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# Uav-Aided Decision Support Tool With Analytic Hierarchy Process For Floodplain Risk Assessment

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**Abstract**
Flooding is one among the recurring hazards affecting Calbayog City, a sea-level coastal city in Samar, Philippines. The city is exposed to destructive typhoons and heavy monsoon rains due it its proximity to rivers and sea compounded intensified by deforestation, improper land use and worsening climate change. Aligned with United Nations Sustainable Development Goals 11 and 13, the study aimed to generate high-resolution flood risk maps of Calbayog City, Samar and develop a web-based decision support tool that houses such maps. The research was carried out over twelve (12) months and involved data collection, modelling and generation of flood risk maps using Analytic Hierarchy Process (AHP), and the construction of the decision support tool. The findings reveal that among the four factors that contribute to flood risk, site elevation is the highest with a normalized weight of 0.6704. It is followed by distance from the river, distance from the sea, and population density with normalized weights of 0.1768, 0.0985, and 0.0543 respectively. It must be noted that insights of the experts are crucial to attaining relevant and more accurate weights of the contributing factors. This study provides a foundation for further exploration and development in the realm of computing as applied to disaster risk reduction. Generally, this research project represents a significant contribution to the field of computing, shedding light on the use of AHP on flood risk assessment.

**Keywords:** analytic hierarchy process; data science; decision support system; flood risk assessment; unmanned aerial vehicles.

## 1. Introduction

The City of Calbayog in Samar, Philippines is situated close to river systems and the coastline. In effect, the city faces an increased risk of flooding, most especially during typhoons and rainy season. Due to the growing impacts of climate change, inappropriate land use practices and ongoing deforestation, this vulnerability is further aggravated and essentially felt by the people of Calbayog.

The study of Chitwatkulsiri and Miyamoto [1] recognizes that urban areas in tropical Southeast Asia are increasingly exposed to intense flash flooding due to the worsening climate change, inadequate drainage systems, land-use problems and vulnerable populations congested in urban spaces. In the Philippine setting, data-driven and localized flood risk assessment is essential for resilience planning considering a number of flood prone river basins or catchment areas which are typically small with short hydrological response times and extensive downstream urbanization [2].

Aligned with the United Nations' Sustainable Development Goals (SDGs) 11 (Sustainable Cities and Communities) and 13 (Climate Action), a research project was initiated and funded by the Commission on Higher Education (CHED). The project focused on floodplain risk assessment in Calbayog City. The three objectives were (1) to gather spatial data of Calbayog City using Unmanned Aerial Vehicles (UAV) for capturing the images of the barangays, (2) to generate a high-resolution flood risk map for the entire city using the Analytic Hierarchy Process (AHP), and (3) to develop a web-based decision support tool tailored for managing flood-related disaster risks.

With thorough floodplain risk assessment, the study will generate high-resolution flood risk maps which will also be validated by domain experts. The maps will provide the city with vulnerable areas susceptible to flooding. With this, the local government can implement measures in enhancing the disaster risk and reduction plans for addressing potential flooding. Essentially, the study will also develop the web-based decision support tool to equip the city with proactive flood risk management. For inclusive and sustainable urbanization, the platform will potentially help the city in minimizing the adverse effects of flooding

Supporting SDGs 11 and 13, the project aligned with the broader global agenda for sustainable urban development and climate action. Establishing highly relevant, more effective and data-driven local government plans and programs geared towards flood risk management and prevention measures, the project aspired to contribute to the creation of resilient and sustainable communities, ensuring a safer and more sustainable future for Calbayog City and its residents.

## 2. Related Work

The Philippines ranked first in the 2022 World Risk Index, released in September, among 193 countries representing 99 percent of the global population. Based on the same report, the country ranked in the highest quintile for exposure, vulnerability, susceptibility, and lack of coping mechanisms, and in the second quintile for lack of adaptation strategies [3]. In the last 500 years, 80% of the natural disasters that our country has faced is hydro-meteorological which includes typhoon and flooding [4]. And in recent years, the city of Calbayog has experienced the immense risks of flooding just like what occurred in 2019 when the city council had declared a state of calamity because of major floods caused by tropical depression Usman's strong rains, which had killed at least three people and displaced thousands of families [5]. The frequency and intensity of typhoons have been increasing in recent years because of global warming, having a significant impact on urban architecture, municipal facilities, and the natural ecological environment in coastal towns [6].

To better combat this problem, people have used emerging technologies just like the unmanned aerial vehicle (UAV). UAVs are a new technology that has the potential to be employed in a variety of industries and areas of human life to deliver a variety of applications and services [7]. As referenced in the study of Qadir et al., [8], the pilotless aircraft is controlled by three key components: the UAV, ground controller and communication platform linking the two. Ejaz et al., [9] supports the idea that pilotless aircrafts provide a wide range of benefits in disaster management, agriculture, and surveillance because of its mobility and versability.

Disaster management is one of the sectors where UAV-based analysis is most prevalent. This must be due to tens of thousands of lives lost each year because of disasters and billions of dollars are squandered in global economies. As a result, it is imperative that measures for automating disaster mitigation, relief, and recovery be implemented as soon as possible. All these as cited by Qadir et al., [8].

To do some tasks as cited by Qadir et al., [8] , UAVs get equipped with other technologies like cameras, microphones, and other sensors depending on the purpose for using it. In disaster management, UAVs can help get a bird's-eye view of disaster affected areas. It can be also used to collect accurate and timely data that describes the impact and extent of the damage which is critical in managing a disaster [10]. And as cited by Alzahrani et al., [7], aerial assessment gives the most accurate and timely information on the situation in a specific area. These are supported by the result of the study of Wu et al., [6] which states that the loss and recovery of disaster sites may be swiftly assessed and analyzed using UAV image data. It could give technical and decision-making assistance in the event of an urban disaster, as well as in environment restoration monitoring and in urban planning and restoration. Through this technology, we can also create a flood risk map which is an important source of information for making flood risk management decisions [11].

In addition, as cited by Alzahrani et al., [7], UAVs play a critical role in allowing rescue teams to reach inaccessible locations and discover them using collected data. UAVs aid in the early discovery of disasters through real-time monitoring, allowing the disaster's impact to be effectively minimized. Aside from these, UAV is also being coupled with another technology for a more effective disaster management effort, and that is the Internet of Things (IoT). This emerging software-defined internet protocol-based communication technologies which is being aimed at reducing the casualties, has caught the interest of disaster mitigation stakeholders by allowing them to quickly locate victims and obtain their relevant information, which can improve the efficiency and effectiveness of Search and Rescue (SAR) missions [12].

The combination of the Internet of Things (IoT) and unmanned aerial vehicles (UAVs) can considerably improve disaster management system performance [9]. These are just a few of the many things that UAV can do together with other technologies in terms of dealing with disaster and its risks. Beyond damage documentation, a key contribution of UAVs to flood studies is their ability to produce very high-resolution digital elevation models (DEMs) through structure-from-motion photogrammetry. In areas with limited topographic data, the study of Gebrehiwot et al. [13] presented that spatial flood assessment mapping can be done by utilizing UAV-based digital elevation models. Adesina [14] advanced the idea that UAV-derived digital elevation models returned a more accurate flood predictions that satellite-based products which oversimplifies ground elevation and overestimate flood extent. Because site elevation and micro-topography are decisive controls on inundation, the use of UAV imagery to capture the terrain of Calbayog City's barangays directly strengthens the reliability of the resulting flood risk maps.

For flood risk analysis and evaluation, in the study of Siddayao et al., [15], they considered a flood-prone area located in northern Philippines and applied the Analytical Hierarchy Process (AHP) method in tandem with a Geographical Information System (GIS). Expert opinions were gathered, together with geographic, statistical, and historical data, and fuzzy membership was used to process them. The AHP results revealed the relative weights of three flood risk indicators, which were then evaluated using a standard consistency measure. The AHP factor weights were merged into the Quantum GIS program to create a color-coded map depicting five degrees of predicted flood risk. However, they were not able to include other relevant parameters or contributing factors that cause flooding due to absence of such data within the locale that they considered.

More recently, there were few studies that explored on the coupling of AHP with GIS for floodplain risk mapping and assessment. Ouma and Taeishi [16] conducted a study in Kenya integrating factors like elevation, slope, drainage density, land use and soil type in calculating for urban flood risk index. The study of Das et al. [17] in West Bengal, India further explored on the model to test its reliability for flood susceptibility, vulnerability and risk zonation. On the other hand, Yilmaz and Alemdar [18] extended the design with multi-criteria techniques using TOPSIS and PROMETHEE to identify daily rainfall, slope, elevation and population density as contributing factors in neighborhood floodplain risk assessment.

Comparable AHP-GIS assessments within the Philippines, such as the GIS-based multi-criteria analysis of Lee and Cabrera [19] for Davao Oriental, likewise highlight that low elevation and coastal proximity concentrate the highest flood risk at the barangay level, underscoring the appropriateness of an elevation- and proximity-driven factor set for Calbayog City.

As with decision support systems that deal with flood disaster, in the study of Puttinaovarat et al., [20], they demonstrated flood detection techniques and analysis through digital photos and web application development for accepting flood reports and inspection data in all areas. The technique relies on crowdsourced data and 3S technology to acquire reliable, real-time data for flood management decisions. In another study, the researchers developed an intelligent system that employs speech recognition, artificial intelligence, and natural language processing to increase societal preparedness for flooding by offering a knowledge engine based on a generalized ontology for catastrophes with a major focus on flooding. By building a data collecting and processing framework combining environmental observations, forecast models, and knowledge bases, the knowledge engine employs flood ontology to connect user input to relevant flood knowledge discovery channels [21].

Meanwhile, in the paper of Mohanty & Karmakar [22], they described the creation of WebFRIS, a web-based flood risk information system for a district in Eastern India, which is prone to flooding. Said information system was built with a variety of open-source online technologies and packages, including Google Maps, PHP, MySQL, and JSON. It displays spatial maps of flood hazard, socioeconomic vulnerability, and flood risk at the village level. As with the work of Ivanov et al., [23], they emphasized the need to connect the different sources of information to better manage flood risks by describing a method for organizing collaborative decision support based on the CLAVIRE e-Science platform, with a focus on urgency. They went on to say that combining simulation scenarios, expert decisions, and a distributed environment to handle complex transdisciplinary problems is a major challenge. Collectively, these systems reflect a broader shift toward web-based decision support tools that translate hazard information into actionable guidance for authorities; Irwin et al. [24], for instance, developed ResilSIM, a near real-time, web-based tool that estimates the resilience of urban systems to water-related disasters and helps decision-makers select adaptation options. A recent systematic review by Elkady et al. [25] confirms that such decision support systems are central to operationalizing community resilience, while emphasizing that their usefulness depends on accessible interfaces and the integration of context-specific spatial data—requirements that motivate the web-based platform developed in the present study.

## 3. Methods

The research was established on a solid foundation through a systematic data collection process. Critical parameters, i.e. population density, distance to rivers and coastlines and the site elevation, were primarily obtained from already existing literature as well as from the Local Government Unit (LGU) of the studied area. The population density figures were obtained directly from the LGU. By means of Google Maps the distances to the rivers and coastlines as well as the site elevation were collected. These data sets constitute the first part of the conceptual framework and serve as input for the flood risk model.

In addition to this information, historical flood events have been documented by local Barangay officials through on-site interviews. This information validates the information derived from the flood risk maps developed from the above-mentioned datasets. High resolution aerial images of the studied Barangays were captured by means of Unmanned Aerial Vehicles (UAVs). These images served as further spatial evidence of the above-mentioned factors affecting the flood risk in study area.

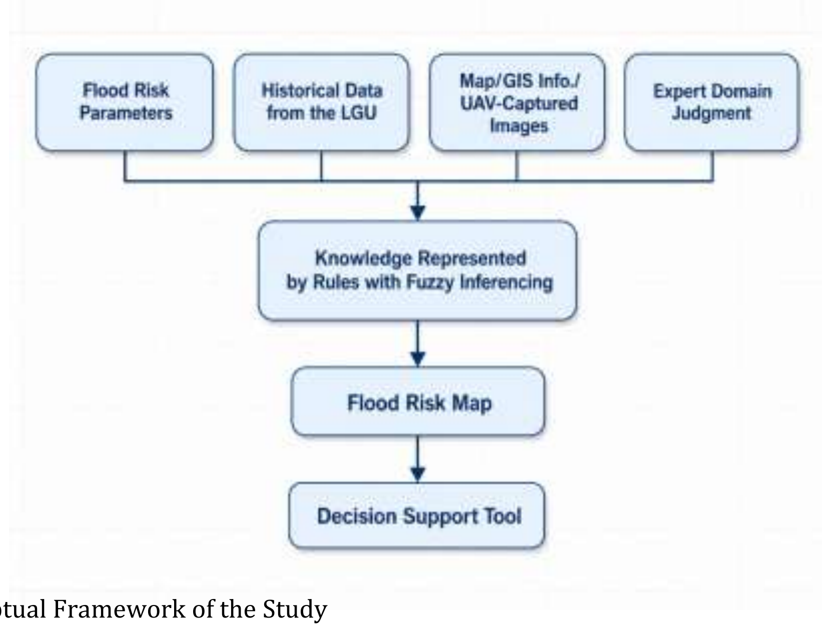



Figure 1. Conceptual Framework of the Study

The second phase of the study entailed the modeling for, and the generation of the flood risk maps for the study areas. In order to ensure methodological rigor, the Analytic Hierarchy Process (AHP) was employed (see Figure 2). AHP is a powerful tool for dealing with complex decision-making problems. The said approach enables a structured comparison among the relevant factors to be studied. The critical parameters studied in this research, namely the population density, the proximity of the study sites to the rivers and coastal areas, and the site elevation were compared pairwise using the AHP. Each of the factors was rated from 1 to 9 in terms of relative importance. The eigenvalue and the corresponding eigenvector for each of the factors were then calculated to derive the weights that would represent the degree of contribution of each of the studied factors to the overall flood risk for the study sites. The consistency of the judgments was also checked in the pairwise comparison. The measure of how far a matrix is from consistency is evaluated by computing for the Consistency Ratio (see Figure 3). The resulting weights for the studied factors were then aggregated with the scores of the critical parameters studied in this research to produce the corresponding flood risk maps for the study sites. The said maps could indicate the corresponding levels of vulnerability of the study sites to flooding.

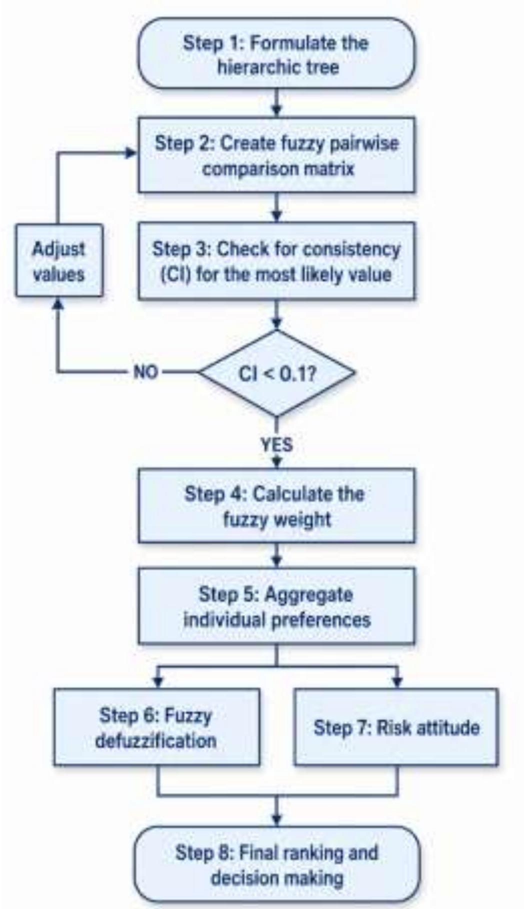


Figure 2. The General AHP Scheme

$$C.R. = \frac{C.I.}{R.I.}$$

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

Figure 3. Consistency Ratio and Consistency Index Formulae

Following the steps in AHP, a response of an expert can be represented using a pairwise comparison matrix $A = [a_{ij}]$

$$A = \begin{bmatrix} 1.00 & 0.11 & 0.33 & 0.33 \\ 9.00 & 1.00 & 7.00 & 7.00 \\ 3.00 & 0.14 & 1.00 & 3.00 \\ 3.00 & 0.14 & 0.33 & 1.00 \end{bmatrix}$$

Then, we compute for the column sums and normalized matrix.
Column sums:
$s_j = \Sigma_i a_{ij}$, for $j = 1,\ldots,n$

Table 1. Column sums $s_j$

| Column j | Criterion | Sum $s_j$ |
|---|---|---|
| 1 | $C_1$ (Population (P)) | $s_1 = 16.00$ |
| 2 | $C_2$ (Elevation (E)) | $s_2 = 1.39$ |
| 3 | $C_3$ (Nearness to River (N_R)) | $s_3 = 8.66$ |
| 4 | $C_4$ (Nearness to Sea (N_S)) | $s_4 = 11.33$ |

The normalized matrix:
$N = [n_{ij}]$, where $n_{ij} = a_{ij} / s_j$

Table 2. Normalized matrix $N = [n_{ij}]$

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|
| $C_1$ | 0.0625 | 0.0791 | 0.0381 | 0.0291 |
| $C_2$ | 0.5625 | 0.7194 | 0.8083 | 0.6178 |
| $C_3$ | 0.1875 | 0.1007 | 0.1155 | 0.2648 |
| $C_4$ | 0.1875 | 0.1007 | 0.0381 | 0.0883 |

Then, compute for the priority vector w
$w_i = (1/n) \Sigma_j n_{ij}$

Table 3. Priority vector w (criteria weights)

| Criterion | Symbol | Weight $w_i$ |
|---|---|---|
| Population (P) | $w_1$ | ≈ 0.0522 |
| Elevation (E) | $w_2$ | ≈ 0.6770 |
| Nearness to River (N_R) | $w_3$ | ≈ 0.1671 |
| Nearness to Sea (N_S) | $w_4$ | ≈ 0.1036 |

Using the weighted sum vector, we compute for the consistency vector (Eigenvalue Estimate)
Compute $y = Aw$, where $y_i = \Sigma_j a_{ij} w_j$. Then form $\theta_i = y_i / w_i$

Table 4. Eigenvalue estimation

| i | $y_i = (Aw)_i$ | $w_i$ | $\theta_i = y_i / w_i$ |
|---|---|---|---|
| 1 | ≈ 0.2160 | ≈ 0.0522 | ≈ 4.137 |
| 2 | ≈ 3.0423 | ≈ 0.6770 | ≈ 4.494 |
| 3 | ≈ 0.7295 | ≈ 0.1671 | ≈ 4.365 |
| 4 | ≈ 0.4102 | ≈ 0.1036 | ≈ 3.958 |

The maximum eigenvalue: $\lambda_{max} = (1/n) \Sigma_i \theta_i \approx 4.2385$

Lastly, we compute for the Consistency Index and Consistency Ratio
$CI = (\lambda_{max} - n) / (n - 1) \approx (4.239 - 4) / 3 \approx 0.080$
For n = 4, the Random Index is RI ≈ 0.90 (Saaty table).
$CR = CI / RI \approx 0.080 / 0.90 \approx 0.088$

Table 5. Consistency measures

| Quantity | Symbol | Value |
|---|---|---|
| Matrix size | n | 4 |
| Principal eigenvalue | $\lambda_{max}$ | ≈ 4.239 |
| Consistency Index | CI | ≈ 0.080 |
| Random Index (n = 4) | RI | ≈ 0.90 |
| Consistency Ratio | CR | ≈ 0.088 |

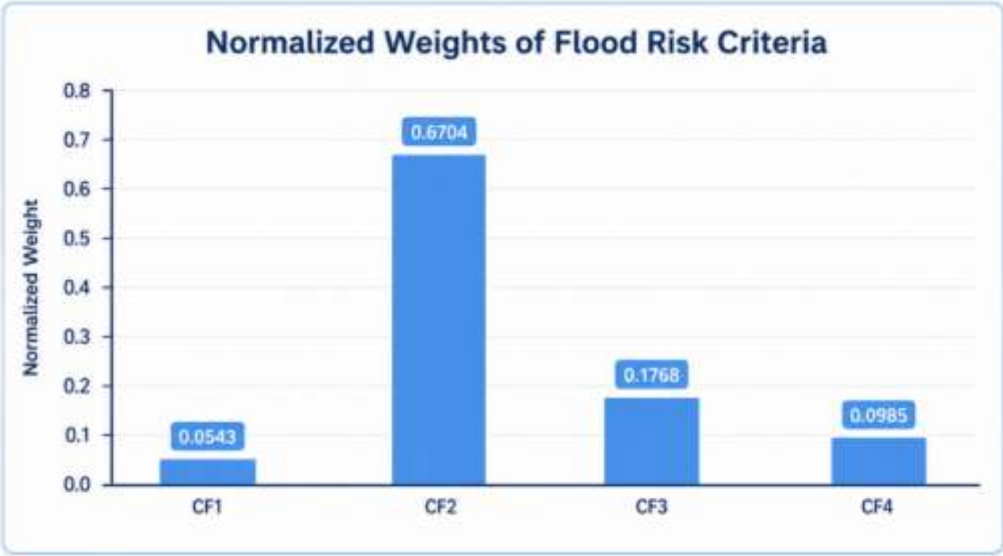
Considering that CR is below the 0.10 threshold, the pairwise judgments are considered acceptably consistent. Aggregating all the pairwise judgements of experts, the resulting matrix can be generated and evaluate the interaction and correlation between the criteria. Essentially, we can now calculate the weight of each factor.

The final phase is to design web based-flood risk map with decision support system. This application was developed to visualize the created flood risk maps and offer flood risk information that can support the Local Government Unit (LGU) and other partners on their planning and decision-making processes related to disaster risk reduction and flood management. Low-risk, moderate-risk, and high-risk flooding regions were identified and added to the system, enabling the Local Government Unit (LGU) to make better disaster management decisions.
Guided by Rapid Application Development principles which allow one to cost-efficiently produce and maintain a quality software product by creating it in a rapid fashion unlike the old system development methodologies [26], this tool aimed to create, store, and update the flood risk maps. It served as a pivotal component in facilitating data-driven decision-making for local authorities, enhancing their ability to proactively manage flood-related disaster risks. The choice of Rapid Application Development for a spatial, map-driven platform follows established practice in comparable systems; Msusa et al. [27], for example, applied the RAD methodology to build a web-based GIS application for multi-hazard early warning, demonstrating that iterative prototyping enables the rapid delivery of usable, map-centered decision support tools for disaster risk reduction.

## 4. Results

This study focused on the generation of the various flood risk maps based on the contributing factors. Basically, there were four integral factors considered in the study: site elevation, distance from the river, distance from the sea, and population density.

From the model and as validated by the domain experts, it was the site elevation which was classified as the primary contributor to flooding. It has an assigned normalized weight of 0.6704. This implies that topography is one of the critical factors that influences the city vulnerability to flooding.




| Contributing Factors | Normalized Weights ($W_i$) |
|---|---|
| Population Density (CF1) | 0.0543 |
| Site Elevation (CF2) | 0.6704 |
| Distance from the river (CF3) | 0.1768 |
| Distance from the sea (CF4) | 0.0985 |

Figure 4. Normalized Weight Values of the Contributing Factors

The distance from the river is the second most important factor for flooding, with a weight of 0.1768. This means that areas closer to rivers are more likely to flood, so we need special flood protection measures for communities near riverbanks. The study also looks at coastal areas and shows that distance from the sea is another important factor, with a weight of 0.0985. This means places closer to the sea face special flood and hazard risks, so they need specific protection measures designed for coastal communities.

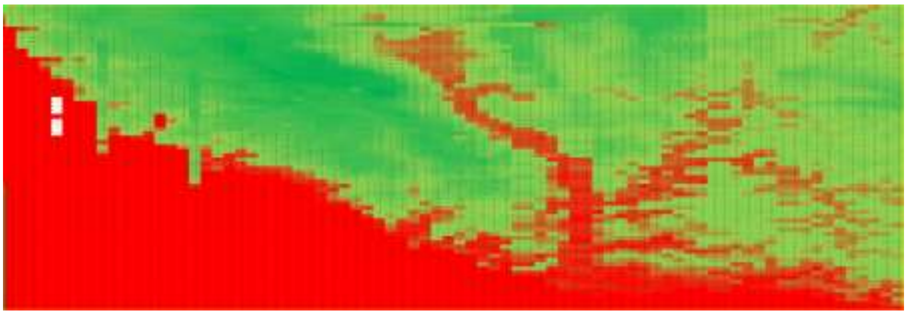


Figure 5. Thematic Map Based on Site Elevation

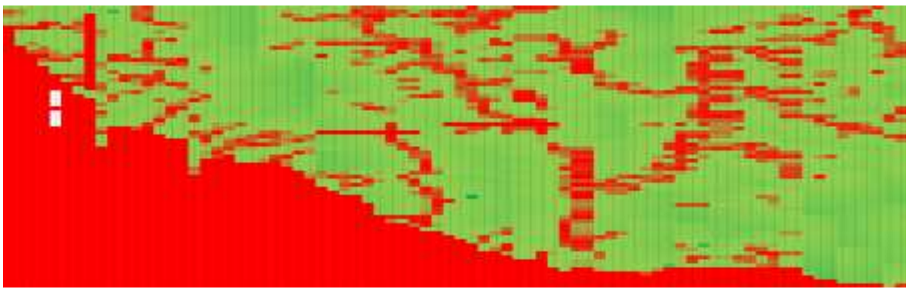


Figure 6. Thematic Map Based on Distance from the River

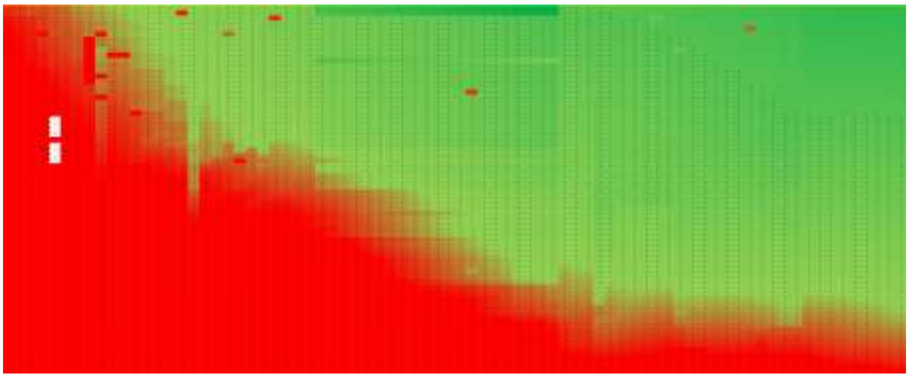


Figure 7. Thematic Map Based on Distance from the Sea

Figure 8. Thematic Map Based on Population Density

The study also looks at how crowded an area is and finds that population density is another factor, with a weight of 0.0543. This means highly populated neighborhoods can be more vulnerable to flooding, so flood risk management in these areas needs careful, well-planned strategies that consider the large number of people living there.

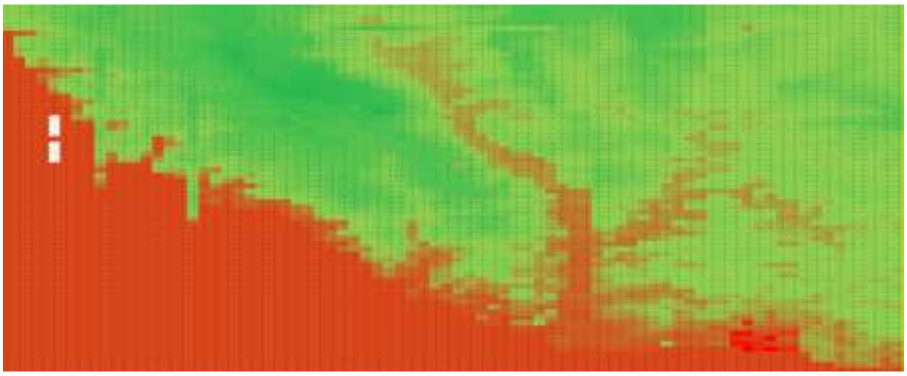


Figure 9. Thematic Map Based on All Four Contributing Factors

The study combines all these different factors into one Overall Risk Map. This map gives a clear picture of which parts of Calbayog City are more likely to experience flooding, based on site elevation, how close areas are to rivers and the sea, and how many people live there. Local authorities can use this map to see which places are most at risk and to plan specific actions to protect those communities and reduce flood damage.

The 70 x 80 grid-flood risk maps presented follow a three-tier color scheme. Red indicates high risk, light green indicates moderate risk, and green indicates low risk. The research findings not only elucidate the key contributing factors to flood risk in Calbayog City but also provide a series of detailed maps that offer actionable insights for informed decision-making and proactive flood risk management.

Figure 10 shows a zoomed in portion of the flood risk map according to site elevation factor as displayed on the web-based decision support platform. Likewise, figures 11, 12, and 13 show a zoomed in portion of the remaining flood risk maps for distance from the river, distance from the sea, and population density, respectively.

Figure 10. Flood Risk Map Based on Site Elevation

Figure 11. Flood Risk Map Based on Distance from the River

Figure 12. Flood Risk Map Based on Distance from the Sea

Figure 13. Flood Risk Map Based on Population Density

On the same platform, figure 14 shows the zoomed-out flood risk map for the overall flood risk, i.e., all four factors have been combined. For a clear and high-definition version of the map, zooming in on it is necessary. Figure 15 shows a zoomed in portion of the overall flood risk map.

Figure 14. Composite Flood Risk Map Zoomed Out

Figure 15. Zoomed In Portion of the Composite Flood Risk Map

The succeeding figures are select screenshots of the developed web-based decision support tool. A platform for the city where the flood risk maps can be generated and displayed. It is a dynamic website where floodplain risk assessments can also be done to other localities. CSV files can be uploaded and inputs from the domain experts are also necessary.

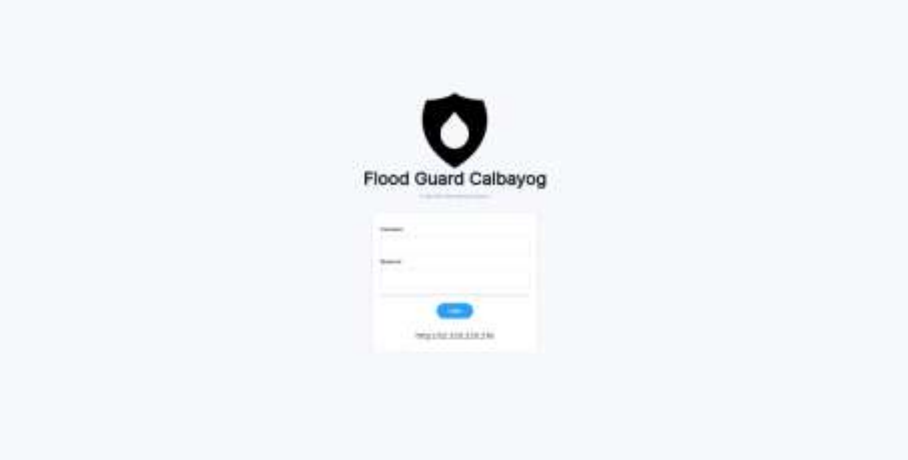



Figure 16. Flood Guard Calbayog Log In

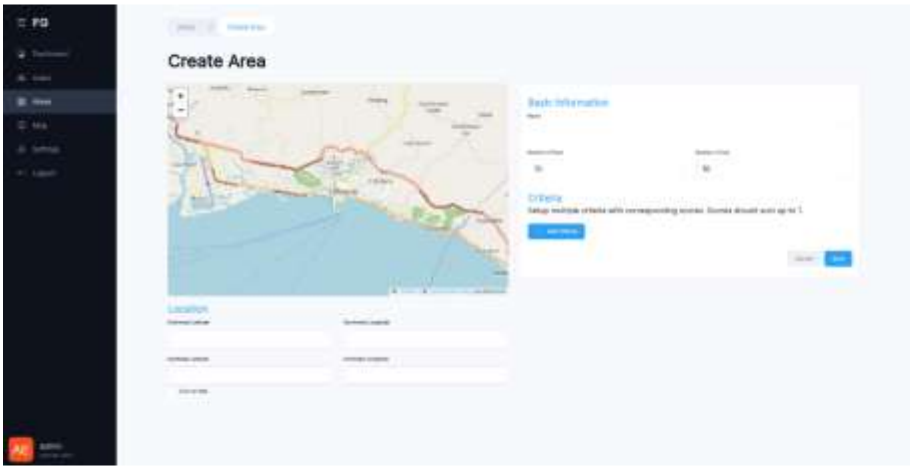



Figure 17. Establishing the Area of the Map

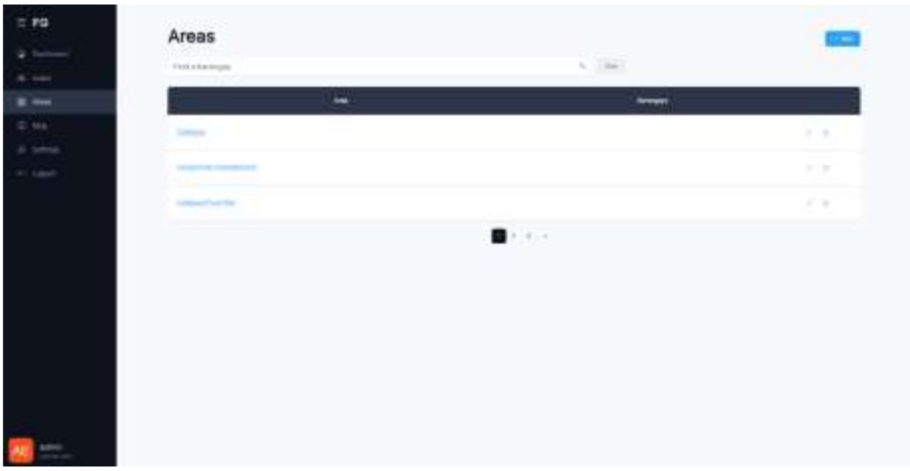



Figure 18. Listing of Areas Established

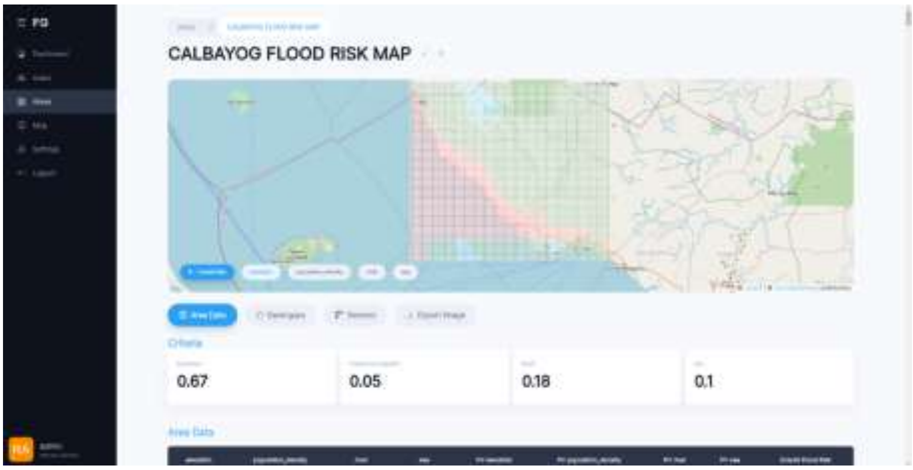



Figure 19. Displaying a Specific Area

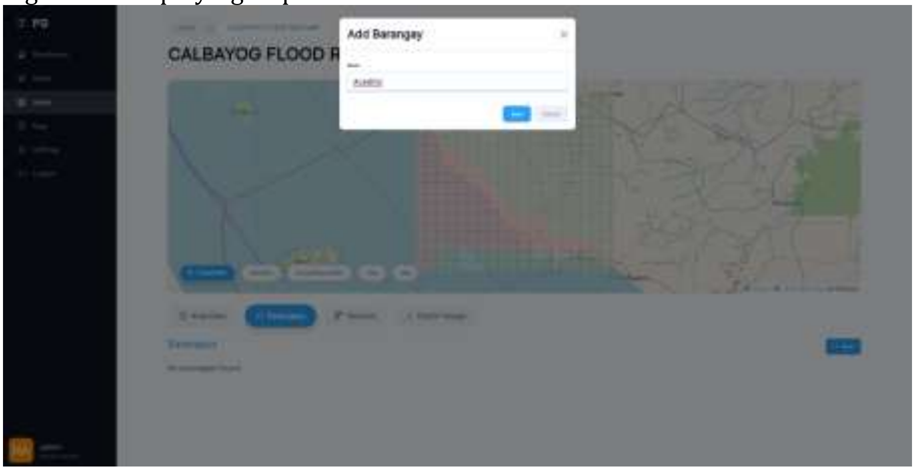



Figure 20. Adding of Barangay to An Area

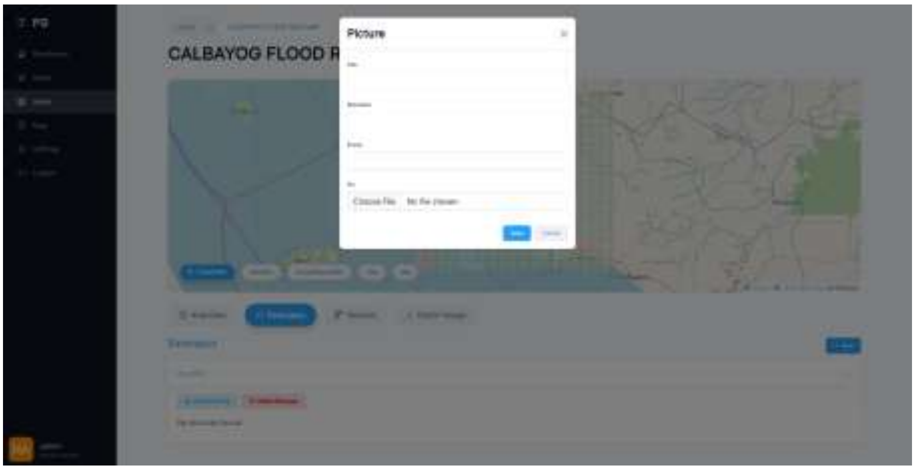



Figure 21. Adding of Image to a Specific Barangay

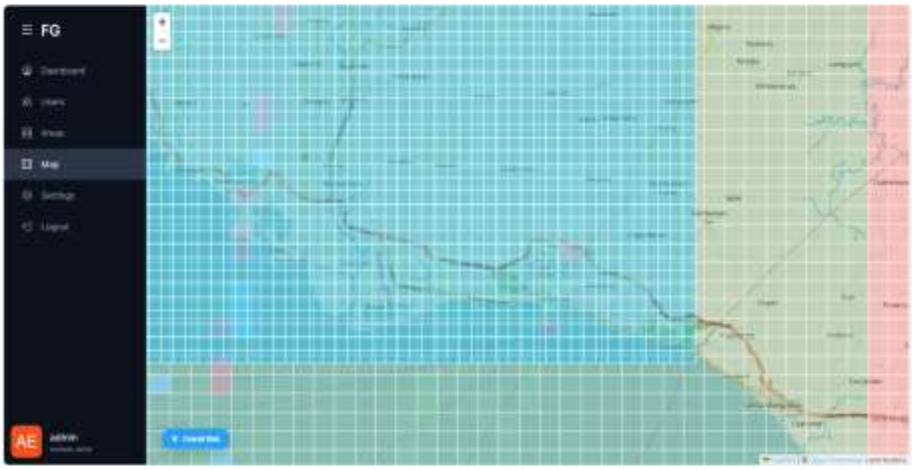



Figure 22. Overall Flood Risk Map Zoomed In

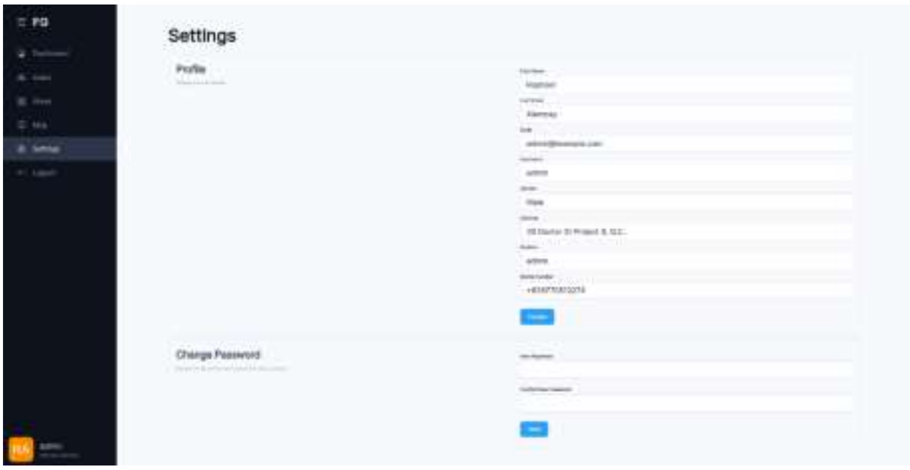



Figure 23. Profile Settings

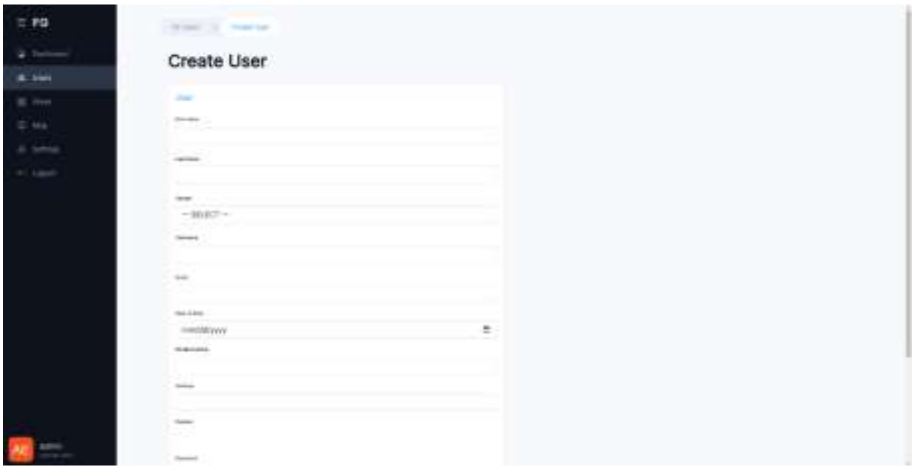



Figure 24. Creating of User Account


Figure 25. Listing of User Accounts

## 5. Conclusion

The comprehensive investigation of floodplain risk assessment in Calbayog City was conducted within the year providing insights for better informed decisions and proactive flood risk management. Primarily, there were four key contributing factors utilized in the study: site elevation, distance from the river, distance from sea and population density.

Site elevation was returned as the highest contributing factor as validated by the domain experts. Areas at lower elevations are easily identified as vulnerable to flooding. Hence, there is a need for targeted interventions by the city. Nearness to rivers and distance from the sea followed as the second and third contributing factors, respectively. Settlements near the riverbanks and coastal areas are evidently requiring flood risk plans and interventions. Another contributing factor is population density; it analyzes how urbanization interplays with vulnerability. Essentially, areas with higher population also entail a more locally adapted flood risk management and prevention.

Using UAV, historical data, contributing factors and validation from the domain experts, the study generated the overall flood risk map. The overall map offered a comprehensive view and system-level picture of the city vulnerability and propensity to flooding.

As Calbayog City continues to face flooding challenges, this study gives a clear picture of the main reasons why certain parts of the city get flooded. It explains how site elevation, nearness to rivers and the sea, and population density contribute to flooding in specific areas. For a more resilient community, environment friendly urban planning and flood risk management are encouraged to be able to adapt to future floods. Future work can be explored by integrating multi-factorial analyses into flood risk management.

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