climate on Earth. Low-lying coastal regions are among the most vulnerable to the effects of climate change, with more than 300 million people living on coasts worldwide, including 20 of the planet's 33 megacities (more than 10 million inhabitants). Due to intensifying extreme weather in recent

years, this recurring natural disaster causes greater loss of life and property. Storm surges and precipitation frequently occur together to create compound disasters. According to the information that is currently available by Global Facility for Disaster Reduction and Recovery (GFDRR), the coastal flood threat in the region you have selected (the Philippines) is rated as high. This indicates that the coast may experience potentially dangerous waves at least once over the span of the next ten years. In relation to McGuire [5], coastal threats occur when the tides move to the land or to the sea, the area between the two changes. This phenomenon may lead to flood dilemmas and will damage the houses, structures, and properties of the people in the area. But in order to prevent these unpleasant effects, the community will establish programs, structures, and warning systems. Numerical models may be an effective way to save time and money because they may deliver pertinent information in a data-scarce environment [6]. Behera et al. [7] stated that, making appropriate decisions regarding the best use and management of groundwater resources requires the development of groundwater models in conjunction with management models.

One of the developing provinces in the Philippines is Pampanga, which is located in the southern-central section of Central Luzon region experienced the problem particularly in Barangay Malusac in Sasmuan. The Department of Environment and Natural Resources (DENR) – Biodiversity Management Bureau (BMB) declared that Sasmuan Pampanga Coastal Wetland (SPCW) is now a Ramsar Site or Wetland of International Importance. The SPCW is the first Ramsar Site in Central Luzon and eighth (8th) in the country that covers more than 3,500 hectares of coastal waters with four (4) barangays viz. Sebitanan, Mabuanbuan, Batang 1st and 2nd, and lastly, Malusac which is the focus of this study.

With regards to the flood problem of barangay Malusac due to high tide, the researchers conducted a study to create a model to exemplify the tidal fluctuations as the cause of flooding in the community. This study aims to create a flood model, identify vulnerable areas, improve existing Flood Response Plan, and provide Flood Response Framework. It used ArcScene and ArcMap Software to analyze the occurrence of flood within the area. Solutions in avoiding floods or lessening the flow of water were not included, but this can be used as a reference for future study. Moreover, the other barangays of SPCW were excluded from the modeling.

II. Materials And Methods

2.1 Study Area

Barangay Malusac is one of the low-lying areas in Pampanga because of its location that is surrounded by river which make it prone to flooding due to high tide. Malusac is situated at approximately 14.8588, 120.6209, in the island of Luzon. Elevation at these coordinates is estimated at 6.0 meters or 19.7 feet above mean sea level [8]. As of PSA data May 2020, Malusac has 8.46 percent of the total population of Sasmuan, Pampanga which is equivalent to 2,488 residents.

Fig.1. 2D Vicinity Map of Malusac, Sasmuan, Pampanga

2.2 Data Collection

The researchers conducted a data collection process in collaboration with officials from the Municipality of Sasmuan and some were obtained by own formulation of the researchers with the assistance of applications and websites. The collected data was then input into software to simulate flooding caused by tide fluctuations. To determine the location of Barangay Malusac and pumping wells, the researchers employed Google Earth Pro. They used Global Positioning System (GPS) Visualizer to obtain elevation or altitude information, which was then converted into comma- separated values (CSV) format. Quantum Geographic Information System (QGIS) was used to access data on area boundaries relevant to the study. Additional data on pumping well depths was obtained with the assistance of officials from Barangay Malusac. The researchers utilized HydroRivers to gather information on land use, residences, and roads. Contour mapping was accomplished using a toolbar in conjunction with ArcMap.

2.3 ArcMap and ArcScene

ArcMap and ArcScene are the main software that we used for our simulation. Usually, this two software are together. The ArcMap is can be used to assign symbols and to design map layouts, while ArcScene is use to visualize the map layout into 3D model and to see the animation of the output of the model.

2.4 Deep Well Hand Pumps

The researchers obtained the location, total depth, and numbers of the pipes of the deep wells with the help of the Engineering Department of the Municipality of Sasmuan and the Barangay Officials of Malusac. According to the Barangay Officials, there are 15 total of number of deep wells: 13 hand pumps; 2 electric pumps. The depth of each deep well from the natural grade line to the aquifer is 400 ft or 121.92 m.

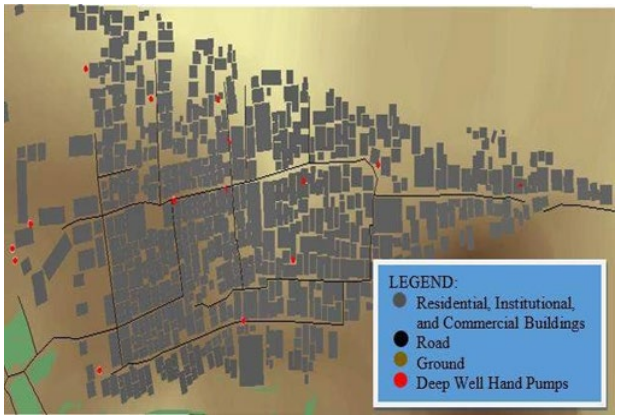

Fig.2.Location of Deep Well Hand Pumps in Barangay Malusac

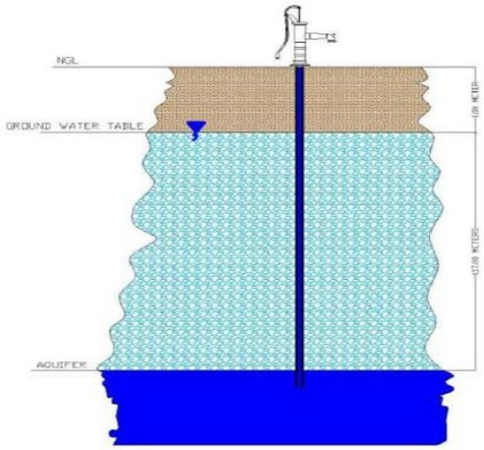

Fig.3. Malusac Detailed Illustration of Deep Well Hand Pump

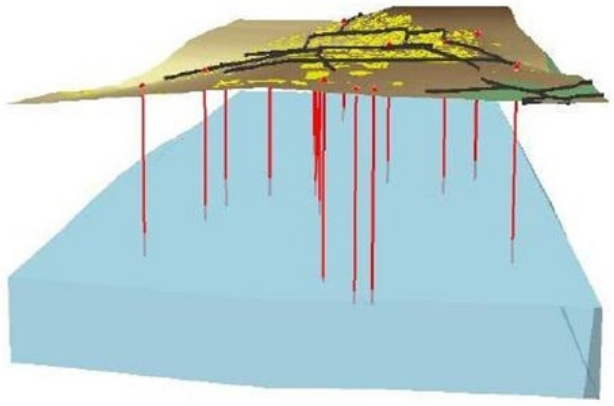

Fig.3. 3D Cross Section of Deep Well Hand Pumps in Malusac

2.5 Elevation

To obtain the elevation, the researchers downloaded the application called GoogleEarth Pro. The steps below narrate how the elevation of the study area was acquired:

STEP1: Open the GoogleEarth Pro then create a path (the area of study). After making the path, export it into KML File to be used in a website which is GPS Visualizer. The file that has been converted from GPS Visualizer is now called GPX File to get the altitude. By using Excel, you can see the coordinates and altitude and after obtaining the coordinates and altitude, you can now go to ArcMap.

ArcMap>File>Add Data (x and y data from the excel)>insert the GPX File>Assign x, y, z coordinates and the altitude>Then press (OK)!

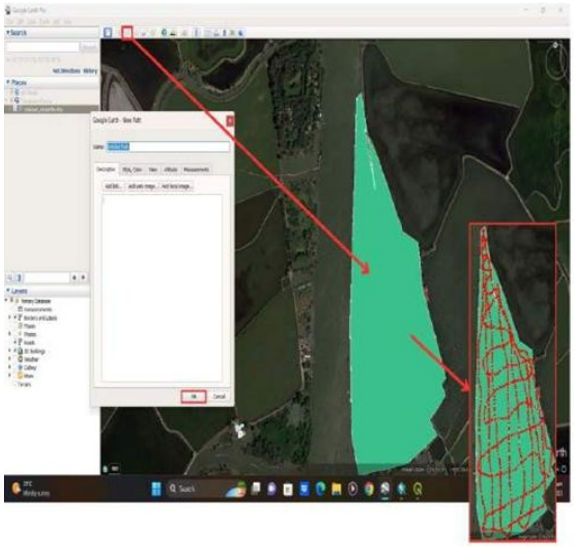

Fig.4. Elevation Coordinates – Malusac, Sasmuan, Pampanga

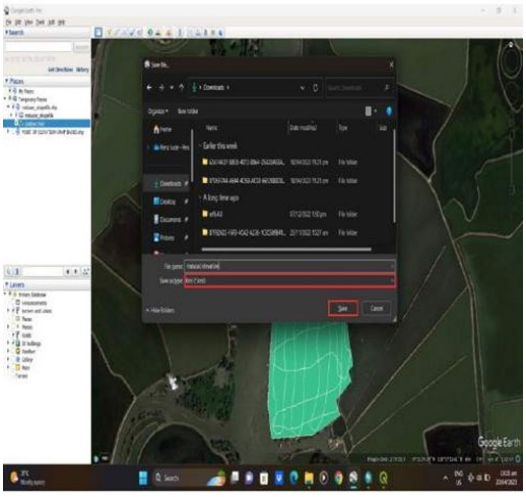

Fig.5. Elevation Coordinates – Malusac, Sasmuan, Pampanga

Fig.6. Coordinates Elevation Visualizer – Malusac, Sasmuan, Pampanga

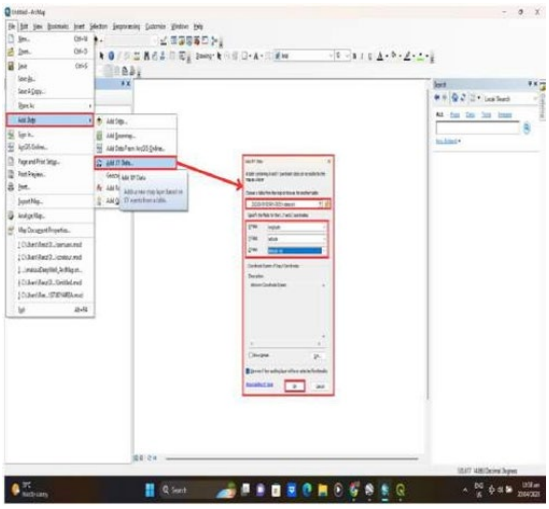

Fig.7. Digital Elevation Model – Malusac, Sasmuan, Pampanga

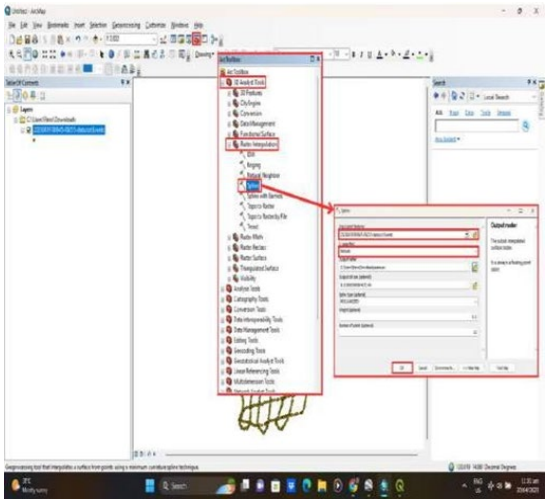

Fig.8. Digital Elevation Model – Malusac, Sasmuan, Pampanga ArcMap>Arc Toolbox>Raster Interpolation>Find the Spline>Input the assigned X, Y, Z coordinates to (Input Point Features)>Save to designated folder>Press (OK) to generate.

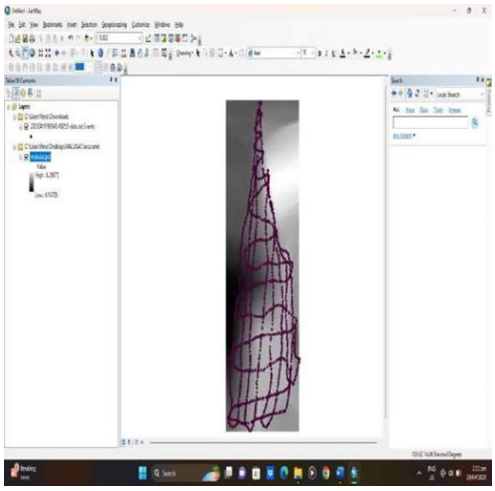

Fig.9. Digital Elevation Model – Malusac, Sasmuan, Pampanga

The figure above is the Digital Elevation Model (DEM) where the light color signifies low elevation and the dark color signifies high elevation.

2.6 Modelling of the Coastal Water Rise Due to Tidal Fluctuations

Step 1: Open the software ArcScene > add data > select DEM file that has been extracted from ArcMap > select add
> right click the data selected > under properties > click base heights > under elevation from surface > floating on a custom surface > elevation from features > change the value to 5.00
> select apply > then the actual elevation will be projected.

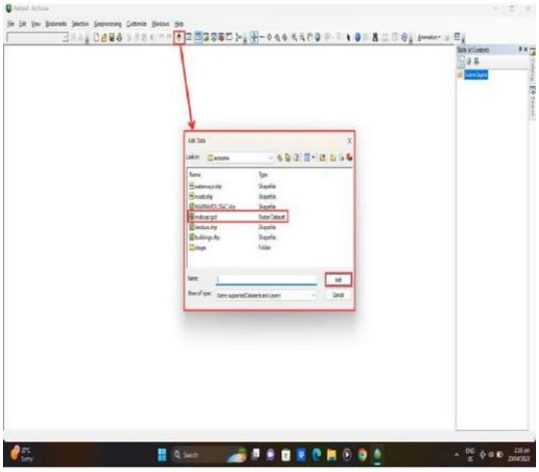

Fig.10. Area Elevation – Malusac, Sasmuan, Pampanga

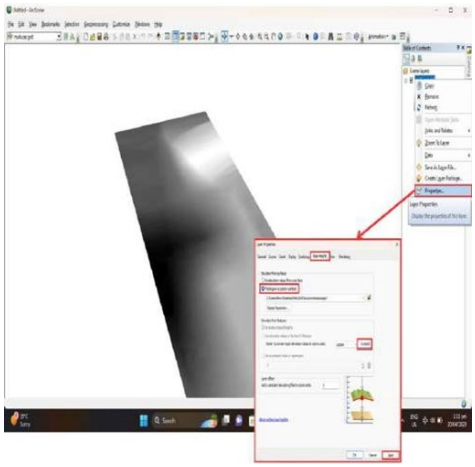

Fig.11. Area Elevation – Malusac, Sasmuan, Pampanga

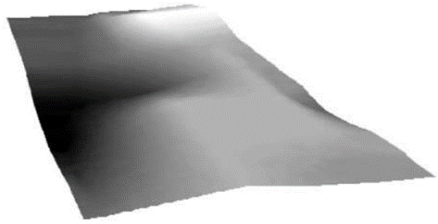

Fig.12. Area Elevation – Malusac, Sasmuan, Pampanga

Step 2: Add data for water > select the file in a shp file type > click add > under properties > click base heights > under elevation from surface > floating on a custom surface > elevation from features > change the value to 3.00 > select apply > go to extrusion > check the extrude features in layer > input value of -115, negative value means downward > select apply > then change color of the both layers.

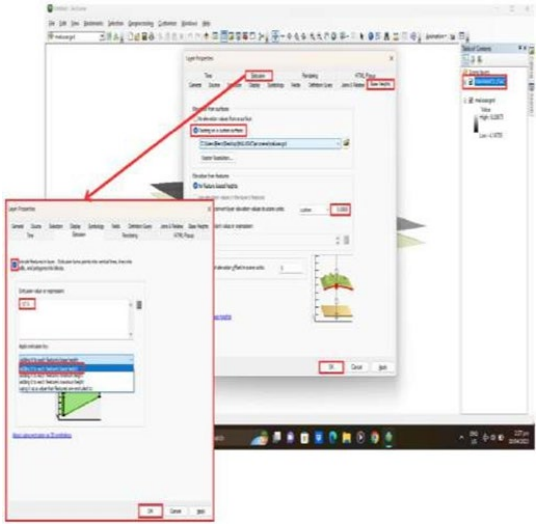

Fig.13. Groundwater Depth/Thickness – Malusac, Sasmuan, Pampanga

Step 3: Under animation bar> select animation manager > click create > under source object > select shp file for groundwater > under destination track > select new > click create, create at least two layers > then close.

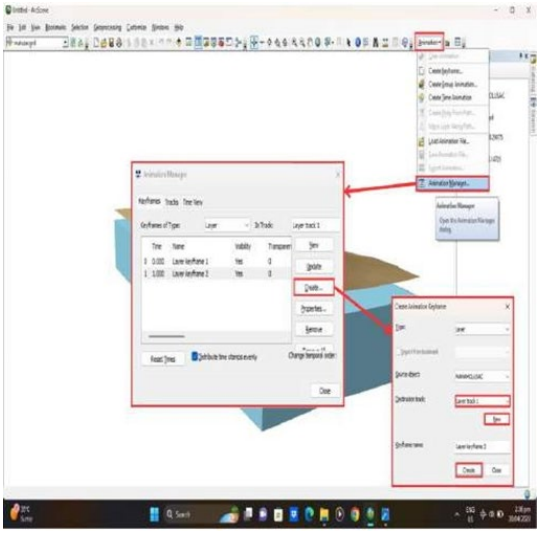

Fig.14. Flood Simulation – Malusac, Sasmuan, Pampanga

Step 4: Open animation control under animation bar > play to show simulation of the rendered data.

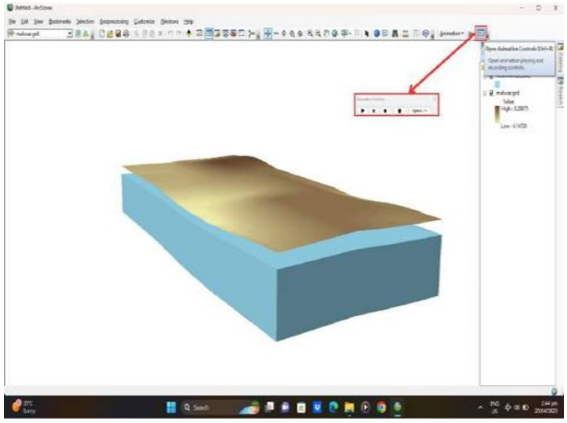

Fig.15. Flood Simulation – Malusac, Sasmuan, Pampanga

2.7 Flood Response Framework

The general response to flooding in Malusac, Sasmuan, Pampanga is outlined and presented by this framework. It will serve as the forecast, preparation, and planning when the flood takes place in the community. This will help the individuals to manage and minimize the risk and damage on the possible effects of the flood.

The aim of the Flood Response Framework is to:

- increase awareness of flood hazard, flood preparation, and flood response, and how the resident's response to the flood that can impact Malusac Sasmuan; and
- discuss the communication procedures utilized in preparation for and during a flood occurrence. This should be applied to improve preparedness.

The main results achieved through the implementation of this framework in flood response planning are:

- people's responsiveness to the impact of flooding in positive outcomes such as the protection of lives and the environment;
- the understanding of the warning system and community response to the flooding incident has significantly increased; and
- the community will be more resilient and aware of the impacts of flooding.

III. Results And Discussion

Modelling of the Sea Level Rise Due to Tidal Fluctuations Paleoclimate records indicate that sea levels have risen by five meters in only one century previously, the general agreement is that such an enormous increase would take place over extended periods of time (hundreds to millennia), (Felongco, 2022). The researchers present up to 4m high of tide for the worst-case scenario that might happen to the community.

3.1 Flood Inundation at 1 meter Height of Tide

1st Scenario: Based on the simulation, the researcher concludes, when the sea level rises at 1m, the barangay Malusac is considered safe from flooding, as the ground capacity can still accommodate and absorbs the water coming from the coastal water, as a result that the water fails to reach the residential area of the Malusac.

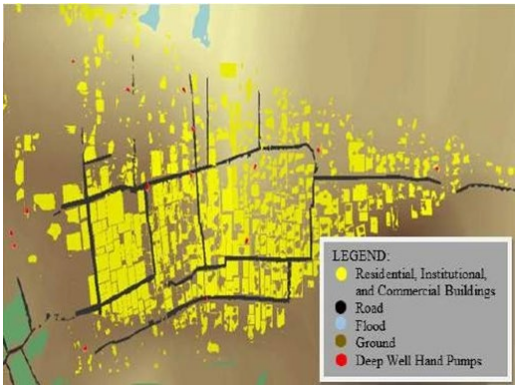

Fig.16. Top View of Tide at 1 meter in Malusac

3.2 Flood Inundation at 2 meters Height of Tide

2nd Scenario: When the sea level rises at 2m, the barangay Malusac is considered safe though some area may experience yellow warning due to possible low flooding that may ranges to a meter of a human body (foot to waist) given that the zones are low-lying and can be easily reached by the water. Thus, the residents shall be ready to organize and lift their belongings in order to avoid such flood impacts.

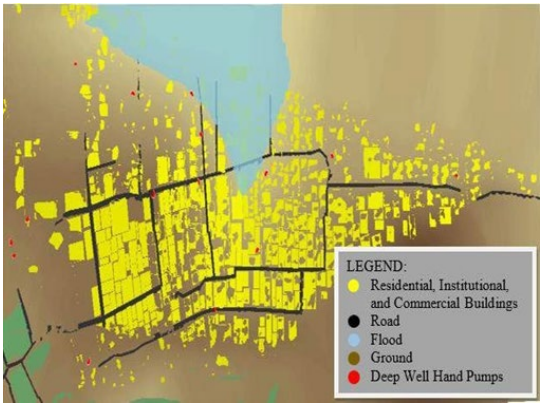

Fig.17. Top View of Tide at 2 meters in Malusac

3.3 Flood Inundation at 3 meters Height of Tide

3rd Scenario: When the sea level rises at 3m, certain areas may experience yellow and orange warning due to mid to high flood elevation in the barangay Malusac which ranges with a maximum height of 2m or an average height of a human. Consequently, residents shall be alert and prepared to evacuate when announced.

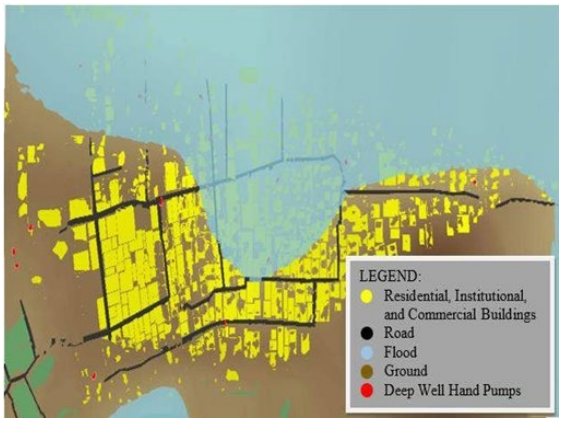

Fig.18. Top View of Tide at 3 meters in Malusac

3.4 Flood Inundation at 4 meters Height of Tide

4th Scenario: When the sea level rises at 4m, at this moment, the whole community must be evacuated and prepared since the red warning signal has been reached. Due to the extreme flooding, the Barangay Officials together with the residents of the area must be ready for the worst scenario that can happen.

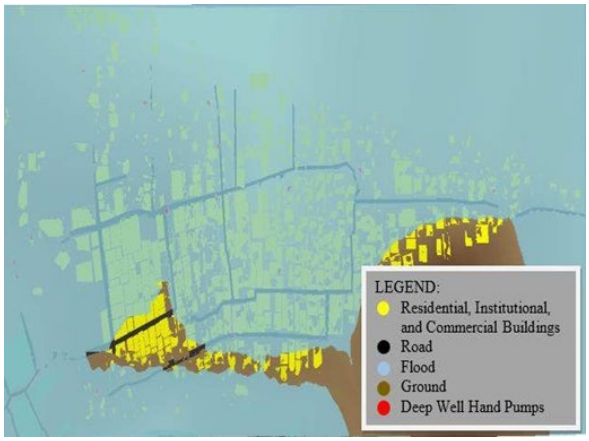

Fig.19. Top View of Tide at 4 meters in Malusac

3.5 Flood Response Framework

The researchers created a framework for the emergency plan of the community based on the findings of the simulation, this includes the warning system, early warning signs and evacuation map. This would help the residents of barangay Malusac to be prepared according to forecasted information on the modelling.

3.5.1 Warning System

The warning system created by the researchers are color coded signals depending on the severity of the possible flood that may occur in certain areas of the community, that shows the probable height of the flood for each of the varying sea level rise.

GREEN SIGNAL: "Safe" – Possible 1m sea level rise that may result to a low to no flood at all.

YELLOW SIGNAL: "Caution" – Possible 2m sea level rise that may result to a maximum of 1m height of flood. The residents shall be cautious and alert for advisory of the barangay officials.

ORANGE SIGNAL: "Threatening" – Possible 3m sea level rise that may result to a maximum of 2m height of flood. The flood is considered a threat; thus, the residents shall evacuate. **RED** *SIGNAL:* "Danger" – Possible 4m sea level rise that may result to a maximum of 3m height of flood. The flood is already a danger; thus, the residents shall evacuate immediately.

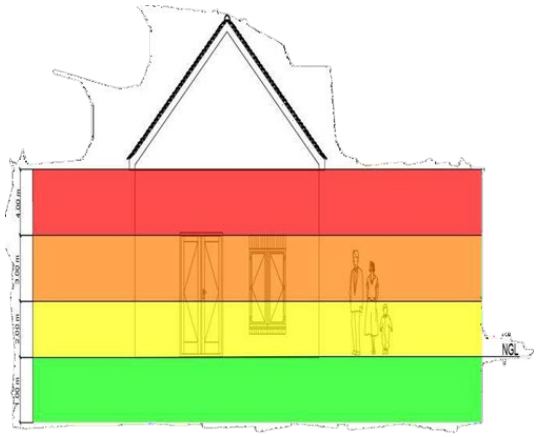

Fig.20. Flood Warning Levels

Fig.21. Flood Prone Areas at 1 meter (based on Flood Warning Levels)

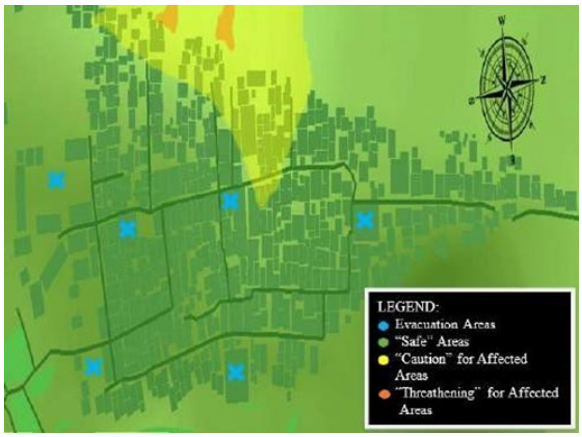

Fig.22. Flood Prone Areas at 2 meters (based on Flood Warning Levels)

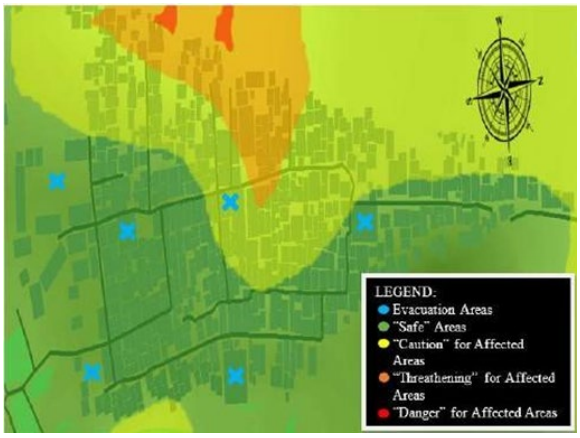

Fig.23. Flood Prone Areas at 3 meters (based on Flood Warning Levels)

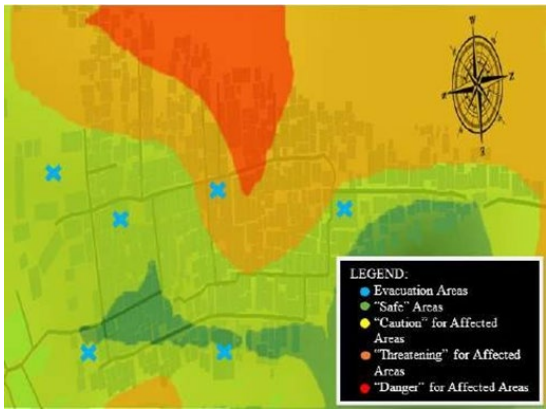

Fig.24. Flood Prone Areas at 4 meters (based on Flood Warning Levels)

3.5.2 Early Warning Signs

Barangay Malusac is surrounded by bodies of water and is considered as one of the low-lying areas of Sasmuan, Pampanga. Hence, they have early warning signs which were last updated in the year 2017. In view of that, the researchers made an updated early warning sign in the use of the simulation as its basis.

Table.1. Early Warning Signs in Malusac (original) - 2017

KAPAG NAKITA ANG KULAY NG BANDILA	NARINIG ANG KAPMANAO SIRENA	Ito ang ibig sabihin	Ito ang dapat gawin
WHITE AND YELLOW FLAG	Walang pagtunog	Mayroong paparating na bagyo na maaaring tumama sa ating probinsya	Ihanda at itaas ang mga gamit para sa posibleng pagtaas ng tubig.
YELLOW FLAG	Walang pagtunog	Mayroong posibilidad ng malakas na pag ulan na maaaring magdulot ng pagbaha sa low-lying areas sa loob ng isang oras higit pa	Ihanda at itaas ang mga gamit para sa posibleng pagtaas ng tubig. Ihanda ang GO-bag
ORANGE FLAG	Mahabang pagtunog na may pagitan ng 10 segundo sa isang minute.	Mayroong posibilidad ng malakas na pag ulan na maaaring magdulot ng pagbaha sa low-lying areas sa loob ng isang oras higit pa	Tignan ang sitwasyon at mag-preemptive evacuation kung kailangan.

RED FLAG	Mahaba at tuloy tuloy na pagtunog sa isang minuto	Mayroong malakas at mapaminsal ang pag-ulan na maaaring magdulot ng matinding pagbaha sa mga high-risk areas sa loob ng isang oras at higit pa.	Pumunta sa designated pickup point ng barangay at evacuation center.
BLUE FLAG	Mahaba at tuloy tuloy na pagtunog sa isang minuto	Possible ang storm surge o tsunami sa mga coastal barangay	Pumunta sa designated pickup point ng barangay o evacuation center sa mataas na lupain.

Table.2. Early Warning Signs in Malusac (updated) – FILIPINO

KAPAG NAKITA ANG KULAY NG BANDILA	NARINIG ANG KAPMANA O SIRENA	Ito ang ibig sabihin	Ito ang dapat gawin
GREEN WARNING	Walang pagtunog	Maaaring may pagtaas ng tubig na hindi hihigit sa isang metro.	Ihanda at itaas ang mga gamit para sa posibleng pagtaas ng tubig. Ihanda ang GO-bag.
YELLOW WARNING	Mahabang pagtunog na may pagitan ng 5-10 segundo sa isang minute.	Maaaring may pagtaas ng tubig na hindi hihigit sa dalawang metro at mayroong posibilidad na bumaha meal talampakan hanggang bewang	Itaas ang mga gamit para sa posibleng pagtaas ng tubig. Ihanda ang GO-bag. Maghanda sa possibleng paglikas kung kinakailangan.
ORANGE WARNING	Mahabang pagtunog na may pagitan ng 15-20 segundo sa isang minute.	Maaaring may pagtaas ng tubig na hindi hihigit sa tatlong metro at mayroong posibilidad na bumaha mula talampakan hanggang ulo.	Tignan ang sitwasyon at mag- handa sa pagpunta sa pinakamalapit na evacuation center
RED WARNING	Mahaba at tuloy tuloy na pagtunog sa isang minuto	Maaaring may pagtaas ng tubig na hindi hihigit sa apat na metro at mayroong posibilidad na bumaha mula talampakan hanggang biga ng bahay.	Pumunta na sa pinakaligtas evacuation center o maghanda sa possibleng paglikas kung kinakailangan.

Table.3. Early Warning Signs in Malusac (updated) - ENGLISH

WARNING SIGNALS	HEARD THE BELL OR SIREN	MEANING OF THE BELL'S SOUND OR SIREN'S SOUND	THINGS THAT NEED TO DO:
GREEN WARNING	No sound	A maximum of one-meter sea level rise is possible.	Prepare and raise objects in preparation for potential high-water levels. Prepare the GO-Bag.
YELLOW WARNING	Long alarms sound that happens every 5-10 seconds or less.	There may be a sea level rise of more than two meters, and there is a possibility of flooding from the feet to the waist.	Raise objects for potential high-water levels. Prepare the GO-Bag. Prepare to evacuate if necessary.
ORANGE WARNING	Long alarms sound that happens every 15-20 seconds or less.	There may be a sea level rise of more than three meters, and there is a possibility of flooding from the feet to the head.	Check the situation and get prepared to evacuate to the nearest evacuation center.
RED WARNING	Long and continuous alarm sounds that happen every 1 minute.	There may be a sea level rise of more than four meters, and there is a possibility of flooding from the feet to the beams of the house.	Go to the closest safe evacuation center or prepare to evacuate if necessary.

3.5.3 Evacuation Map

In accordance to the research findings and observations during the site visit, prone areas around Malusac were distinguished, with that, evacuation map was developed and may possibly use by the community.

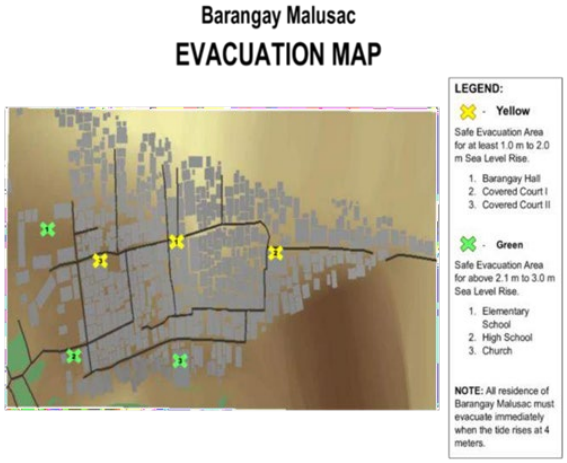

Fig.25. Evacuation Map of Barangay Malusac, Sasmuan, Pampanga

IV. Conclusion And Recommendations

The researchers conducted a study on the flood effects of sea level rise in Barangay Malusac, Sasmuan, a coastal area in the province of Pampanga. The objective of the study was to create a simulation that could help the community forecast different scenarios during high tide. The researchers have analyzed the findings and developed a model that demonstrates that Barangay Malusac is prone to flood due to sea level rise. The area has a shallow ground level and is considered one of the low-lying areas in the municipality. Additionally, its geographical location is surrounded by water bodies, which leads to saturated ground surfaces. The study has successfully achieved its objective of helping the community predict potential flooding caused by sea level rise through the simulation. The results will enable officials to understand the impact of rising sea levels on the community and identify areas that are most vulnerable to flooding. It also provides a new flood response framework for officials and residents to better prepare for future floods. In conclusion, according to the model created, sea level rise during high tides may result in flood heights ranging from 1 to 3 meters. In a worst-case scenario where the tide reaches a maximum of 4 meters, causing flooding throughout the community, residents are advised to evacuate from the barangay.

In regard to the limitations observed and the study's conclusions, future researchers might consider including the rainfall data to further investigate the flood in the community and can also use this study to deeply assess the interaction of wells with groundwater to evaluate the quality of water. In addition to that, future researchers may further develop this simulation by incorporating the time duration of the flood to improve and to raise awareness and preparation in the community and may use this study as a reference to propose a flood structure design to conduct a new study. Furthermore, future researchers may use this as a guide to conduct another research or simulation to its bordering coastal land area (e.g., Batang 1st & 2nd, Sebitanan, Mabuanbuan). Since this research has already provided the Flood Response Framework for the community, involvement of the residents is highly recommended to evaluate the effectiveness of the simulation and the framework. Future researchers may expand this study by including the simulation for the intrusion of the groundwater and the surrounding water bodies in the community. Moreover, they might also consider coordinating with different departments, MGB, MDRRMO, NAMRIA and PAGASA for accurate and credible data to improve the simulation.

REFERENCES

[1]. G. E. Jóhannsdóttir, "Methods for Coastal Flooding Risk Assessments: An Application in Iceland," DIVA, 2019.

[2]. B. D. Bowes, J. M. Sadler, M. A. Morsy, M. Behl, and J. L. Goodall, "Forecasting Groundwater Table in a Flood Prone Coastal City with Long Short-term Memory and Recurrent Neural Networks," Water, vol. 11, no. 5, p. 1098, May 2019.

[3]. A. Howard, K. Agllias, M. Bevis, and T. Blakemore, "'They'll tell us when to evacuate': The experiences and expectations of disaster-related communication in vulnerable groups," International Journal of Disaster Risk Reduction, vol. 22, pp. 139–146, Jun. 2017.

[4]. G. B. Griggs and B. G. Reguero, "Coastal Adaptation to Climate Change and Sea-Level Rise," Water, vol. 13, no. 16, p. 2151, Aug. 2021.

[5]. C. McGuire, "Adapting to Sea Level Rise in the Coastal Zone: Law and Policy Considerations Download (225 Pages)," 2013.

[6]. A. Akter and S. Ahmed, "Modeling of groundwater level changes in an urban area," Sustainable Water Resources Management, vol. 7, no. 1, Jan. 2021.

[7]. A. Behera, R. P. Pradhan, S. Kumar, G. J. Chakrapani, and P. Kumar, "Assessment of Groundwater Flow Dynamics Using MODFLOW in Shallow Aquifer System of Mahanadi Delta (East Coast), India," Water, vol. 14, no. 4, p. 611, Feb. 2022.

[8]. "Malusac, Sasmuan, Pampanga Profile – PhilAtlas."