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ASSESSING THE EFFECTIVENESS OF FLOOD CONTROL STRUCTURES IN LAS NIEVES, AGUSAN DEL NORTE USING UAS-GENERATED ELEVATION MODELS, LIDAR DTM AND FLOOD SIMULATION MODELS

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ABSTRACT: Due to the geographic placement of the Philippines, an average of 20 typhoons visited the country every single year. These typhoons brought about major changes affecting economic interests, destroying properties, and claiming lives. With the lineup of typhoons Sendong (Washi) and Odette (Rai), the tropical depression Vicky (Krovanh), and the super typhoons Pablo (Bopha) and Yolanda (Haiyan), there is a need to reinforce efforts in managing the before, during, and after the onslaught scenario of these natural phenomena. The construction of Flood Control Structures (FCS) is a way to minimize or mitigate the effects of typhoons. The question would then be on whether or not these structures were effective. In this study, the FCS was evaluated by using the terrain of high-resolution LiDAR DTM integrated with the Elevation Models processed from UAS-acquired images and using it as input for HEC-RAS. A 60m-altitude was chosen during the image acquisition with an 80% endlap and sidelap. Only two FCS were available in the study area, and they will be evaluated in their flood extent per barangay. For the entirety of the study area, only two FCS in Maningalao and EG Montilla were available. The images were then processed using Agisoft Metashape Professional software to produce the DSM, DTM, and Orthomosaic of the FCS. DSM was used in the evaluation of the terrain with the FCS and DTM was integrated to the LiDAR DTM to represent the terrain without FCS. By using a hypothetical rainfall event of 25-year, 50-year and 100-year return periods, it was revealed that for the terrain without FCS in (1) Maningalao, the flood extent per return periods were 419.79 ha, 424.73, and 430.24 ha, respectively, and in (2) EG Montilla were 276.14 ha, 278.90 ha, and 280.42 ha, respectively. For the terrain with FCS, the extent for: (1) Maningalao were 417.72 ha, 424.55 ha, and 430.82 ha, respectively, and (2) EG Montilla were 275.93ha, 278.83 ha, and 280.41 ha, respectively. Between the simulation of the two terrains, there were clear differences for the 25-year period. However, during the 50-year return period, these differences were significantly reduced and during the 100-year return period, the differences were insignificant. Moreover, the study aimed to provide a map indicating the low to high susceptible areas to flooding for the establishment of flood control structures. After the determination of the seven parameters or factors that needed to be considered, a weighted overlay tool with weights set to equal influence was then used. A final map was then generated after adding a map constraint of the 100-year flood event map of the municipality. Results indicated that there are only 11 barangays that contain highly susceptible areas of which Poblacion and Maningalao are the only barangays whose highly susceptible sites lie in a riverbank of the Agusan River and Magus creek, respectively. Furthermore, it can be inferred from the resulting map that areas nearest to evacuation centers and dense residential buildings have been classified as more susceptible sites due to the narrowness and exclusivity of these parameters.

1. INTRODUCTION

Water, one of the most prevalent substances known to man, has evolved into a valuable commodity over time. Water is necessary for all aspects of human life. However, it is the overabundance of water that causes problems. The Philippines has a well-defined rainy season due to the monsoons. Other weather processes produce precipitation, such as tropical cyclones, thunderstorms, ITCZ, and frontal passes. Even with a single event, these have the potential to produce much rain, enabling the creation of a disastrous phenomenon, flooding. Natural catastrophes, including flooding, often strike the Philippines, ranking third in the World Risk Index with a risk percentage of 27.98%. It is also the country with the third-highest risk of natural disasters (Garschagen et al., 2015).

A flood is defined as a gradual abnormal rise in streamflow's surface-level elevation until it reaches a maximum height and then gradually lowers to its average level. The events in the sequence are all set in a specific time frame. One event that can visualize the effects of flooding is when Typhoon Ketsana reached the country in 2009. It flooded over 21,700 hectares, or 34% of the heavily urbanized National Capital Region, affecting 4.9 million people and leaving 464 dead and 37 missing, causing US$ 240 million in property, infrastructure, and farm damage.

Region XIII, or the CARAGA region, located northeast of Mindanao, is split into two climate types. The region accommodates the third largest river basin in the Philippines, the Agusan River Basin (ARB). It is in Mindanao's northeastern region and has a drainage area of 10,921 km^2. Within the region, the Agusan River flows primarily through three provinces. The river rises on the Davao Oriental slopes. It flows north through Compostela Valley, Agusan Marsh in Agusan del Sur, and Agusan del Norte before emptying into Butuan Bay. The Municipality of Las Nieves in Agusan del Norte experiences river outflow due to the river systems of the Agusan River Basin, making it prone to flooding.

Building flood control structures are necessary to protect people and property in coastal and riverbank locations, including urban and agricultural communities, residences, and other economically vital areas. These structures redirect water flows by turning rivers, slowing natural changes in embankments and beaches, and preventing flooding of vulnerable coastlines and floodplains (USAID, 2011). Like many other types of infrastructure built for mitigation purposes, FCS was built to last decades.

In this paper, the researchers attempted to assess the effectiveness of the FCS in Las Nieves, Agusan del Norte (Figure 1). This analysis would be done by simulating flood models using the generated Elevation Models (DEM) of the Unmanned Aerial System (UAS) integrated into a LiDAR terrain model (DTM). The assessment will focus on the flood extent of the barangay where the FCS are: EG Montilla and Maningalao. A site susceptibility analysis for flood control establishments was created using Multi-Criteria Decision Making (MCDM).

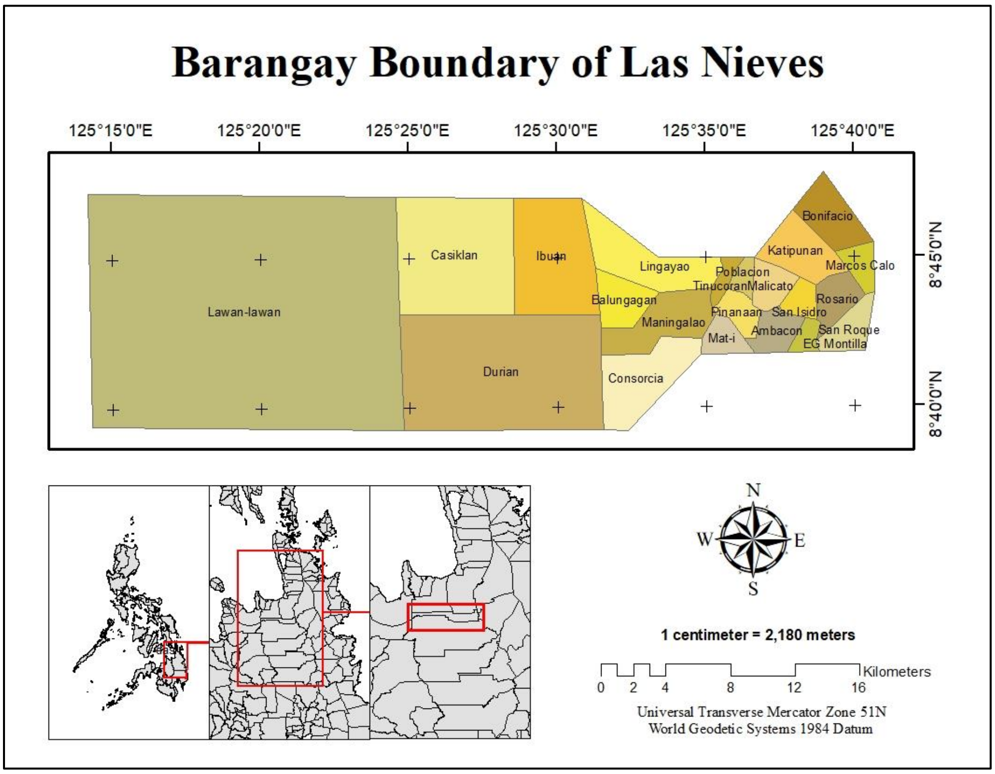

Figure 1. Boundary map of Las Nieves, Agusan del Norte

2. METHODOLOGY

2.1 UAS-Generated Elevation Models and Terrain Integration

The researchers prepared two flight plans for the survey: one per area with different parameters. Because the FCS involved in the study are near bodies of water and trees within the proximity, the researchers used 3D photogrammetry as a planning method. The usual suggested flying heights were 50m, 100m, and 150m. The 150m flying height was omitted because of aerial restrictions as set in the law. The 100m flying height produces fewer images because the flight area was relatively small. The considered flying height was 60 meters after accounting for the nature of the terrain. The sidelap and endlap were decided through the recommendation of the LMB Technical Bulletin No. 2 series of 2017. After checking all the pre-flight checks, the researchers then executed the plan. All flights took less than two minutes because the areas covered were not broad. After completing all flights, it was then exported to a computer machine for processing.

All the images acquired were loaded into Agisoft Metashape Professional. This software can produce elevation models and orthomosaic from aerial images. To build a DSM, all artificial and natural objects in the class must be ticked for the ground points of the dense cloud. For DTM, only the ground class would be checked. The Orthomosaic was processed to identify the extent of the FCS in both locations. The elevation models and the orthomosaic were exported with a Spatial Reference of WGS 84 UTM Zone 51N.

Polygons were made to extract the desired extent from the DEMs produced from UAS images. The orthomosaic was utilized to determine the geometry of all FCS, two in Maningalao and one in EG Montilla. The extraction process creates a new raster for only the extent of the FCS used in the integration.

The researchers created a hole in the LiDAR DTM to make room for integrating the FCS generated from UAS Survey. The integration was completed by mosaicking these two rasters with the same cell size.

2.2 Flood Simulation

The HEC-RAS model was requested from CCGeo through ENGAGE CARAGA Project 3 and was used to simulate three return periods for the extreme rainfall events: 25-year, 50-year, and 100-year. The researchers used two terrains in the simulation, one with FCS and one without FCS.

2.3. Flood Susceptibility for FCS Establishment

The researchers used the land use/land cover data of Las Nieves to extract annual and bare crops to generate the agricultural crop data layer. Data such as road network, agricultural crop, and evacuation centers underwent Euclidean Distance in Spatial Analyst tool to raster the data with a 10 x 10 cell size and established proximity with its closest source. Building Footprints were used to extract Residential Footprints. They were then processed through Kernel Density in Spatial Analyst tool to generate a data layer with a magnitude-per-unit area of residential buildings. All criteria, including Slope, Elevation, and Soil Type, were then reclassified.

The reclassification tool enabled the data layers to be reclassified according to their susceptibility classes and corresponding values. It was also employed for raster analysis to rasterize remaining datasets in a cell size of 10x10. Rasterization of all criteria was needed to utilize the weighted overlay tool. Elevation, slope, and soil type are the factors taken from the study conducted by Al-Ruzouq et al. (2019). Their objectives were to determine suitable sites for dam construction. Residential areas and proximities to the agricultural crops, road network, and evacuation centers were criteria taken from Ali (2000), which uses different criteria to determine suitable sites for urban land development.

A Kernel Density was used to determine a particular spatial feature's magnitude per unit area. It was also used to determine the density of residential buildings in the study area. On the other hand, the researchers used Euclidean Distance to create cells of proximities from a data source. Reclassification of the seven (7) criteria proceeded once the Euclidean Distance and Kernel Density for the other criteria was through. Reclassification parameters were based on related literature and were classified with their corresponding susceptibility classes. To proceed with weighted overlay, reclassified and rasterized all the data of each criterion and set it to have uniform cell size. Flood Susceptibility using Multi-Criteria Decision Analysis (MCDM) can be done by applying weights based on related literature or equal weights. This study uses equal weights to set equal influence among criteria. In the Weighted Overlay Tool of Spatial Analyst Tools, reclassified data layers of agricultural crops, road networks, evacuation sites, slope elevation, soil type, and residential buildings density were added in the "Weighted overlay table," respectively.

The researchers used an overlaid constraint to identify areas we should not consider in site selection. It was done to refine the site susceptibility map and consider only those areas belonging to a flood plain. For this study, a 100-year flood event map of Las Nieves was utilized as the constraint.

3. RESULTS AND DISCUSSION

3.1 Flood Control Structures Elevation Models

Sixty-five (65) images were captured from the Magus Bridge FCS, and sixty-four (64) images were acquired on the flight in EG Montilla FCS. These images were processed and were then used to generate orthomosaic maps. Orthomosaic is one of the products of UAS-image processing done through Agisoft Metashape software. The DSM, which depicts the area with the FCS' surface, and the DTM, which only displays the terrain of the FCS' location, were then generated. Both the DSMs and the FCS DTMs were processed through Agisoft Metashape Professional.

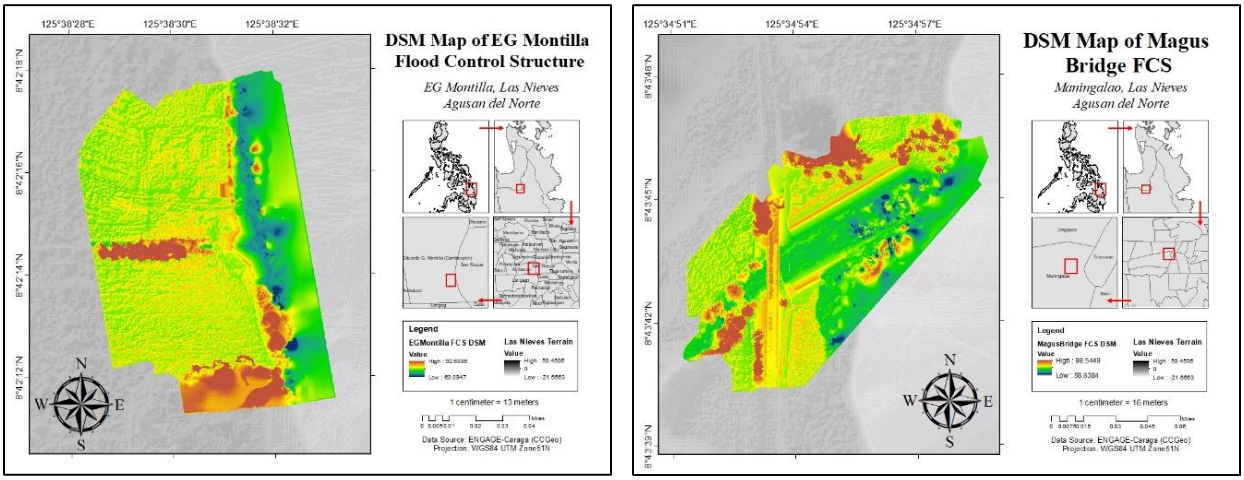

Figure 2. DSM maps of the flood control structures generated by UAS

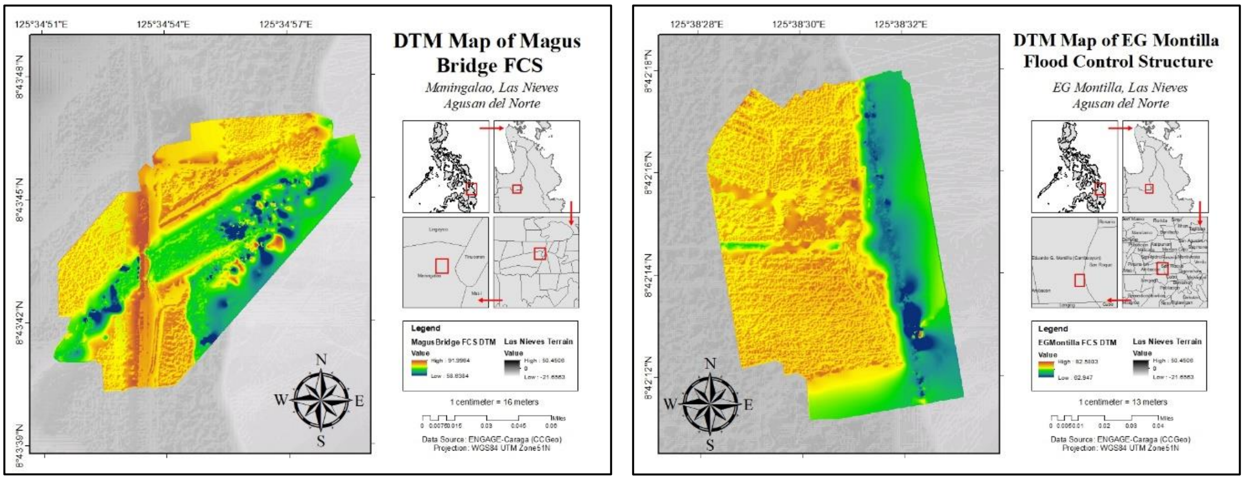

Figure 3. DTM maps of the flood control structures generated by UAS

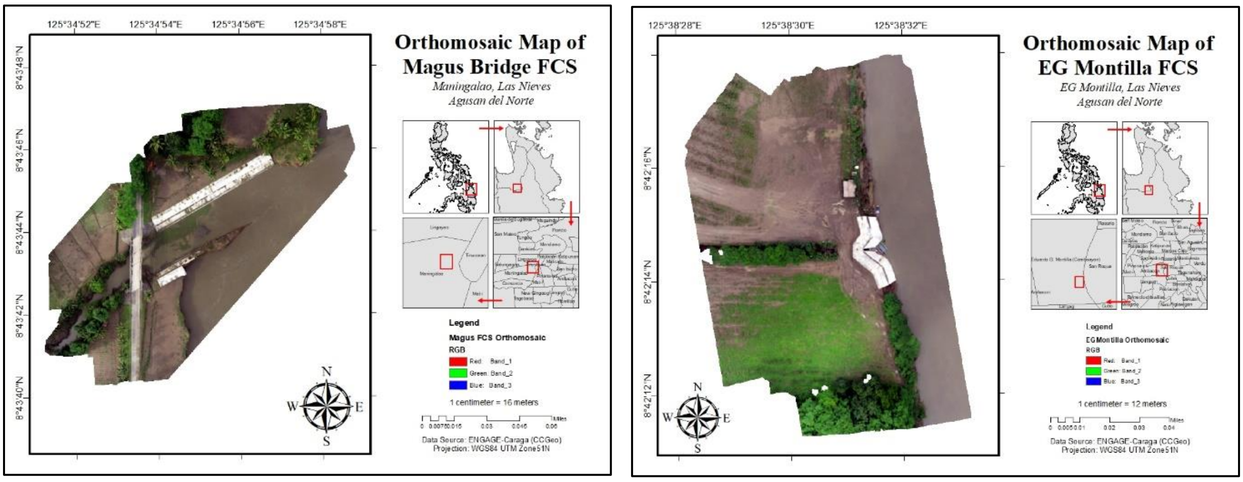

Figure 4. Orthomosaic maps of the flood control structures generated by UAS

3.2 Hydraulic Modelling and Generation of Flood Extent Maps

The researchers obtained the return periods utilized in the hydraulic modeling from the calibrated hydrologic model requested. The return periods of 25-year, 50-year, and 100-year were used in simulating the flood model. To better assess the effectiveness of the flood control structures, the researchers focused on the barangays where the FCS were located: Maningalao and EG Montilla. Maningalao has an approximate area of 1663.34 ha, while EG Montilla has an approximate area of 288.572 ha.

With FCS, the total area covered by flood in Maningalao on the 25-year, 50-year, and 100-year simulations were 417.72, 424.55, and 430.82 hectares, respectively. For EG Montilla, the flooded area during the 25-year, 50-year, and 100-year simulations are 275.93ha, 278.83 ha, and 280.41 ha, respectively.

Simulation using the terrain without FCS shows the area flooded without FCS. For the three return periods, 25-year, 50-year, and 100-year, the flooded areas in Maningalao totaled 419.79 ha, 424.73, and 430.24 ha, respectively. In EG Montilla, the flooded area for the 25-year return period is 276.14 ha, for the 50-year return period is 278.90 ha, and the 100-year return period is 280.42 ha.

For further assessment, the researchers identified the land cover of the difference in the area. For barangay Maningalao, four main land covers were identified from the difference in the area with and without FCS for the 25-year return period. Perennial Croplands comprised 46.13% of the entire area, and Shrubs had 36% of the area. In comparison, Annual Croplands and Open Forests comprised 11.07% and 6.8%, respectively. In the 50-year return period, only three major land covers were identified: shrubs comprising 52.3%, perennial croplands for 34.52%, and 13.18% for annual croplands. The 100-year return period, on the other hand, is still divided into three major land covers. However, perennial cropland owns the highest area with 69.95%, and shrubs comprise 25.29%. The least area is the annual cropland with 4.76%. For EG Montilla, although bareland amounted to 52.72% of the area not affected in the 25-year return period because of FCS, 43.16% of this is still that of the annual croplands, and about 4.12% are shrubs. For the 50-year return period, 97.9% of the area that was not flooded because of the FCS was bare cropland, while 2.1% were annual crops. For the 100-year return period, 96.99% of the area was made up of bare cropland, while 3.01% was made up of annual croplands.

Table 1. Extent of flooding on different land cover per return period

Barangay	Return Period	Land Cover	Percentage Area
Maningalao	25 years	Shrubs	36.00%
		Perennial Cropland	46.13%
		Annual Cropland	11.07%
		Open Forest	6.80%
	50 years	Perennial Cropland	34.52%
		Annual Cropland	13.18%
		Shrubs	52.30%
	100 years	Perennial Cropland	69.95%
		Annual Cropland	4.76%
		Shrubs	25.29%
E.G. Montilla	25 years	Bare Cropland	52.72%
		Annual Cropland	43.16%
		Shrubs	4.12%
	50 years	Bare Cropland	97.90%
		Annual Cropland	2.10%
	100 years	Bare Cropland	96.99%
		Annual Cropland	3.01%

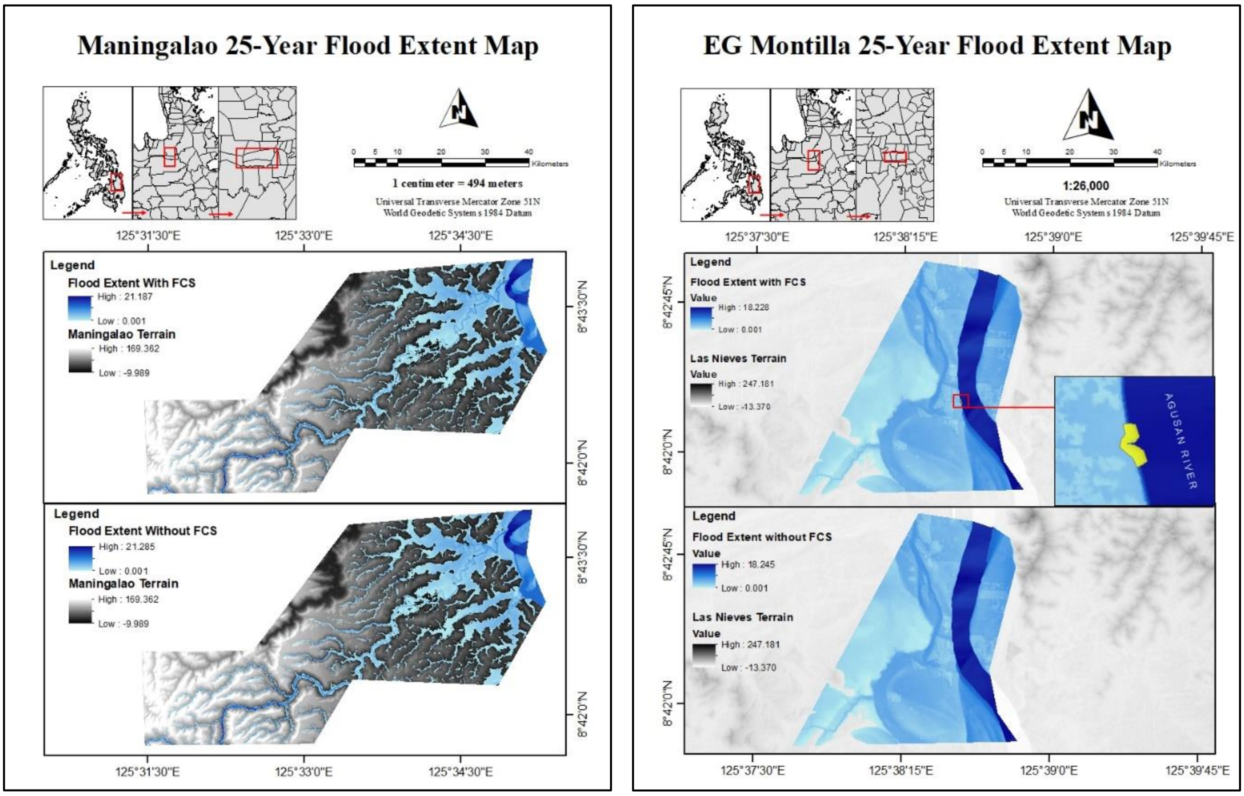

Figure 5. Flood extent maps for the 25-year return period

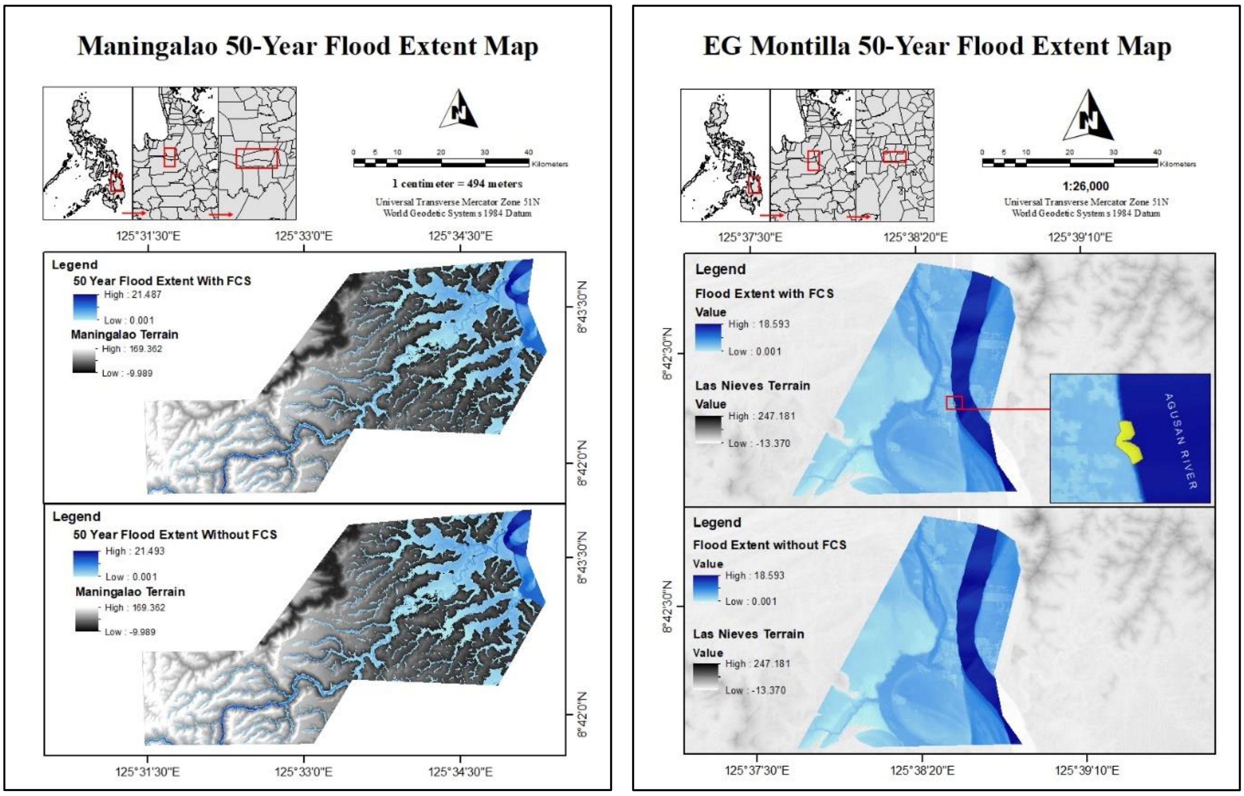

Figure 6. Flood **e**xtent maps for the 50-year return period

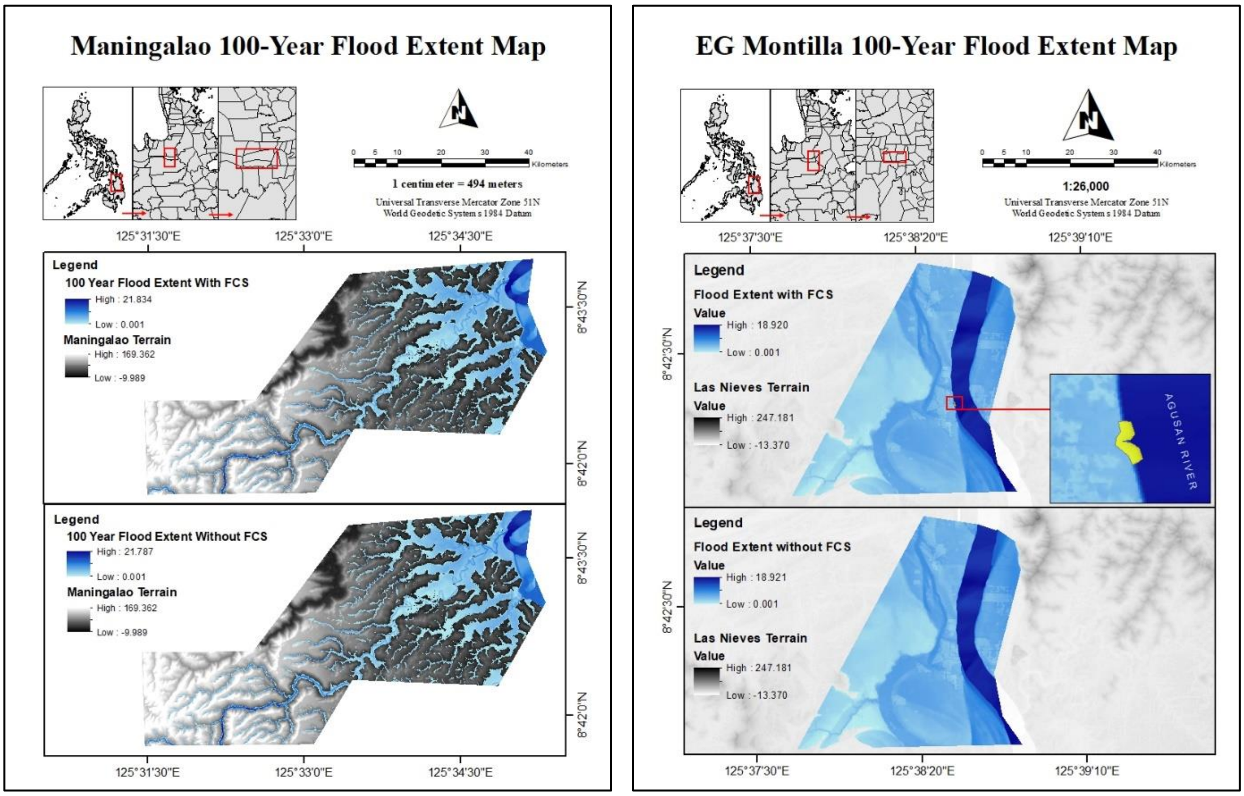

Figure 7. Flood **e**xtent maps for the 50-year return period

3.3 Weighted Overlay Analysis and Constraint Maps

After overlaying the seven (7) criteria, a weighted overlay map was generated. It was based on an equal influence for all the criteria to have a uniform weight, eradicating biased judgment.

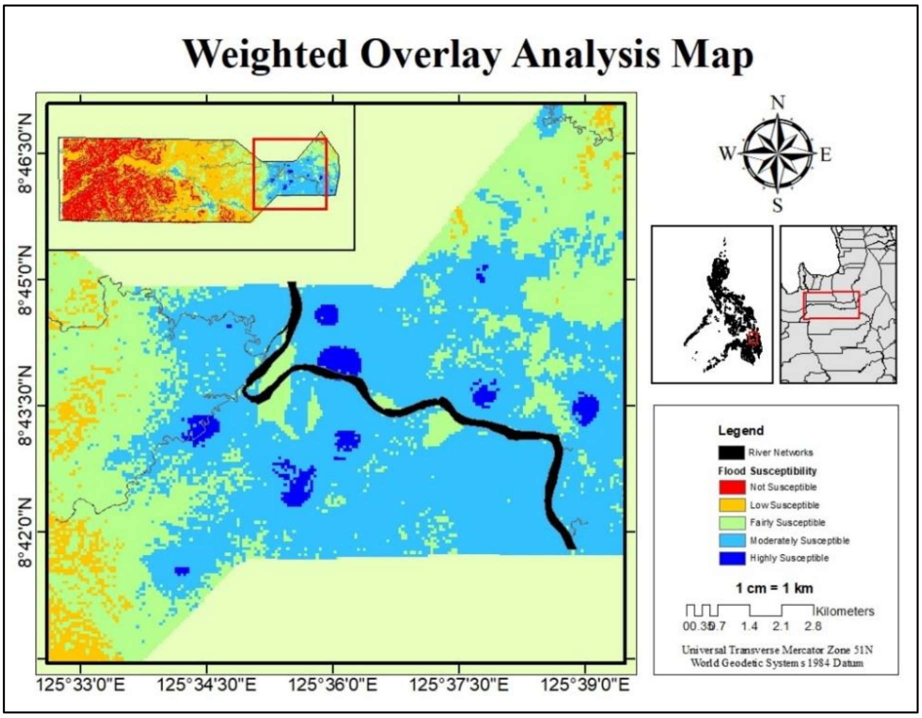

Figure 8. Weighted overlay analysis map of the seven criteria

The generated weighted overlay analysis map is depicted in Figure 8. Red areas are regions that are not vulnerable to flooding, while yellow areas represent the less susceptible. Light green represents areas for fairly susceptible, light blue for moderately susceptible, and blue for highly susceptible areas, respectively. It can be seen from the map that areas with highly and moderately susceptible classes lie in the vicinity of the Agusan River, where the flood plain is located. For the entire study area, 15674.9 ha are not flooded susceptible for FCS establishment, which accumulates 27% of the entire municipality, 25483.3 ha less susceptible which is 43%, 10791 ha that are fairly susceptible, which is 18%, 6616.95 ha that are moderately susceptible which is 11%, and only 238.723 ha or 1% are highly susceptible for FCS establishment in Las Nieves, Agusan del Norte.

After the weighted overlay analysis, a constraint data layer was added. This study used a 100-year flood extent as an extreme flooding scenario to assure that flood susceptible sites for FCS establishment are located within the flood plain. Figure 9 represents the constraint applied to the weighted overlay analysis.

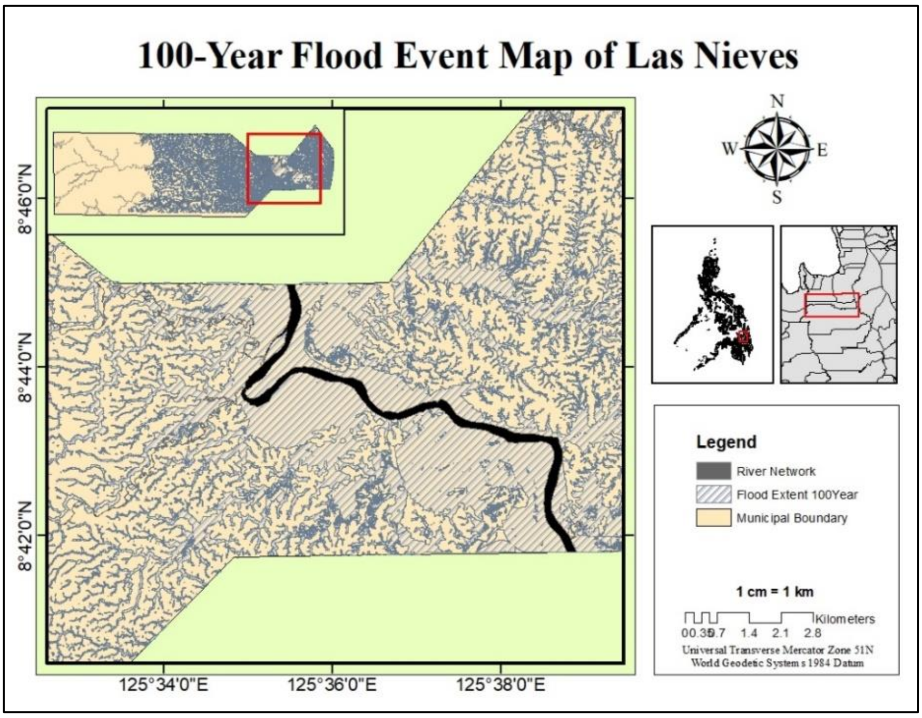

Figure 9. 100-Year flood event map of Las Nieves

3.4 Flood Susceptibility Map for Flood Control Structures Establishment

Figure 10 shows the final flood susceptibility map whose extent is within a 100-year flood event constraint with river networks overlaid. Dark green represents the Highly Susceptible areas with 131.43 hectares, light green for Moderately Susceptible areas with 3644.83 hectares, yellow for Fairly Susceptible areas with 2492.04 hectares, orange for Less Susceptible areas with 2373.81 hectares, and red for Not Susceptible areas having 132.08 hectares.

The barangays that have highly susceptible areas for flood control structures are only Consorcia which only consists of 1.88 hectares or 1.43%, San Isidro with 1.91 hectares (1.45%), San Roque with 1.99 hectares (1.52%), Katipunan with 3.40 hectares (2.58%), Malicato with 3.80 hectares (2.89%), Rosario with 12.40 hectares (9.43%), Pinanaan with 15.90 hectares (12.09%), Tinucoran with 17.00 hectares, Maningalao with 22.45 hectares (17.08%), Mat-i with 23.49 hectares (17.88%), and Poblacion which has the largest area of 27.23 hectares (20.72%).

Moreover, only the barangays of Maningalao and Poblacion contain highly susceptible sites within a river network: Magus Creek and Agusan River. Furthermore, it can be inferred that areas near evacuation centers and dense residential buildings tend to be classified as more susceptible sites due to their narrowness. One of the reasons may also be because of the equal influence set to all criteria during weighted overlay analysis.

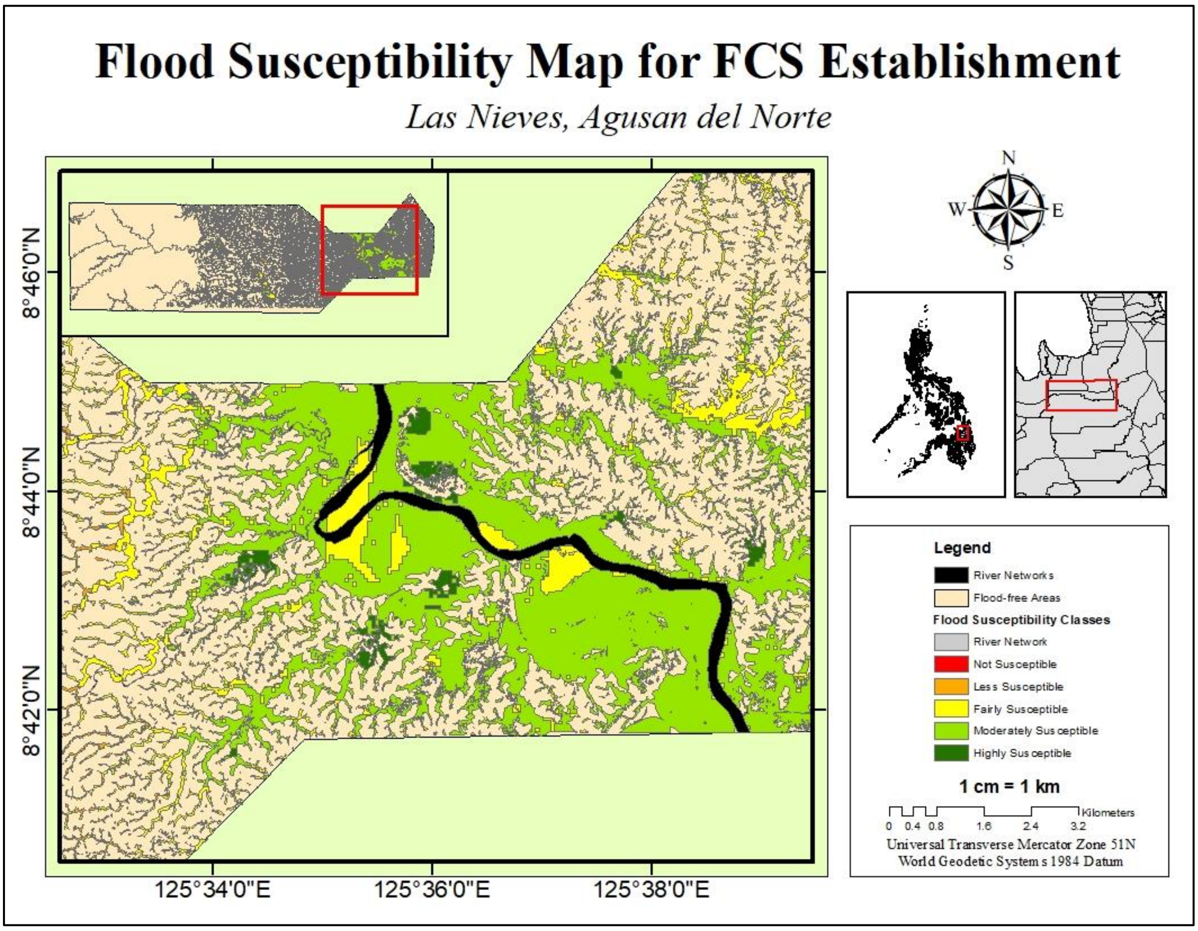

Figure 10. Flood susceptibility map for FCS establishment in floodplain areas of Las Nieves, Agusan del Norte

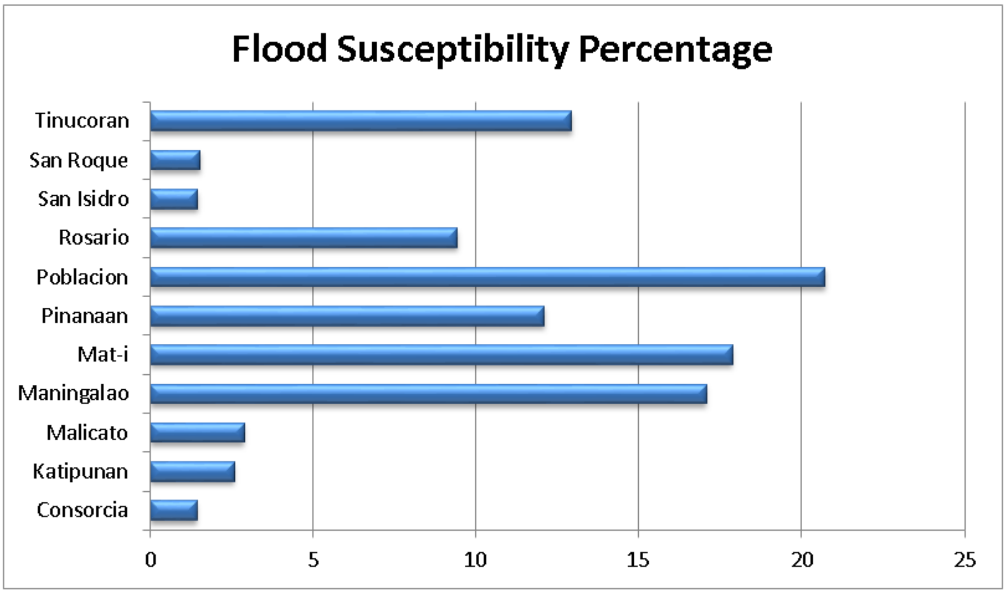

Figure 11. Statistics on the highly susceptible areas per barangay

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Acquiring UAS images has difficulty and is heavily dependent on the nature of the terrain and the obstructions within the surveyed area. The parameters considered during the flight planning also rely on the result of the reconnaissance. There was scarce research on the flight parameters for acquiring the images of the FCS, and some of them do not conform to the limitations for UAS flight.

To better compare the effectiveness of the FCS, the researchers compared the area of flooding within barangays Maningalao and EGM Montilla. The conclusion is that with the presence of the FCS, the area flooded is smaller compared to the absence of the FCS. This shows the effectiveness of the Flood Control Structures. On the other hand, site susceptibility was created where criteria have equal influence. That means equal weights were assigned to every criterion and could affect the susceptibility analysis. Highly susceptible sites were located mainly in the flood plain. However, the researchers can infer that the data such as proximity to evacuation sites and density of residential buildings had influenced the entire process.

4.2 Recommendations

The following suggestions are made for the study's improvement: (1) test other parameters used in the aerial acquisition for comparison, (2) use other flood maps to better assess the effectiveness of the flood control structures, and (3) consider other factors/criteria in site susceptible and consider AHP of RRL-based weights.

5. ACKNOWLEDGEMENT

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