RESEARCH ARTICLE OPEN ACCESS

Flood Risk Mapping and Proposed Mitigation Techniques for the Residential Alleys of Tinajero, Bacolor, Pampanga using ArcGIS

Trax Ezra C. Tolentino*, Jessa Mae D. Pineda*, Kristian Carlo N. Sapnu*, Kristine C. Sison*, Julia Andrei S. Uncad*, Francis Cayanan**, Aaron S. Malonzo**
*(Department of Civil Engineering, Don Honorio Ventura State University, Pampanga, Philippines
Email: traxezratolentino4@gmail.com)

--************************----------------------------------

Abstract:
As a persistent concern worldwide, flooding impacts people, possessions, and infrastructure, including the Philippines. As one of its aids, a flood risk map is a tool for identifying risk areas concerning the global problem. This study aimed to generate a flood risk map and formulate mitigation techniques focusing on the flood-prone regions of Tinajero, Bacolor, Pampanga. ArcGIS software was utilized in the process, together with interview questionnaires that were used to gather relevant information that helped assess the problem based on the experiences of every resident. The result of the flood risk map showed that Zones 1 and 2 demonstrated higher risk than in Zone 3. However, a certain part of Zone 3, located at the San Guillermo Resettlement Village, showed high risk. In addition, interviews with the residents affected by flooding experience the recurring problem at least twice a year, leading to injuries, health issues, and evacuation. They also experienced an economic burden that resulted from borrowing money to renovate and recover. Additionally, in minimizing the flood damage in the area of Tinajero, Bacolor, Pampanga, a few proposed mitigation measures were formulated based on the generated map and responses from residents, these include: providing boats in Barangay Tinajero to aid rescue efforts, particularly for affected residents during floods; opening the creek for improved water flow; fixing the clogged drainage system for efficient water management during heavy rainfall; creating employment and business opportunities; conducting flood preparation discussions; implementing proper waste management practices; and initiating tree planting projects as a contribution to the overall resilience and sustainability of the community.

Keywords **—Flooding, Flood Risk, Flood Risk Map, ArcGIS, Mitigation Techniques**

--************************----------------------------------

I. INTRODUCTION

Floods are a diachronic and global phenomenon that has an impact on many people, property, and infrastructure [1]. The International Disaster Database (EM-DAT) reports that among weather-related disasters, floods are the most frequent and devastating in terms of the number of people impacted: inundations have had an impact on almost 1 billion people in the past ten years (2006-2015), and the total economic damage is estimated to be over 300 billion U.S. dollars [2]. Having this said, numerous eminent scientists believe that flooding events have increased worldwide during the past few years because of climate change [3].

About one-third of all natural disasters are flooding. They account for 77 percent of the economic damages from extreme weather events and storms [4]. Hence, the global number of flood disasters decreased from 222 in the previous year to 176 in 2022 [5].

In the Philippines, flooding is a significant ongoing issue throughout the monsoon season, made worse by low-pressure areas (LPA) that intensify into tropical storms and typhoons. The archipelago is regarded as being in the "Typhoon Alley" in the western Pacific, with 20 tropical storms passing annually through the Philippine Area of Responsibility (PAR), most of which originate in the Pacific [6].

Subsequently, climate change, inadequate drainage, and rising agricultural enterprises have made flooding in the Philippines a risk throughout time. About 94 percent of affected building characteristics in all flood scenarios are found in residential buildings connected to the local community, making them the most vulnerable to flood dangers [7].

In Pampanga, the amount of flooding affecting households has risen to 125,301 families or 429,976 individuals. The floodwater flows towards lower areas, so at least 1,487 families have been compelled to move to evacuation centers[8].

The dedicated Geographic Information System (GIS) software will analyze potential floods in the study area. Arc Geographic Information System (ArcGIS)is a software program for managing and studying geographical information, which involves visualizing statistical data about the Earth's geography, such as climate patterns or trade movements, by creating layered maps [9]. The client, server, and online GIS software ArcGIS is designed to meet the evolving needs of delivering a comprehensive and scalable GIS platform [10].

The ArcGIS software will address the flooding issue in the community of Tinajero, Bacolor by implementing engineering intervention strategies. A comprehensive analysis of the flood risk in the area will be conducted, considering various parameters that will serve as a layer for flood risk assessment. This analysis will generate a flood risk map, which will serve as the foundation for the development and execution of effective flood mitigation techniques. This study aims to create a more resilient community that can withstand climate change and natural disasters.

Using GIS software and multi-criteria analysis, mapping flood risks is an effective means of identifying areas that are susceptible to flooding. This method aids water resources planners and decision-makers in drawing attention to areas that require more extensive evaluations of flood risks, such as utilizing hydrological and hydraulic models. This streamlined yet dependable process can significantly decrease resource demands while producing relatively precise flood risk assessments [11]. Moreover, a flash flood mapping system was created. This system proved to be successful in identifying specific regions within flood-prone areas. It has advantageous impacts on urban and infrastructure planners, risk managers, and emergency services personnel who respond to drastic and severe rainfall circumstances [12].

The flood risk assessment is commonly utilized to gain insight into flood disaster evaluation and enhance warning and awareness efforts [13]. In addition, the most efficient approach to mitigate damage from natural calamities is implementing an urban flood risk assessment model that considers aspects of urban planning like building features and land usage. The research related to that advocates for regulating vulnerable flood-prone areas and high-risk sites during land development planning to lessen harm [14].

1.1 Background of the Study

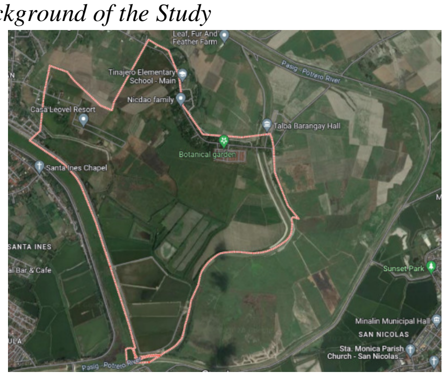

Figure 1. Map of Tinajero,Bacolor, Pampanga

Barangay Tinajero, situated in Bacolor, Pampanga, has endured a disastrous history brought by catastrophic events. In a preliminary interview with a barangay official from Tinajero, several pieces of evidence highlighted a significant issue facing the town. In 1991, the barangay was severely affected by the turbulent aftermath of Mount Pinatubo's volcanic eruption, followed by devastating floods in 1995.

The residents of Tinajero revealed that Tinajero used to serve as a location for fishing, agriculture, and the cultivation of *sasa* (a plant used to produce vinegar) in the past. The place itself is also low-lying and near rivers, making it suffer from frequent floods. In the past, the main sources of livelihood in Tinajero were fishing and farming, but these have disappeared ever since the entire area was buried by lahar following the eruption of Mount Pinatubo in 1991.

Figure 2. Flooding in Tinajero, Bacolor, Pampanga
Retrieved from: https://news.abs-cbn.com/tvpatrol

Figure 3. Flooding in Tinajero, Bacolor, Pampanga
Retrieved from: https://news.abs-cbn.com/tvpatrol

Shared by the barangay residents, as the town is nestled in a lowland area, Tinajero's geographical vulnerability places it at high risk of flooding; during periods of moderate precipitation, the barangay experiences flooding, persisting for approximately one week before subsiding. In a recent flooding event in the barangay, as depicted in the figures above, the area was severely affected by prolonged heavy rainfall lasting approximately a week caused by Typhoon Egay. The flooding surpassed the breast water level, indicating a significant and detrimental impact on the community. This recurring issue adversely affects the residents' primary source of income - agriculture. The livelihoods of many inhabitants have suffered due to the frequent inundation of their lands.

In 2016, while concreting the barangay's roads, the drainage system was not correctly designed or completed, resulting in ongoing difficulties related to flood management. Although the drainage infrastructure is visible in the main roads of the barangay, some sections of it are currently non-functional.

Additionally, the constant passage of heavy equipment during the construction of a dike crossing Tinajero and Talbaworsened the condition of the barangay roads, causing rapid deterioration.

In the barangay under study, variations in elevation exist, with Zone 1 being the highest. Even though Zone 2 is the lowest, some parts of Zone 3 are still the most susceptible to floods. The barangay official reported that severe flooding consistently occurs in San Guillermo Resettlement Village within Zone 3, with water levels exceeding neck level.

The barangay official also mentioned that even without rain, the San Guillermo Resettlement Village in Tinajero experiences flooding, particularly when water is released from the dam. Areas in lower elevations are quickly submerged in these instances. With this, San Guillermo Resettlement Village residents in Tinajero are forced to evacuate as the floodwaters rise. This adds to the already challenging situation for the community, which is dealing with the impact of flooding during the rainy season.

Barangay	Elevation (ft)	Barangay	Elevation (ft)
Balas	118	Mesalipit	23
Cabalantian	39	Parulog	46
Cabambangan	22	Potrero	144
Cabetican	33	San Antonio	75
Calibutbut	217	San Isidro	62
Concepcion	62	San Vicente	36
Dolores	105	Sta. Barbara	92
Duat	115	Sta. Ines	23
Macabacle	36	Talba	22
Magliman	52	Tinajero	19
Maliwalu	164	---	---

Table 1. Elevations of Barangays in Bacolor, Pampanga

As seen in the table above, each barangay in the Municipality of Bacolor have varying elevations. The data emphasizes how vulnerable these areas are to flooding. Highlighted in red, Barangay Tinajero, having the lowest elevation, is the most susceptible to floods among the other barangays in Bacolor. This then offers concrete evidence of the increased likelihood of floods in Tinajero.

To solve the flooding issues after recognizing the urgent necessity for mitigation measures, the local government of Tinajero has reconstructed the neighboring Pasig-Potrero River. However, the detrimental effects of floods are still being felt by the residents, nonetheless, in spite of these actions, highlighting the complexity of resolving these issues in a lasting manner.

1.2 Objectives of the Study

The primary objective of this research is to create a flood risk map and propose flood mitigation techniques for the barangay of Tinajero in Bacolor, Pampanga. The researchers have evaluated the susceptibility of Tinajero, Bacolor, Pampanga by evaluating seven principal parameters: rainfall, drainage density, distance to river, distance to road, elevation, slope, and land cover. Then, a face-to-face interview was conducted with the residents of Tinajero that examined the impact of floods on their lives, focusing on their safety, health, and economic aspects.

1.3 Significance of the Study

The study will provide significant benefits for various stakeholders such as the residents, local government, future developers, and future researchers.

1.4 Scope and Delimitation

This research concentrated on evaluating flood exposure and creating strategies to reduce flooding in the alleys of Tinajero, Bacolor, Pampanga. The study focused on collecting data and evaluating the susceptibility of these regions to flooding along with suggesting customized methods for preventing and reducing flood risks. The study did not explore the design elements of the suggested mitigation strategies due to time constraints, within the research project.

The study was conducted in specific areas within Tinajero, Bacolor, Pampanga, to ensure that the data collection, analysis, and the formulated flood mitigation techniques appears solely on the affected areas.

The research timeline spanned five (5) months starting from the data collection, to the completion of the suggested mitigation strategies. The researchers utilized ArcGis as the primary tool for flood risk mapping in Tinajero, Bacolor, Pampanga. The flood vulnerability assessment did not include commercial areas or industrial zones as the study focused on the residential alleys in the study area where most people are affected. The elements related to flooding such as water quality or ecological impact were also not included.

Overall, this research aimed to understand thoroughly the flood risk in the residential alleys of Tinajero, Bacolor, Pampanga and the proposed flood mitigation techniques that are suitable in the study area. The scope of the study ensured that it remains focused and relevant to the objective of flood risk assessment and mitigation solely within the residential alleys of Tinajero, Bacolor, Pampanga.

1.5 Conceptual Framework

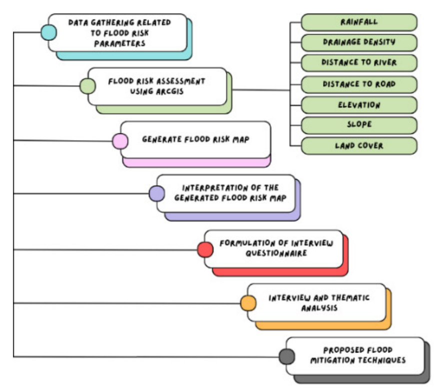

Figure 4. Conceptual Framework

II. METHODOLOGY

2.1 Research Design

This research employed both quantitative and qualitative research methods. This combined method involved collecting and analyzing numerical and narrative data to comprehensively understand a research problem [15]. The quantitative component used a descriptive design to systematically obtain information and describe phenomena, situations, or populations [16]. Quantitative research involves collecting and analyzing numerical data to understand patterns or relationships between variables [17]. In this study, the researchers used ArcGIS to analyze several geographical and environmental data, which are primarily quantitative, such as elevation, slope, rainfall, drainage density, distance to river, distance to road, and land cover, to create a flood risk map. The tools and methods that were used are within the ArcGIS software to provide quantitative outputs and measurements, to create spatial analysis.

2.2 Research Instrument

First is the ArcGIS software that facilitated the collected data through a numbers of research instruments forming a unified platform for visualization and comprehensive analysis. This application helped in creating a detailed flood risk map, highlighting the areas that are susceptible to flood.

Second, the use of an interview questionnaire, which was formulated to gather information from the first-hand experiences of the residents during the flood events, focusing mainly on the health, safety, and economic effects of it in their daily lives. Subsequently, suitable flood mitigation techniques were structured based on the map generated, as well as the responses of the participants, and observations of the researchers.

2.3 Data Collection Method

Rainfall. The Annual Rainfall Map for Tinajero, Bacolor, Pampanga was acquired from the Climatic Research Unit's CRU TS v4.07 Data Variables: PRE data, and utilized the 2011-2020 dataset. The generated map was reclassified into five classes.

Drainage density. The data was obtained by digitizing the drainage features from high-resolution satellite images. Higher drainage density values indicated lower infiltration rates and higher surface flow velocity[18]. After being processed in ArcGIS, the map was reclassified into five classes.

Distance to river. Using the HydroSHEDS database, the shapefile for rivers in the study area was obtained. Then the map was generated in ArcGIS and was reclassified into five classes.

Distance to road. The data collected for the distance to road was obtained from the Open Street Map. After generating the map based on the distance to the road of the study area, it was reclassified into five classes.

Elevation. The OpenTopography Data DEM was utilized to obtain elevation data and then processed using ArcGIS. The DEM provides detailed elevation information in each area, enabling the researchers to create an elevation map for Barangay Tinajero.

Slope. The researchers utilized the USGS EarthExplorer Datasets to gather the slope data, and then it was processed in ArcGIS. The resulting slope map illustrates the steepness of the terrain at each part of the Barangay Tinajero.

Land Cover. The land cover data in generating a landcover map was obtained through the USGS EarthExplorer Datasets. After utilizing ArcGIS to analyze the data, the software generated detailed classifications for the land cover of the study area. Using the MCD12Q1 International Geosphere-Biosphere Programme (IGBP) legend and class descriptions, the land cover for Barangay Tinajero was classified into four [29] [19].

In addition to analyzing and generating the flood risk map, researchers gathered relevant information from the residents of Tinajero through face-to-face interviews.

The interview questionnaires were aligned with the research problem. They were validated by a Municipal Disaster Risk Reduction Management (MDRRM) Officer of Bacolor, a Barangay Disaster Risk Management Official, and a Language Validator.

2.4 Sample Size

Ten (10) respondents were selected for the study, with a focus on individuals residing along the residential alleys in Tinajero[20]. In qualitative research, there are no definitive rules when it comes to choosing the right sample size. Rather, factors including the allotted time, the resources at hand, and the research's stated objectives frequently have an impact on it [21].

III. RESULTS AND DISCUSSIONS

Through ArcGIS, the study area encompassed the entire barangay of Tinajero in Bacolor, Pampanga.

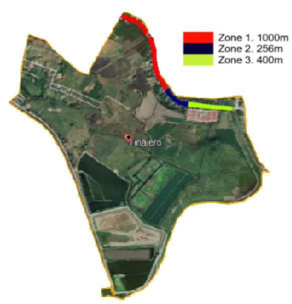

Figure 5. Map of Tinajero, Bacolor, Pampanga

3.1 Rainfall

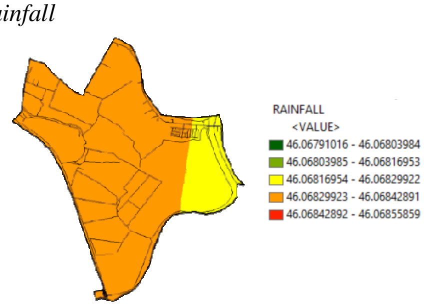

Figure 6. Rainfall Map

Rainfall plays a crucial role in the occurrence of floods. As the rainfall volume increases, so does the surface runoff, which in turn raises the likelihood of flooding. This implies that areas with higher precipitation levels face a greater potential for flood-related issues [22]. Intense rainfall may overpower natural water channels, causing water to gather in low-lying zones. The hazards of flooding can be detrimental to both human settlements and critical infrastructure, posing significant challenges for those living and working in these regions [23].

The rainfall map, illustrated with a numerical categorization, showcases varying rain intensities. The values are arranged from lowest to highest, ranging from 46.06791016 to 46.06855859. These values are represented by the average depth per month, expressed in millimeters (mm/month) [24]. In studies with a smaller area, it is common to observe limited variations in the data collected. This can be attributed to the reduced complexity and heterogeneity within the study area [25]. The red markings denote very heavy rainfall, while the transition to green indicates decreased precipitation.

The provided map illustrates that Tinajero's rainfall distribution varies across its zones. In Zones 1 and 2, heavy rainfall is prevalent throughout, while Zone 3 experiences heavy precipitation in approximately half of its area. Conversely, the remaining half of Zone 3 witnesses moderate rainfall.

Given the varying rainfall patterns across Tinajero's zones, it is inferred that the risk of flooding varies within these zones. In Zones 1 and 2, which experience uniform heavy rainfall, the risk of flooding is generally higher due to the increased likelihood of intense precipitation events. This can lead to potential waterlogging, overflowing of water bodies, and inundation of low-lying areas, posing a significant threat to the communities, infrastructure, and ecosystems in these zones.

In Zone 3, the risk of flooding is not uniform across the entire zone. The half with heavy rainfall share a similar risk profile as Zones 1 and 2, including a certain portion of the resettlement village situated at its left side, making them prone to flooding during heavy rainfall events. However, one-third of Zone 3 with moderate rainfall experiences a relatively lower risk of flooding compared to the heavily rainfall-affected areas. Nevertheless, this does not mean that this part of Zone 3 is entirely flood-safe, as the risk can still increase during extreme weather conditions or when the rainfall intensity escalates.

3.2 Drainage Density

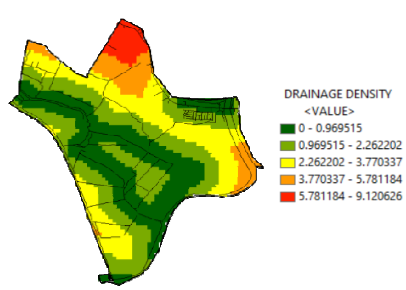

Figure 7. Drainage Density Map

The drainage density serves to characterize the distribution and spacing of the catchment's drainage system [26]. This is represented by the total length of channels per unit area of the watershed, which is expressed as kilometers per square kilometer (km/km^2) [27]. Within the context of drainage density classification, the values range from less than 2 to greater than 8 [28]. The map provided illustrates a range of values, generated by ArcGIS, arranged from the lowest to highest, with values spanning from 0 to 9.120626.

In this context, high values marked in red indicate very high drainage density. Values marked in orange signify high drainage density, while yellow markings represent moderate drainage density. A green and yellow legend denotes low drainage density, and the transition to a 0 value marked in green implies a very low drainage density. High drainage density values indicate reduced infiltration rates, increased surface flow velocity, and heightened sediment yield, all of which are notable contributors to flood occurrences [29].

Therefore, in this area of Tinajero, Bacolor, Pampanga, Zone 1 is categorized with red, orange, and yellow, indicating very high, high, and moderate drainage density.

On the other hand, Zone 2 has yellow and light green colors representing moderate and low drainage density.

In Zone 3, there is a light green that is visible in the resettlement village and a dark green color indicating low to very low drainage density.

It can be inferred that Zone 1 experiences a slow infiltration rate and has an increase in surface flow velocity, resulting in a high likelihood of flooding due to the slow infiltration of water into the soil and a higher chance of water accumulating in this area. In Zone 2, the runoff and water filtration are moderate to low, with a slightly higher drainage density compared to Zone 3. In Zone 3, there is low drainage density, indicating a reduced likelihood of water flowing out but faster infiltration into the soil, making it less prone to flooding.

3.3 Distance to River

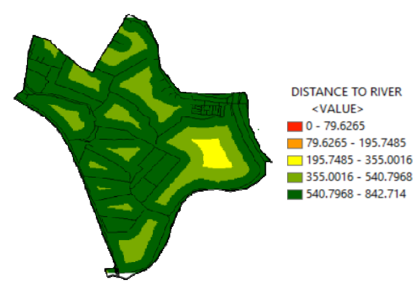

Figure 8. Distance to River Map

In the research, a graphical representation of the river's distance uses a color scale. It starts with red for the range of 0 to 79.6265, indicating the shortest distance to a river, and then transitions to dark green, symbolizing the farthest distance. Regarding ArcGIS mapping standards, measurements within the 1.00 range are generally indicated in meters, as per the guidelines [30]. It has been noted that the degree of flooding within an area is directly correlated with its distance from a river. Areas that are more distant from this water system tend to experience less flooding, whereas those in closer proximity are more prone to flood events [31].

The Tinajero region of Bacolor, Pampanga, exhibits zones categorized as dark green, which implies that these areas are geographically distant from the nearby rivers, as observed through spatial analysis and topographical studies. However, this attribute could potentially enhance vulnerability to flooding in the event of inadequate drainage outlets. The accumulation of water in such areas may result in overflow, thereby elevating the probability of flood occurrences in Tinajero[32].

3.4Distance to Road

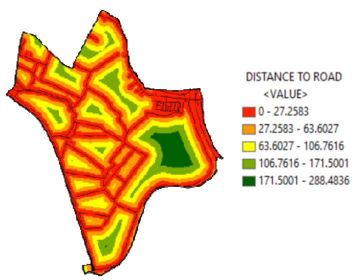

Figure 9. Distance to Road Map

Roads can sometimes obstruct the natural water flow, causing water to accumulate and raise flood risk in surrounding regions. A range of colors where the red color indicates the closest distance to the road while the dark green color shows the area that is farthest from the road. Being near a road may increase the likelihood of flooding. Furthermore, road construction and planning might change surface drainage features, which may not always be properly addressed, leading to heightened flood susceptibility [33].

The default unit for measurements of distances in ArcGIS software is expressed in linear units, specifically in meters [34].

The figure shows that Zone 1 is categorized with red, orange, and yellow, ranging from 0 to 106.7616 meters which indicates that it is very close, close, and a moderate distance to the road.

In Zone 2, it is mostly red followed by orange with a small portion of yellow, which indicates that it is very close, close to the road, and some portion of it has a moderate distance from the road.

Lastly, in Zone 3, there is a red and orange that indicates it is very close to the road, with some portions close to the road.

As stated, being close to the road can sometimes increase the risk of flooding due to changes in the surface drainage features of an area. This suggests that Zones 1, 2, and 3 of Tinajero, Bacolor, Pampanga can experience an increased risk of flooding due to the distance to the road.

3.5 Elevation

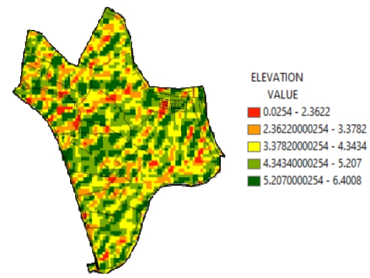

Figure 10. Elevation Map

The data is visually represented using a color-based scheme, where dark green denotes the highest elevation, and red signifies the lowest elevation. The resulting elevation measurements are accurately measured in meters, ensuring a comprehensive understanding of the geographical aspects [35].

Elevation is the most important factor which affects flooding and in general the occurrence of flood increases with decreasing elevation. The low elevation is seen as one of the main conditioning factors for floods in the study area [36].

In the provided map, Zone 1 primarily exhibits dark green, light green, and yellow hues, which indicates high to average elevations and reduced flood vulnerability. A portion of orange hues can also be seen in the said zone, which denotes a below-average elevation, that suggests minimal flood susceptibility.

Zone 2 features yellow to light green hues, signifying average to above-average elevation.

Zone 3 showcases a light-to-dark green front, representing high elevation and decreased flood likelihood. However, a certain portion of the resettlement village displays red hues, indicating a low elevation and is prone to flood occurrence.

3.6 Slope

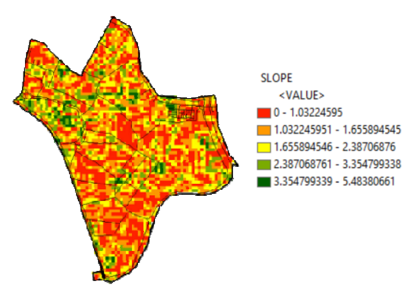

Figure 11. Slope Map

Areas with low elevation and gentle slopes are more likely to flood and experience water-logging. Steep slopes allow water to flow faster, while flat or gentle slopes cause runoff to accumulate and release slowly. As a result, low-gradient slopes in lower areas are more prone to flooding compared to high-gradient slopes [36].

A range of colors from dark green to red, where the red indicates that there is a very low slope, which means that the surface is almost flat, while the dark green shows that there is a very high slope or the surface is very steep.

The values derived from the slope map were classified in terms of degrees [37]. The figure shows that the area comprises varying slope levels.

In Zone 1, it can be observed that there is a fair amount of red, orange, and yellow, with a little portion of light green. This indicates that there is a very low, low, moderate, and slightly high slope in the area.

In Zone 2, it consists of mostly red, orange, and yellow, with a small part of light green and dark green. This suggests that there is a very low, low, moderate, high, and very high slope in the area.

Lastly, in Zone 3, there is a majority of red and orange, followed by yellow, and a portion of light and dark green in a certain portion of the resettlement village. This infers that the area has mostly a very low and low slope, followed by a moderate slope, while high and very high slopes are evident in that certain portion of the resettlement.

Therefore, the barangay Tinajero might suffer from flooding because of the stagnation of water due to low slopes. Since it is mostly comprised of very low slopes, the flood water might stay longer because it does not flow somewhere else due to low slopes affecting surface runoff.

3.7 Land Cover

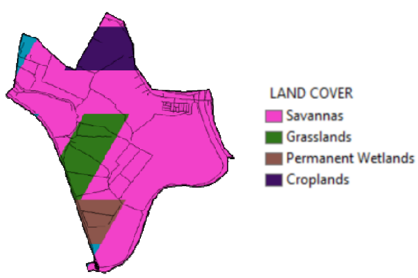

Figure 12. Land Cover Map

Land cover information serves to quantify the extent of various territorial classifications, such as forested areas, agricultural lands, impervious surfaces, and water bodies encompassing wetlands or open water regions within a specified geographic area [38]. Alterations in land cover have resulted in a significant rise in the occurrence of floods following precipitation occurrences. These changes in land cover influence natural drainage systems, surface runoff, and infiltration capacities, all of which contribute to the increased likelihood of flooding [39].

In the context of land cover classification, the study employed the MCD12Q1 International Geosphere-Biosphere Programme (IGBP) legend and class description. The study area is primarily divided into four categories: Savannas, Grasslands, Permanent Wetlands, and Croplands. To specifically examine the residential alleys within the area, it is noted that Savannas are significantly present in the portion of Zone 1, and the entirety of Zone 2 and Zone 3, while croplands are observed in the majority of Zone 1.

Savannas represent a significant global terrestrial ecosystem, characterized by a diverse combination of trees and grasses, encompassing both open woodland and grassland environments [40]. In connection to this, findings in a study about the flood risk factor of Savanna indicated that there was a substantial likelihood of flooding incidents occurring in Savanna over the subsequent 30 years. This consequently led to significant disruptions in the daily functioning of the local community [41].

On the other hand, cropland refers to the area where agricultural crops are cultivated[42]. In a study conducted in Pennsylvania, USA, it was found that croplands are more susceptible to potential flood risks than non-crop farmlands. Particularly, cropland parcels experience an average 13% decrease in value when exposed to a 1% or higher annual probability of flooding [43].

3.8 Flood Risk Map

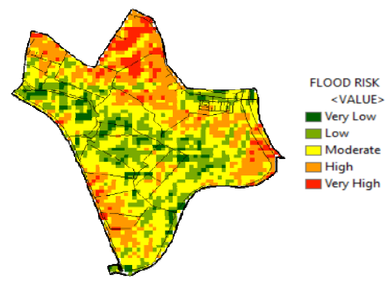

Figure 13. Flood Risk Map

The flood risk map utilized five different colors to represent the varying degrees of flood danger across the designated region. Red indicates the most severe flood risk while dark green signifies the lowest flood risk. The results denoted that the likelihood of experiencing a flood in a particular area is evident when at higher flood risk, posing potential flooding events compared to regions that are a lower risk. High risk may result in constant intense flooding, which causes serious damage to properties, destruction of infrastructures, negative impact on the environment, and threats to the safety and well-being of the people residing in the area [44].

An in-depth analysis of the map showed that Zones 1 and 2 are significantly higher than Zone 3. However, there are parts of Zone 3 that are in the high risk as well such as the Resettlement Village. Local observations and interviews conducted with the residents proved the further findings, as it highlights the specific areas that are more susceptible to severe flooding incidents within Zone 3 than the other Zones.

Zone 1 and Zone 2 display a mostly higher flood risk compared to Zone 3. This indicates that these areas are more prone to flooding incidents, which must be prioritized in flood management and prevention measures. Zone 3, has a lower flood risk, but specific sections within this zone show high flood risk, which should also be addressed.

Based on the information provided, some evidences were found. In Zone 1, characterized by its high drainage density and elevation, water rapidly flows towards this area and drains into other zones. Conversely, Zone 3 features varying infiltration rates, with the resettlement area having a lower elevation and higher infiltration. This leads to water from other zones accumulating in this area due to the low surface flow velocity. Furthermore, this accumulation may result in increased flooding, as rainwater struggles to reach waterways.

On the other hand, a certain portion of the resettlement village in Zone 3 has a steep slope, but its low elevation makes it susceptible to flooding. As the lowest point in the barangay, this particular area suffers the most damage during floods.

To ensure the safety and well-being of the residents living in these zones, it is crucial to implement targeted flood management strategies based on the varying flood risks across the regions.

3.9 Thematic Analysis

QUESTION: **What are the effects of flooding in terms of the safety and health aspect of the residents of Barangay Tinajero, Bacolor, Pampanga?**		***Thematic Analysis***
Categories	***Codes***	
Category 1: Frequency of Flooding Incidents	$TR1_{a1}$, $TR2_{a1}$, $TR2_{a1.1}$, $TR2_{a1.2}$, $TR3_{a1}$, $TR4_{a1}$, $TR4_{a1.1}$, $TR5_{a1}$, $TR6_{a1}$, $TR7_{a1}$, $TR7_{a1.1}$, $TR7_{a1.2}$, $TR8_{a1}$, $TR9_{a1}$, $TR9_{a1.1}$, $TR10_{a1}$	*"The residents of Barangay Tinajero are consistently affected by floods, occurring twice a year or more, resulting in substantial disruptions to their daily lives. The residents, along with their families, have encountered injuries and health concerns due to the flooding. To escape the rising waters, many families are forced to evacuate from their homes and seek temporary shelter in elevated areas, such as the Tinajero Elementary school, which serves as the evacuation center for the entire barangay during flooding."*
Category 2: Injury or Health Issues	$TR1_{b1}$, $TR1_{b1.1}$, $TR2_{b1}$, $TR2_{b1.1}$, $TR3_{b1}$, $TR4_{b1}$, $TR4_{b1.1}$, $TR5_{b1}$, $TR7_{b1}$, $TR7_{b1.1}$, $TR7_{b1.2}$, $TR10_{b1}$, $TR10_{b1.1}$	
Category 3: Need for Evacuation	$TR1_{c1}$, $TR2_{c1}$, $TR2_{c1.1}$, $TR3_{c1}$, $TR3_{c1.1}$, $TR4_{c1}$, $TR4_{c1.1}$, $TR7_{c1}$, $TR7_{c1.1}$, $TR8_{c1}$, $TR8_{c1.1}$, $TR9_{c1}$, $TR9_{c1.1}$, $TR10_{c1}$, $TR10_{c1.1}$	

Table 2. Thematic Analysis 1

QUESTION: **What are the effects of flooding in terms of the economical aspect of the residents of Barangay Tinajero, Bacolor, Pampanga?**		***Thematic Analysis***
Categories	***Codes***	
Category 1: Financial Losses	$TR1_{e1}$, $TR2_{e1}$, $TR2_{e1.1}$ $TR2_{e1.2}$, $TR3_{e1}$, $TR3_{e1.1}$, $TR4_{e1}$, $TR4_{e1.1}$, $TR4_{e1.2}$, $TR4_{e1..3}$, $TR5_{e1}$, $TR5_{e1.1}$, $TR5_{e1.2}$, $TR5_{e1.3}$, $TR6_{e1}$, $TR6_{e1.1}$, $TR7_{e1}$, $TR7_{e1.1}$, $TR7_{e1.2}$, $TR7_{e1.3}$, $TR8_{e1}$, $TR8_{e1.1}$, $TR8_{e1.2}$, $TR9_{e1}$, $TR9_{e1.1}$, $TR9_{e1.2}$, $TR10_{e1}$, $TR10_{e1.1}$	*"The residents of Barangay Tinajero have faced financial setbacks due to flooding. Their expenditures surge during such events compared to regular days. Additionally, they found it necessary to cancel or delay their work or business for a few days while waiting for the weather to settle, for the water levels to recede, and to allocate time for repairing their damaged properties. The residents also suffered damage to their houses, appliances, and crops. To recover from the flood's effects, they usually borrowed money to repair their properties and replace lost items."*
Category 2: Cancellation of Work	$TR2_{f1}$, $TR2_{f1.1}$, $TR3_{f1}$, $TR3_{f1.1}$, $TR5_{f1}$, $TR5_{f1.1}$, $TR6_{f1}$, $TR6_{f1.1}$, $TR7_{f1}$, $TR7_{f1.1}$, $TR7_{f1.2}$, $TR8_{f1}$ $TR8_{f1.1}$, $TR8_{f1.2}$, $TR9_{f1}$, $TR9_{f1.1}$, $TR9_{f1.2}$, $TR10_{f1}$, $TR10_{f1.1}$	
Category 3: Damage to Property	$TR1_{g1}$, $TR1_{g1.1}$, $TR1_{g1.3}$, $TR2_{g1.1}$, $TR2_{g1.2}$, $TR2_{g1.4}$, $TR3_{g1}$, $TR3_{g1.1}$, $TR3_{g1.3}$, $TR4_{g1.1}$, $TR4_{g1.2}$, $TR4_{g1.5}$, $TR5_{g1}$, $TR5_{g1.1}$, $TR5_{g1.2}$, $TR6_{g1.3}$, $TR6_{g1.4}$, $TR6_{g1.5}$, $TR7_{g1.1}$, $TR7_{g1.2}$, $TR7_{g1.3}$, $TR7_{g1.4}$, $TR9_{g1.1}$, $TR9_{g1.2}$, $TR10_{g1}$, $TR10_{g1.2}$	
Category 4: Flooding Expenses	$TR1_{h1.1}$, $TR1_{i1}$, $TR2_{h1}$, $TR2_{i1}$, $TR4_{h1}$, $TR4_{i1}$, $TR7_{h1}$, $TR7_{i1}$, $TR9_{h1}$, $TR9_{i1}$, $TR10_{h1}$,$TR10_{i1}$	

Table 3. Thematic Analysis 2

QUESTION: **What can you suggest to lessen the impact of flooding in the community of Barangay Tinajero?**		***Thematic Analysis***
Categories	***Codes***	
Category 1: Immediate Response	$TR1_{d1}$, $TR3_{d1}$, $TR5_{d1}$, $TR7_{d1}$, $TR7_{d1.1}$, $TR8_{d1}$	*"Most of the residents are urging the local authorities to mitigate the impact of flooding in Barangay Tinajero by elevating low-lying areas, as flooding originates from there. Another concern voiced by the residents is the need for the repair of drainage systems, as they are clogged. Residents seek immediate action and response from local authorities during floods, including timely dissemination of warnings. Some request financial assistance to recover from flood-related losses and damages. They also call for the local authorities to provide job and business opportunities for those affected by the floods. Additionally, they emphasize the need for promoting better waste management practices."*
Category 2: Financial Help	$TR1_{j1}$, $TR2_{j1.1}$, $TR5_{j1}$, $TR9_{j1}$,	
Category 3: Community Development through Elevation Improvement and Drainage Management	$TR2_{d1}$, $TR5_{d1.1}$, $TR6_{d1}$, $TR8_{j1}$, $TR8_{j1.1}$, $TR9_{d1}$, $TR9_{j1.1}$	
Category 4: Employment and Business Opportunities	$TR2_{j1}$, $TR7_{j1}$	
Category 5: Waste Management	$TR4_{d1}$	

Table 4. Thematic Analysis 3

IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary of Findings

After a thorough analysis, this study has found valuable results, which contribute to a better understanding of the topic and pave the way for future investigations.

In this context, the seven (7) parameters are used to assess the flood risk in three zones of Tinajero, Bacolor Pampanga.

- *Rainfall.* The risk of heavy rainfall is high in Zone 1, Zone 2, and approximately half of Zone 3. The remaining part of Zone 3 has a moderate susceptibility to rainfall.
- *Drainage Density.* Zone 1 has varying levels of drainage density, from moderate to very high. Zone 2 has a range from moderate to low, while Zone 3 has a very low drainage density.
- *Distance to River.* All zones are at a considerable distance from the local river. Zone 1 and 2 vary from moderate to very close distances, while Zone 3 is closer, varying from close to very close.
- *Distance to Road.* Zone 1 and 2 have varying distances from moderate to very close to roads, while Zone 3 has distances that vary from close to very close.
- *Elevation.* Zone 1 indicates average to high elevations, while Zone 2 varies from low to high elevations. Zone 3 is at risk of flooding due to its low elevation.
- *Slope*. Zone 1 varies from very low to high slope, while Zone 2 and 3 both vary from very low to very high slopes.
- *Land Cover*. Zone 1 is mostly croplands, and Zone 2 and Zone 3 are entirely savannas.

In general, based on the parameters mentioned, Zone 1 and 2 have a higher flood risk compared to Zone 3. However, within Zone 3, some specific sections also exhibit high flood risk. This indicates that even though Zone 3 has a lower overall flood risk, certain areas within it should not be overlooked when planning flood mitigation and prevention measures.

The residents of Barangay Tinajero are consistently affected by floods, occurring twice a year or more, resulting in substantial disruptions to their daily lives. The residents along with their families, have encountered injuries and health concerns due to the flooding. To escape the rising waters, many families are forced to evacuate from their homes and seek temporary shelter in elevated areas, such as the Tinajero Elementary School, which serves as the evacuation center for the entire barangay during flooding.

The residents of Barangay Tinajero have faced financial setbacks due to flooding. Their expenditures surge during such events compared to regular days. Additionally, they found it necessary to cancel or delay their work or business for a few days while waiting for the weather to settle, for the water levels to recede, and to allocate time for repairing their damaged properties. The residents also suffered damage to their houses, appliances, and crops. To recover from the flood's effects, they usually borrowed money to repair their properties and replace lost items.

4.2 Proposed Mitigation Techniques

The flood risk map serves as a valuable tool for understanding the complex interplay of factors that contribute to flood risk in these zones. By identifying high-risk areas, authorities and communities can take targeted actions to reduce the potential impact of floods and protect lives and properties.

Together with the researcher's observations and interviews with the residents of Tinajero, this study would like to propose the following measures to minimize the impacts of flooding in the said area:

1. Providing boats in Barangay Tinajero can help speed up rescue operations, especially for affected residents.
2. Opening the creek to allow for better water flow.
3. Fixing the clogged drainage system to ensure efficient water flow during rainfall.
4. Creating employment and business opportunities for residents who may be affected by flooding.
5. Conducting monthly assemblies for flood preparation discussions.
6. Implement proper waste management by having a local garbage truck, exchanging recyclable materials for benefits, and organizing cleanup drives.
7. Initiating a tree planting project (at least once a month).

4.3 Conclusion

From the findings of the study, it can be concluded that Barangay Tinajero, Bacolor, Pampanga is prone to flooding. By utilizing ArcGIS, it was determined that all zones within this area are susceptible to floods, potentially posing risks to the safety and financial stability of its residents. Additionally, the residents living in alleys may face additional challenges related to security and finances if the flooding persists. With this, it is crucial for both residents and local authorities to acknowledge this issue and collaborate in developing solutions to address the challenges presented by recurrent flooding.

4.4 Recommendations

Relative to the findings of the study, the researchers would like to suggest the following:

1. While the flood risk assessment appears accurate, as per residents' experiences, flooding remains a significant concern. It would be beneficial for future researchers to explore additional parameters or factors contributing to this issue, particularly in the resettlement area, which seems more vulnerable than depicted on the map.
2. Explore urban development and vegetation cover parameters.
3. Employ alternative software to gain a fresh perspective on evaluating flood risks across each zone.
4. Increase the sample size for the interview to ensure the validity of the responses.
5. Conduct an in-depth analysis to identify the reasons behind the flood vulnerability in each zone, considering all relevant parameters.
6. Develop or study structural mitigation techniques that can help minimize the impact of flood risks.

Considering the possibility of having financial assistance from the government, the following can be suggested:

1. Elevating low-lying areas by constructing embankments can help reduce the impact of flooding.
2. Establishing emergency facilities (i.e. clinic).
3. Install speakers or sirens to disseminate information to residents in the surrounding area.
4. Providing pump trucks to help remove water from flooded areas and transport it to waterways.

REFERENCES

[1] A. N. Angelakis, G. Antoniou, K. Voudouris, N. Kazakis, N. Dalezios, and N. Dercas, "History of floods in Greece: causes and measures for protection," *Natural Hazards*, vol. 101, no. 3, pp. 833–852, Apr. 2020, doi: 10.1007/s11069-020-03898-w.

[2] G. J.-P. Schumann, L. Giustarini, M. Zare, and B. Gaffinet, "Call to action: Pushing scientific and technological innovation to develop an efficient AI flood mapper for operational SAR satellites," *EGU21*, Mar. 2021, doi: 10.5194/EGUSPHERE-EGU21-5943.

[3] G. Soulios, G. Stournaras, K. Nikas, and C. Mattas, "The floods in Greece: the case of Mandra in Attica," *Bulletin of the Geological Society of Greece*, vol. 52, no. 1, p. 131, Dec. 2018, doi: 10.12681/bgsg.16419.

[4] E. Lechowska, "What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements," *Natural Hazards*, vol. 94, no. 3, pp. 1341–1366, Dec. 2018, doi: 10.1007/s11069-018-3480-z.

[5] "Number of flood disasters worldwide 1990-2022 | Statista." Accessed: Nov. 10, 2023. [Online]. Available: https://www.statista.com/statistics/1339730/number-of-flood-disasters-worldwide/

[6] F. J. Tan, E. Jade, R. Rarugal, F. Aldrine, and A. Uy, "One-Dimensional (1D) River Analysis of a River Basin in Southern Luzon Island in the Philippines Using Lidar Digital Elevation Model," 2018. [Online]. Available: www.sciencepubco.com/index.php/IJET

[7] G. R. Puno, R. A. L. Amper, E. M. Opiso, and J. A. B. Cipriano, "Mapping and analysis of flood scenarios using numerical models and GIS techniques," *Spatial Information Research*, vol. 28, no. 2, pp. 215–226, Apr. 2020, doi: 10.1007/s41324-019-00280-2.

[8] Ian Ocampo Flora, "Flooding affects 125,301 families in Pampanga." Accessed: Nov. 10, 2023. [Online]. Available: https://www.sunstar.com.ph/pampanga/local-news/flooding-affects-125301-families-in-pampanga

[9] "What is ArcGIS?" Accessed: Nov. 10, 2023. [Online]. Available: https://www.geospatialworld.net/blogs/what-is-arcgis/

[10] Esri, "What is ArcGIS?," 2021. [Online]. Available: www.esri.com,

[11] D. Rincón, U. T. Khan, and C. Armenakis, "Flood risk mapping using GIS and multi-criteria analysis: A greater toronto area case study," *Geosciences (Switzerland)*, vol. 8, no. 8, Aug. 2018, doi: 10.3390/geosciences8080275.

[12] I. Elkhrachy, "Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA)," *Egyptian Journal of Remote Sensing and Space Science*, vol. 18, no. 2, pp. 261–278, Dec. 2015, doi: 10.1016/j.ejrs.2015.06.007.

[13] J. S. Cabrera and H. S. Lee, "Flood-prone area assessment using GIS-based multi-criteria analysis: A case study in Davao Oriental, Philippines," *Water (Switzerland)*, vol. 11, no. 11, Nov. 2019, doi: 10.3390/w11112203.

[14] K. Park and M. H. Lee, "The development and application of the urban flood risk assessment model for reflecting upon urban planning elements," *Water (Switzerland)*, vol. 11, no. 5, May 2019, doi: 10.3390/w11050920.

[15] "Mixed Methods Research - Types & Analysis - Research Method." Accessed: Nov. 28, 2023. [Online]. Available: https://researchmethod.net/mixed-methods-research/

[16] Voxco, "What is Descriptive Research Design? ." Accessed: Nov. 28, 2023. [Online]. Available: https://www.voxco.com/blog/descriptive-research-design/#:~:text=Descriptive%20research%20design%20is%20a,problem%20rather%20than%20the%20why.

[17] "Qualitative vs Quantitative - Research - LibGuides at University of South Carolina Upstate." Accessed: Nov. 29, 2023. [Online]. Available: https://uscupstate.libguides.com/c.php?g=1172600&p=9148042

[18] N. Dragičević, B. Karleuša, and N. Ožanić, "Different approaches to estimation of drainage density and their effect on the Erosion Potential Method," *Water (Switzerland)*, vol. 11, no. 3, p. 593, Mar. 2019, doi: 10.3390/w11030593.

[19] D. Sulla-Menashe and M. A. Friedl, "User Guide to Collection 6 MODIS Land Cover (MCD12Q1 and MCD12C1) Product," 2018, doi: 10.5067/MODIS/MCD12Q1.

[20] "Qualitative Research Designs, Sample Size and Saturation: Is Enough Always Enough?," *Journal of Advocacy, Research and Education*, vol. 8, no. 3, Dec. 2021, doi: 10.13187/jare.2021.3.60.

[21] M. Moran, "Qualitative Sample Size - 09-04-2013." [Online]. Available: http://www.statisticssolutions.com/qualitative-sample-size/

[22] M. Măgureanu, M. Sfîrcoci, L. Copăcean, and L. Cojocariu, "Life Science and Sustainable Development https://www.lssd-journal.com
____ ____ FLOOD RISK OF GRASSLANDS IN THE MOUNTAIN AREA OF WESTERN ROMANIA." [Online]. Available: https://www.lssd-journal.com

[23] "PAGASA." Accessed: Apr. 10, 2024. [Online]. Available: https://bagong.pagasa.dost.gov.ph/information/climate-change-in-the-philippines

[24] I. Harris, T. J. Osborn, P. Jones, and D. Lister, "Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset," *Sci Data*, vol. 7, no. 1, Dec. 2020, doi: 10.1038/S41597-020-0453-3.

[25] I. J. Jackson, "Tropical rainfall variations over a small area," *J Hydrol (Amst)*, vol. 8, no. 1, pp. 99–110, 1969, doi: 10.1016/0022-1694(69)90033-X.

[26] N. Dragičević, B. Karleuša, and N. Ožanić, "Different Approaches to Estimation of Drainage Density and Their Effect on the Erosion Potential Method," *Water 2019, Vol. 11, Page 593*, vol. 11, no. 3, p. 593, Mar. 2019, doi: 10.3390/W11030593.

[27] "Topic: Drainage Density." Accessed: Apr. 21, 2024. [Online]. Available: https://www.netmaptools.org/Pages/NetMapHelp/drainage_density.htm

[28] S. Sukristiyanti, R. Maria, and H. Lestiana, "Watershed-based Morphometric Analysis: A Review," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Feb. 2018. doi: 10.1088/1755-1315/118/1/012028.

[29] C. Abha, B. Prakash, J. Varun, P. Asha, and S. Ruchi, "Frequency ratio analysis to determine the landslide susceptibility in East Sikkim district of Indian Himalayan region," *Disaster Advances*, vol. 17, no. 1, pp. 44–61, Jan. 2024, doi: 10.25303/171DA044061.

[30] "About distance units and editing—ArcMap | Documentation." Accessed: Apr. 22, 2024. [Online]. Available: https://desktop.arcgis.com/en/arcmap/latest/manage-data/editing-fundamentals/about-distance-units-and-editing.htm

[31] R. K. Samanta, G. S. Bhunia, P. K. Shit, and H. R. Pourghasemi, "Flood susceptibility mapping using geospatial frequency ratio technique: a case study of Subarnarekha River Basin, India," *Model Earth Syst Environ*, vol. 4, no. 1, pp. 395–408, Apr. 2018, doi: 10.1007/S40808-018-0427-Z/METRICS.

[32] "The Problem of a Poor Drainage System During Flood Relief: [Essay Example], 908 words GradesFixer." Accessed: Apr. 22, 2024. [Online]. Available: https://gradesfixer.com/free-essay-examples/the-problem-of-a-poor-drainage-system-during-flood-relief/

[33] G. Huang, "Enhancing Dialogue between Flood Risk Management and Road Engineering Sectors for Flood Risk Reduction," *Sustainability 2018, Vol. 10, Page 1773*, vol. 10, no. 6, p. 1773, May 2018, doi: 10.3390/SU10061773.

[34] "Calculate Distance (Raster Analysis)—ArcGIS Pro | Documentation." Accessed: Apr. 21, 2024. [Online]. Available: https://pro.arcgis.com/en/pro-app/latest/tool-reference/raster-analysis/calculate-distance.htm

[35] "Use the elevation analysis geoprocessing services—ArcGIS Data Appliance | Documentation." Accessed: Apr. 22, 2024. [Online]. Available: https://doc.arcgis.com/en/data-appliance/latest/use/use-elevation-geoprocessing-services.htm

[36] V. Ramesh and S. S. Iqbal, "Urban flood susceptibility zonation mapping using evidential belief function, frequency ratio and fuzzy gamma operator models in GIS: a case study of Greater Mumbai, Maharashtra, India," *Geocarto Int*, vol. 37, no. 2, pp. 581–606, 2022, doi: 10.1080/10106049.2020.1730448.

[37] J. G. Gacu, C. E. F. Monjardin, D. B. Senoro, and F. J. Tan, "Flood Risk Assessment Using GIS-Based Analytical Hierarchy Process in the Municipality of Odiongan, Romblon, Philippines," *Applied Sciences 2022, Vol. 12, Page 9456*, vol. 12, no. 19, p. 9456, Sep. 2022, doi: 10.3390/APP12199456.

[38] N. O. and A. A. US Department of Commerce, "What is the difference between land cover and land use?".

[39] M. Paul Mwangi, uelOchola J. Date, D. Mil, and S. Onywere, "ROLE OF LAND USE AND LAND COVER CHANGE IN

FLOOD RISK MANAGEMENT IN KILIFI COUNTY Signature:- 5lml1j~~'O:tA~1".

[40] D. J. Beerling and C. P. Osborne, "The origin of the savanna biome," *Glob Chang Biol*, vol. 12, no. 11, pp. 2023–2031, Nov. 2006, doi: 10.1111/J.1365-2486.2006.01239.X.

[41] "Savanna, IL Flood Map and Climate Risk Report | Risk Factor." Accessed: Apr. 10, 2024. [Online]. Available: https://riskfactor.com/city/savanna-il/1767821_fsid/flood?utm_source=redfin

[42] "Glossary:Cropland - Statistics Explained." Accessed: Apr. 21, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Cropland

[43] H. Wang, "Estimating Flood Risk Impact on Farmland Values Using Boundary Discontinuity: Evidence from Lancaster County, Pennsylvania," *Risk Analysis*, vol. 41, no. 8, pp. 1274–1288, Aug. 2020, doi: 10.1111/RISA.13623.

[44] "What is 'flood risk'?" Accessed: Apr. 10, 2024. [Online]. Available: https://www.floodsite.net/juniorfloodsite/html/en/student/thingstoknow/geography/risk1.html