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Vulnerability to Flooding of the Towns of Mabitac and Santa Maria, Laguna, Philippines

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ABSTRACT

The combination of flood modelling and socio-economic analysis was used to determine the flood vulnerability of the towns of Santa Maria and Mabitac, Laguna, Philippines. Geograhic Information System (GIS)-hazard mapping and vulnerability-resilience indicator were used to assess the interaction of a flood hazard and the socio-economic conditions of the people in the area. The Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center's River Analysis System (HEC-RAS) modelling system was used to derive the synthetic hydrograph and delineated the inundated areas in the flood-prone barangays (village) of Santa Maria and Mabitac. The flood modelling predicted the flood depths in seven out of ten communities and delineated the inundated barangays of the two towns. The social vulnerability analysis indicated that Barangays (village) Jose Rizal, Masinao, Adia and Coralan in Santa Maria and Barangays San Antonio, Libis ng Nayon, Bayanihan, Pag-asa, Nanguma and Lambac in Mabitac are very vulnerable to flooding. The study revealed environment-related aspects that are helpful in reducing the impacts of flooding such as, strengthening the flood warning system and emergency response capacity through flood hazard zonation mapping and rehabilitation of the watershed in Santa Maria.

Key words: *GIS mapping, social vulnerability, flood modelling*

INTRODUCTION

The Philippines is located in the western rim of the Pacific, an area which is prone to extreme weather disturbances such as typhoons. The country is in the path of an average of 20 typhoons a year. The typhoons that cross the archipelago are normally accompanied by intense rainfall that can trigger heavy flooding in low-lying areas of the country. Rain-induced flooding has been a common feature of the cyclonic climate of the country particularly during the months of July to October (*Perez 2003*).

The flood events that took place in many parts of the country such as in the provinces of Leyte and Quezon several years ago and recently in Pasig City, Marikina and many towns of Laguna including Mabitac and Santa Maria, demonstrated the devastating effects of floods to life and property and to the total development of the affected towns. Heavy losses in private properties and infrastructure occured in these places were staggering and brought major setback in economic and social development. Rehabilitation costs were almost unaffordable and the communities suffered emotionally and financially.

In the Philippines, the Department of Public Works and Highway-Japan International Cooperation Assistance used the Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS) software for hydrograph simulation. The hydrograph served as input in modelling the effects of flood control facilities to reduce the discharge at the downstream reaches. The Hydrologic Engineering Center's River Analysis System (HEC-RAS) was also used to simulate flooding due to two tropical storms in the Lower Tar Sub-basins in North Carolina (*Abshire 2012*). The HEC-RAS and HEC-HMS models with ArcView were used for hydrologic risk management for Romagna River Basins (*Pistocchi and Mazzoli 2002*).

A study that helps understand how the flood events interact with the socio-economic conditions such as flood vulnerability analysis is an indispensable method in planning and managing future activities as well as in developing contingency plans in times of an emergency (*Bizimana and Schilling 2010*). Hence, this study was conducted to assess the impact of extreme flood events using Geographic Information System (GIS)-hazard mapping and vulnerability-resilience indicators.

METHODOLOGY

The study used the GIS image data processing in generating the needed datasets for synthetic hydrograph and flood modelling. Social vulnerability indicators were used in assessing the social vulnerability of the people in the flood-

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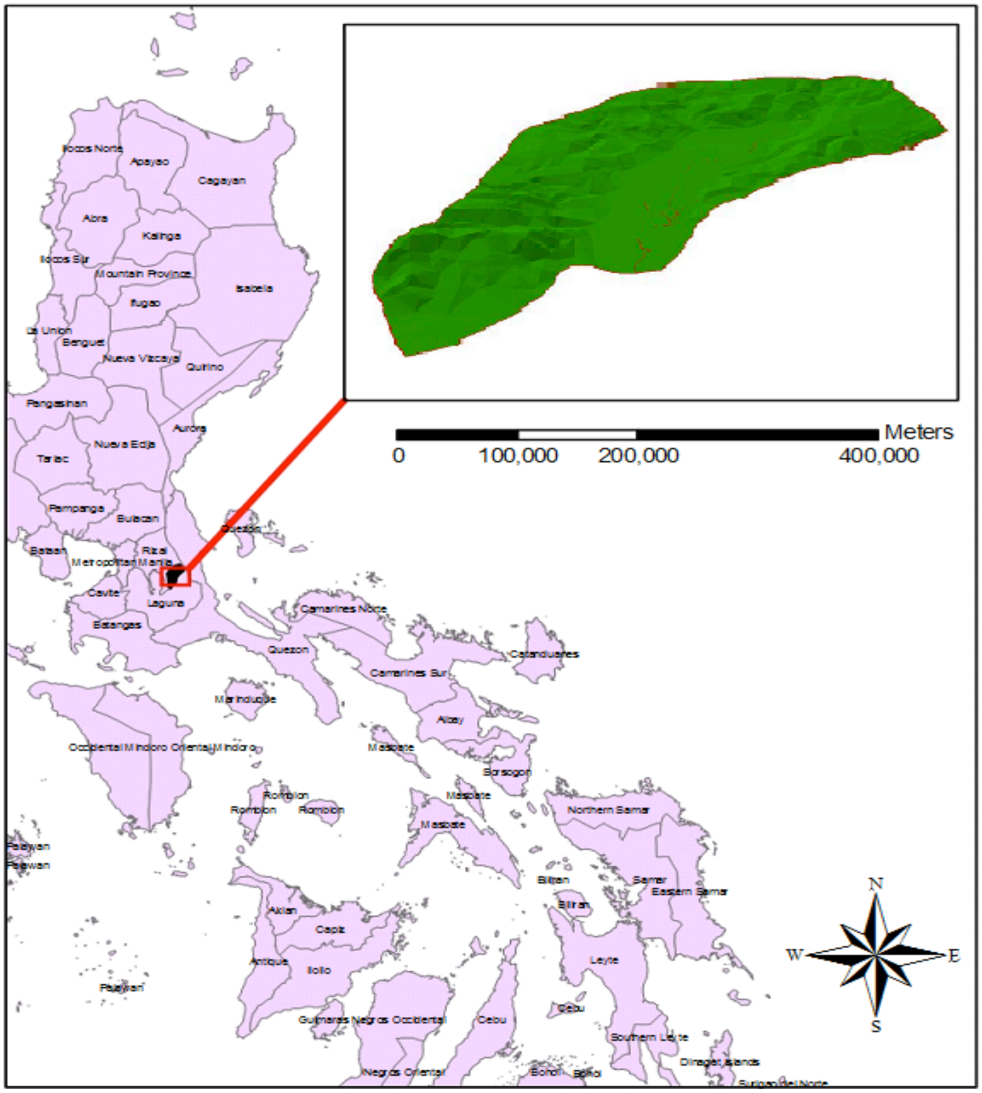

Figure 1. Location and three dimensional model of the study area.

prone barangays of Mabitac and Santa Maria, Laguna.

Hydrograph modelling

The first step in hydrograph modelling using the Hydrologic Engineering Center Geospatial Hydrologic Modelling System (HEC-GeoHMS) tool of the ArcGIS is the terrain pre-processing using the digital elevation model as data input.

The output of the terrain pre-processing, together with the Curve Number (CN) grid, soil type and CN look up table, served as inputs in basin processing (*USACE 2009*, *Ponce and Hawkins 1996*). Its product is the HEC-HMS schematics containing the basin model, basin map and basin data needed in flow hydrograph modelling.

The HEC-HMS schematics, meteorological data (storm return period of rainfall intensity) control specifications (simulation period and date of simulation) formed part in the simulation of the synthetic hydrograph using the HEC-HMS software (**Figure 2**).

Flood modelling

The HEC-GeoRAS, an extension of ArcGIS, was used in creating the required geometric datasets such as river centerline, main channel banks (left and right), flowpaths, and cross-section cutlines needed in flood modelling in HEC-RAS (**Figure 3**). After creating the necessary datasets, a GIS import data were created and imported to HEC-RAS. The GIS import data, synthetic hydrograph and Manning's roughness coefficient formed part in the flood simulation using HEC-RAS (*USACE 2002*). A RAS GIS export data set was created after the simulation and re-imported in ArcGIS. The data were used to create a continuous water surface elevation that interacts with the digital terrain model to produce flood plain extents, and water depth grids.

The flood map was further classified based on the depth of flooding criteria. The classification criteria that were considered together with their corresponding depth were as follows:

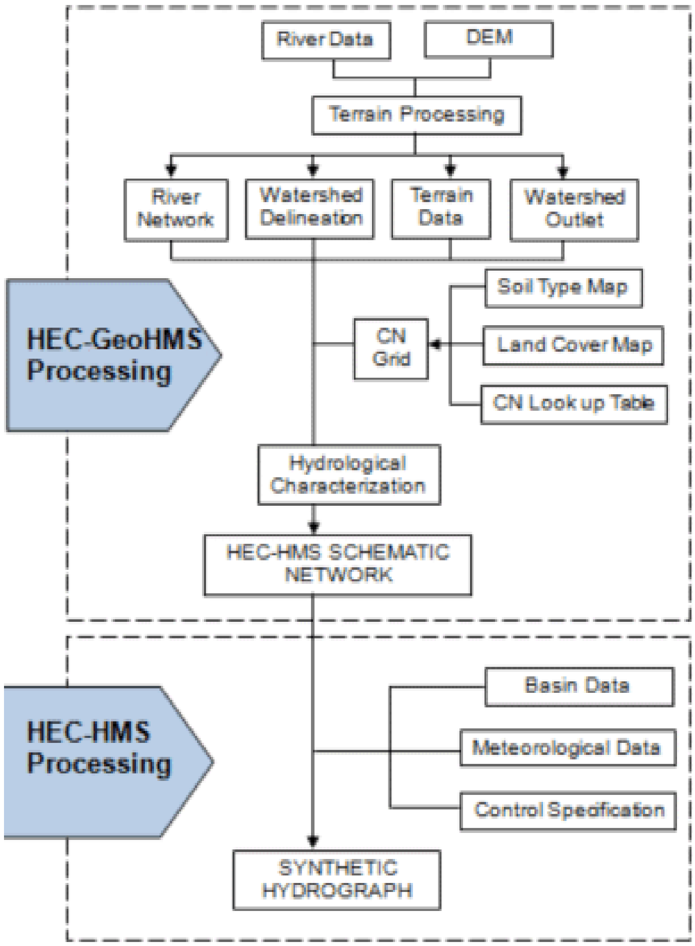

Figure 2. Flowchart for the synthetic hydrograph modelling (*Maidment 1993*).

Low	0.30 to 0.61 m
Moderate	0.62 to 1.45 m
Severe	1.46 to 3.59 m
Very Severe	greater than 3.59 m

Social vulnerability analysis

The assessment of social vulnerability is carried out using proxies or vulnerability indicators. Secondary data were obtained from different offices of the two municipalities and primary data were collected through survey and interview. The major variables as well as sub-variables that were used to measure the social vulnerability are presented in **Table 1**. These variables had been considered in numerous studies conducted in other countries. The weight distribution of each variable was based on the previous studies conducted in developed countries such as in Australia and the United States.

Calculation of social vulnerability index

The social vulnerability index was determined using the formula (Cutter 1997):

SoVI = 0.30*DI + 0.40*SEI +0.15*NRDI +0.15*SPII

Where:
SoVI = Social Vulnerability Index of a barangay in the study area
DI = Demographic Index of a barangay in the study area
SEI = Socio-economic Index of a barangay in the study area
NRDI = Natural Resource Dependence Index of a barangay in the study area
SPII = Strength of Public Infrastructure Index of a barangay in the study area

The variable index is the sub-index of the major variables used in social vulnerability analysis in the flood-prone barangays of the town (**Table 1**). It was determined using the following formula:

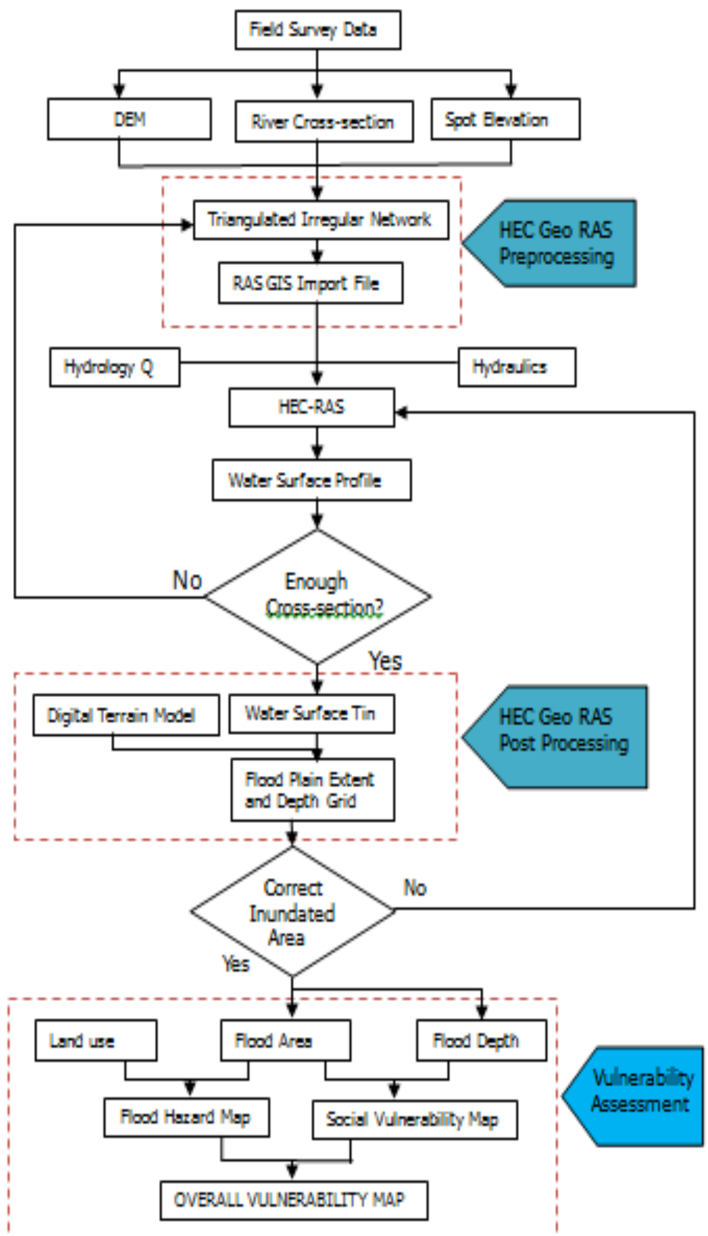

Figure 3. Flowchart for flood vulnerability mapping using HEC-RAS and ArcGIS (*Maidment 1993*).

$$\text{Variable index} = \frac{x}{\text{Maximum value of } x}$$

The x is the fraction of the variable used in calculating the variable index. It was computed using the formula:

$$x = \frac{\text{Raw value of corresponding variable/parameter}}{\text{Variable/parameter total of the town}}$$

The measure of social vulnerability for the monthly family income and barangay monthly revenue was adjusted from a range of 0 to 1 to permit the addition or multiplicative averaging (*Cutter 1997*). This was accomplished by normalization procedure where its the average of is called standardized vulnerability index. The formula is:

$$Vij = (Xij - Min\ Xi) / (MaxXi - MinXi)$$

Where:

Vij = the standardized vulnerability index for a vulnerability parameter i for a vulnerable place j
Xij = the observed value of a particular place j for a particular vulnerability parameter i
Min Xi and Max Xi = the minimum and maximum values of the observed range of values of a vulnerability parameter

The overall social vulnerability index for each *barangay* was the average of the computed indices of the different social indicators. The computed index was rescaled from 1 to 5 using the weight shown in **Table 1**.

RESULTS AND DISCUSSION

The computed peak flow discharges in different rivers reaches ranged from 8 to 57 $m^3 s^{-1}$ for the 5-year return period (**Table 2**). The interpolated intensity of extreme rainfall events obtained from rainfall gauging stations in provinces of Rizal and Laguna for such peak flow discharge was 45.7 mm $(hr)^{-1}$.

The smallest peak flow discharge of 8 $m^3 s^{-1}$ was recorded in the river tributary (R840) of the river network. The river tributary had the smallest sub-basin area and was located at the edge of the study area, hence had lesser volume of water per unit area.

A rainfall intensity of 74.5 mm h^{-1} increased the peak flow discharges of the different river reaches. The smallest and highest increment is 1.1 $m^3 s^{-1}$ (R840) and 10.2 $m^3 s^{-1}$ (R330), respectively.

The highest peak flow discharges of the river reaches were 10.2 to 74.5 $m^3 s^{-1}$ with a 20-year storm return period. The computed rainfall intensity for such condition was 80.0 mm h^{-1}.

The river reach (R330) immediately after the intersection of the river tributary (R840) (**Figure 4**) and the middle reach of the main river had the highest peak flows of 57, 67.2 and 74.5 $m^3 s^{-1}$, respectively for the 3 storm return periods that were considered in this study.

Spatial extent and depths of flooding for the 5-year storm return period

The spatial distribution of the flooded area for the 5-year storm return period was widely distributed among the different barangays of the towns of Santa Maria and Mabitac. The deepest simulated flood depth occurs in both towns, scattering from the top most portion of Barangay Coralan in Santa Maria and the lower portion of Barangay Bayanihan in Mabitac. The rest of the flooded areas in the town of Santa Maria such as Barangays Talangka, Bagong

Table 1. Major and sub-variables used in social vulnerability analysis.

Major Variable	Weight %	Sub-variable
Demographic index	30	Number of renters and separated couples Number of individuals per household Number of disabilities Age and Gender Educational Attainment
Socio-economic index	40	Number of families with income below poverty level in a community Number of family members with permanent jobs Number of families with cars/vehicles
Natural resources dependence index	15	Number of environmental resources which provide income to people within the area Number of families whose jobs are located within the community/barangay
Strength of public infrastructure index	15	Travel time and road condition from the house to the evacuation area Number of health centers within the community Number of communication systems available in the area

Table 2. Simulated peak flow discharges of the river reaches using extreme rainfall values.

StormReturn Period (Year)	Discharge (m^3s^{-1})							Rainfall Intensity mm hr^{-1}
	R170	R210	R250	R290	R330	R360	R840	
5	32.4	33.6	56.0	45.3	57.0	45.0	8.0	41.6
10	38.5	40.0	66.0	52.4	67.2	53.3	9.1	48.4
20	42.4	43.9	73.4	59.1	74.5	59.2	10.2	53.5

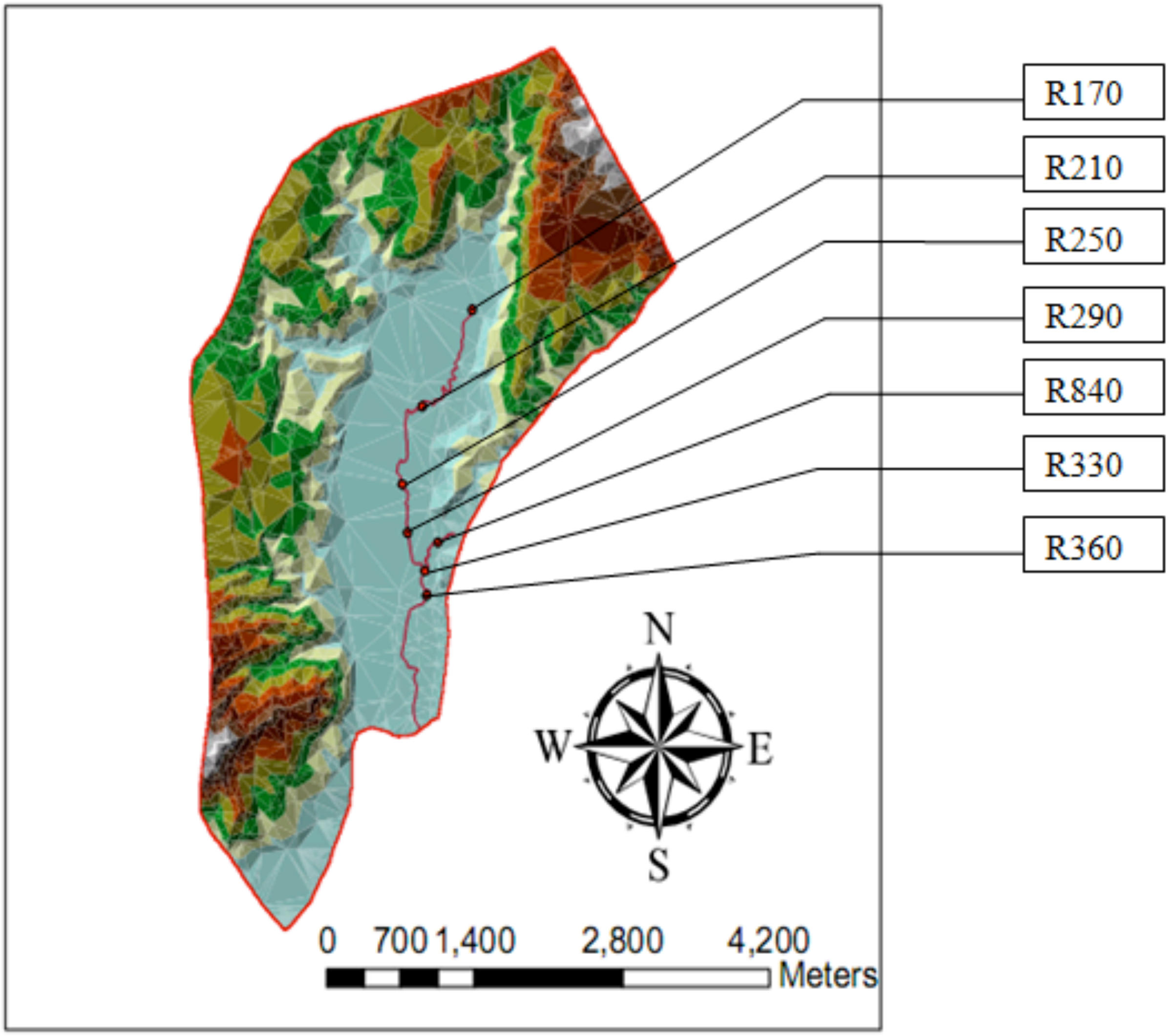

Figure 4. Locations of the river reaches in the river network.

Pook, Barangay 1, 2, 3 and 4, Kayhakat, Masinao and Adia were estimated to have low to moderate flooding with 0.3 to 1.45 m flood depths (**Figure 5**).

With the 5-year return period flood simulation, the estimated area in Santa Maria, which is classified as very severely flooded is about 0.413 km^2. About 2.16 km^2 is classified as severely flooded and 6.12 km^2 is classified as low to moderately flooded (**Table 3**).

Flood simulation also indicated that a larger portion of the town of Mabitac, Laguna (**Table 4**) was prone to severe flooding compared to the town of Santa Maria (**Table 3**). Portions of Barangays San Antonio, Nanguma, Sinag-tala, Libis ng Nayon and Lambac in Mabitac is prone to a very severe flooding of 3.6 to 5.22 m depth. Most parts of the same barangays were likewise estimated to be prone to flooding of 1.5 to 3.59 m depth (**Figure 4**).

With 5-year storm return period flood simulation, about 1.02 km^2 were very severely flooded and about 6.44 km^2 were severely flooded in Mabitac. About 6.09 km^2 had low and moderate flooding (**Table 4**).

The simulated heavy flooding in many parts of Mabitac can be attributed to the terrain of the area. The town is located in a lower elevation and is in the path of flood water discharge of different river tributaries from the mountainous

Table 3. Estimated flooded area (km²) in Santa Maria, Laguna.

Storm Return Period (Year)	Flooding Classification				Total
	Low	Moderate	Severe	Very Severe	
5	2.512	3.615	2.160	0.413	8.700
10	1.096	2.882	5.003	0.645	9.626
20	0.782	1.286	6.763	1.226	10.057

Table 4. Estimated flooded area (km²) in Mabitac, Laguna.

Storm Return Period (Year)	Classification				Total
	Low	Moderate	Severe	Very Severe	
5	2.976	3.120	6.443	1.025	13.564
10	1.281	4.617	5.149	2.986	14.033
20	0.883	4.771	3.623	5.106	14.383

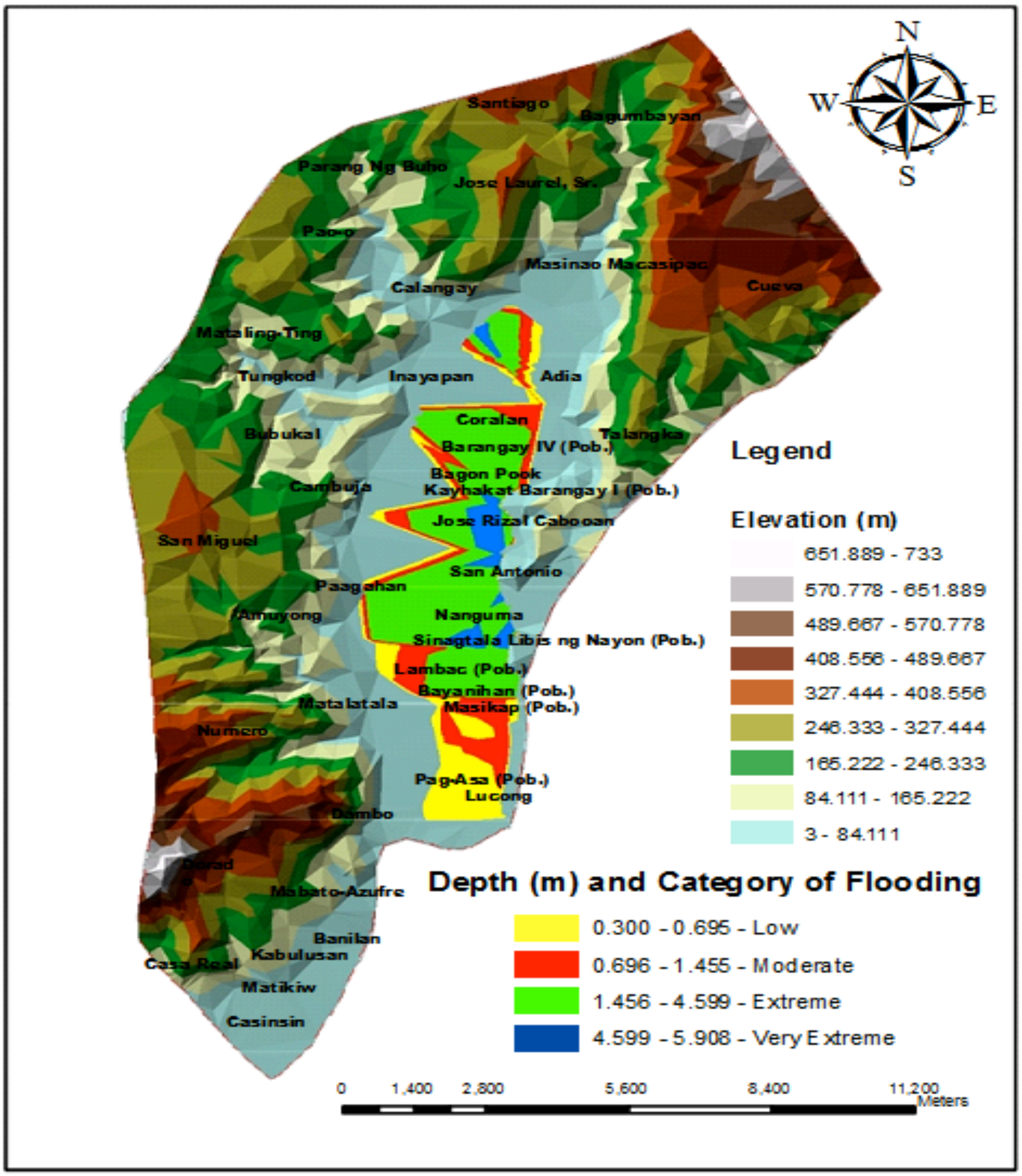

Figure 5. Depths and extent of flooding of a 5-year storm return period of extreme rainfall event.

areas of the Sierra Madre (**Figure 3**).

Spatial extent and flood depths for the 10-year storm return period

The flood trend for the 10-year storm return period simulation was similar to the 5-year storm return period. The main difference is the change in depth of the flooded areas in the two towns. The areas with moderately, severely and very severely flooded significantly increased whereas the areas that were not flooded decreased (**Figure 6**). The total flooded areas likewise increased from 22.26 to 23.66 km^2 for the 5- and 10-year storm return periods, respectively.

There was a considerable increase of very severely flooded areas in Barangays San Antonio, Nanguma, Sinagtala, Lambac and Libis ng Nayon in Mabitac, Laguna. The increase in severely flooded area was very remarkable in Nanguma. From a small spot that developed at the edge of the flooded area in the southern portion of the barangay, it spread out and reached the heavily flooded area in Barangay Sinagtala. From 1.02 km^2, the very severely flooded area increased to 2.98 km^2 for the 5-year and 10-year storm return periods, respectively (**Table 4**). The moderately flooded areas also increased from 3.12 to 4.62 km^2.

The areas that were classified as severely flooded under the 10-year return period increased by 1.96 km^2 when compared to the 5-year storm return period (**Table 4**). This is due to the significant increase in flood depths in these areas brought by a more intense rainfall. The total flooded area for Mabitac with a 10-year storm return period was 14.03 km^2, compared to 13.56 km^2 for the 5-year storm return period. The total flooded area in Santa Maria for the 10-year storm return period increased to about 1.40 km^2 in comparison with the 5-year storm return period. An increase of about 0.23 km^2 was recorded for the area classified as very severely flooded and the increase was mostly in Barangay Jose P. Rizal. This barangay had been observed by residents as one of the most flood-prone area in the town of Mabitac.

The low and moderately flooded areas in Santa Maria decreased considerably, whereas the very severely flooded was more than doubled (**Table 3**). The higher rainfall intensity of the 10-year storm return period increased the flood depths causing severe flooding in the moderately flooded areas.

Spatial extent and flood depths for the 20-year storm return period

Higher intensities of rainfall under the 20-year storm period further worsened the flooding of the low-lying areas of the two towns. The flood depths in the very severely flooded areas with the 10-year storm return period further increased under the 20-year storm return period. The extent of very severely flooded areas was nearly doubled in comparison with the 10-year storm return period (**Table 5**). The low flooded areas were about 1.66 km^2 and these were found at the outskirts of the moderately flooded areas.

The simulation showed that there are a total of 24.43 km^2 flooded area in Mabitac and Santa Maria with 20-year storm return period. A large portion is in the town of Mabitac, which is about 14.38 km^2 (**Figure 7**).

The very severely flooded areas of the town also increased from 2.98 to 5.10 km^2, most of which were in Barangays San Antonio, Nanguma, Sinagtala, Libis ng Nayon, Lambac and Bayanihan.

The estimated total flooded area in the town of Santa Maria was about 10.06 km^2, relatively smaller than in Mabitac because a large portion of its area was not covered by the study. A large portion of the flooded area was in the rice fields between the residential zone and the hilly land located at the edge of Barangay Jose Rizal (**Figure 6**).

Most of the areas that were classified as low to moderately flooded were found at the outskirts of the two towns. This was expected because these areas were the transition zones between the flood plain and mountainous areas that surround the two towns.

Due to the sharp transition between the flood plain and the mountainous areas in the southern portion of Barangays Jose Rizal in Santa Maria and San Antonio in Mabitac, the sharp edge of the mountainous areas created temporary water damming, which increased the flood water depth.

Comparison of the simulated and actual flood depths

Based on the interviews with the residents, the flood depths during the past flood events in many areas of the two

Table 5. Estimated total flooded area (km^2) in Santa Maria and Mabitac, Laguna.

Storm Return Period (Year)	Classification				Total
	Low	Moderate	Severe	Very Severe	
5	5.486	6.734	8.603	1.438	22.261
10	2.376	7.497	10.164	3.630	23.668
20	1.663	6.056	10.383	6.332	14.383

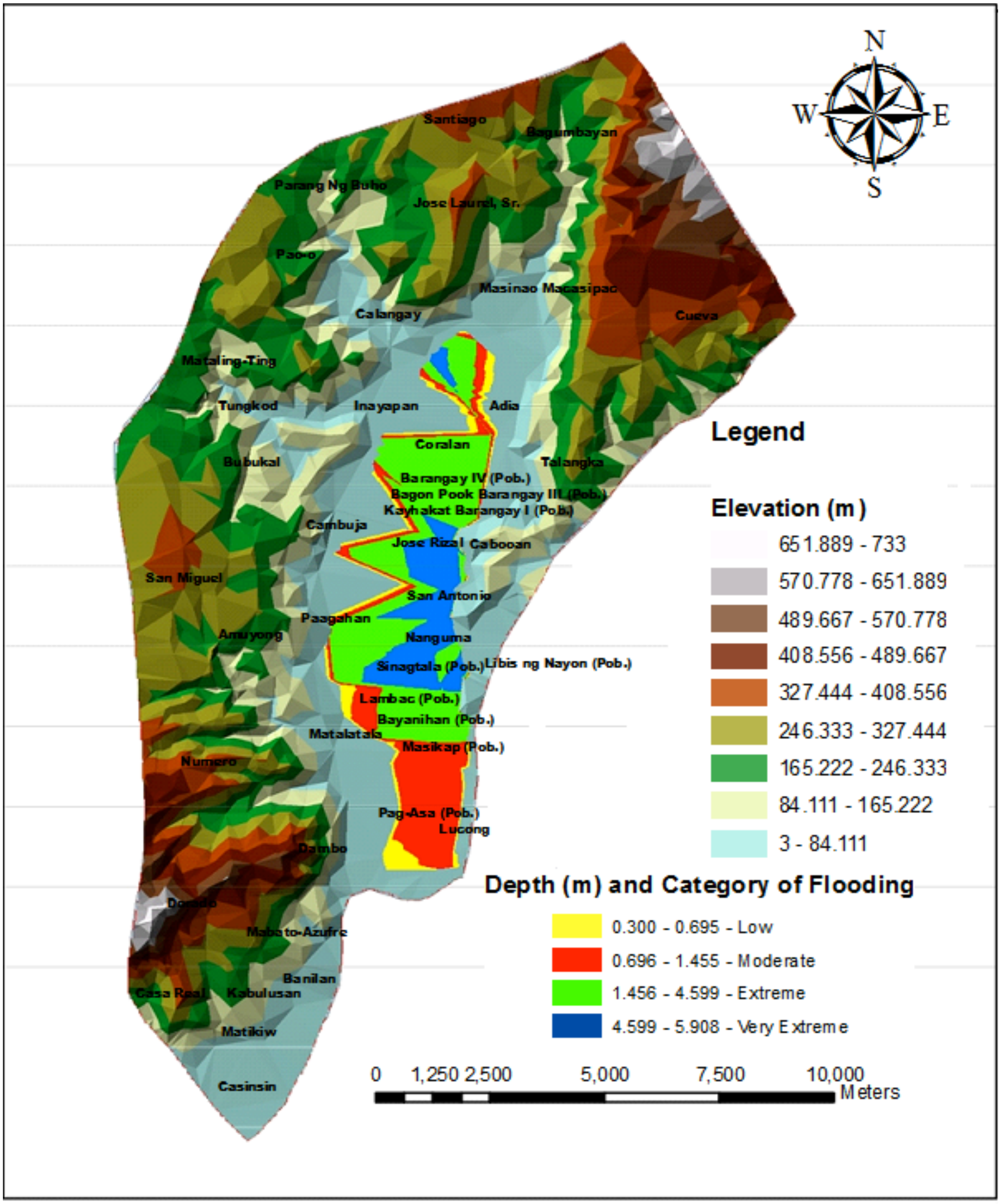

Figure 6. Depths and extent of flooding of a 10-year storm return period of extreme rainfall event.

towns, particularly in the settlement areas of Barangays Talangka, Masinao, Coralan and Jose Rizal, coincided with the simulated flood depths (**Figure 8**). The model also predicted the flood depths in Barangays Lambac, Bayanihan and Libis ng Nayon in Mabitac, Laguna. The simulated flood depths in Masinao and Libis ng Nayon for the 20-year storm return period were 1.09 and 3.3 m, respectively. The actual flood depths in these areas, based on the interview were 1.2 and 3.1 m, respectively.

There were however locations which the model over-estimated the flood depths. These are the areas where there had been extensive landfilling. These areas were found in Barangay 1 in Santa Maria and Sinagtala and Nanguma in Mabitac. The simulated flood depths in Barangay 1 and Sinagtala were 1.9 and 4.6 m, respectively. On the other hand, the actual flood depths in these areas were 0.8 and 3.5 m only.

The flood simulation using HEC-RAS model can be used to predict the spatial extent and depth of flood events. Updating of the topographic map for areas with extensive land development is needed to accurately predict the flood depths.

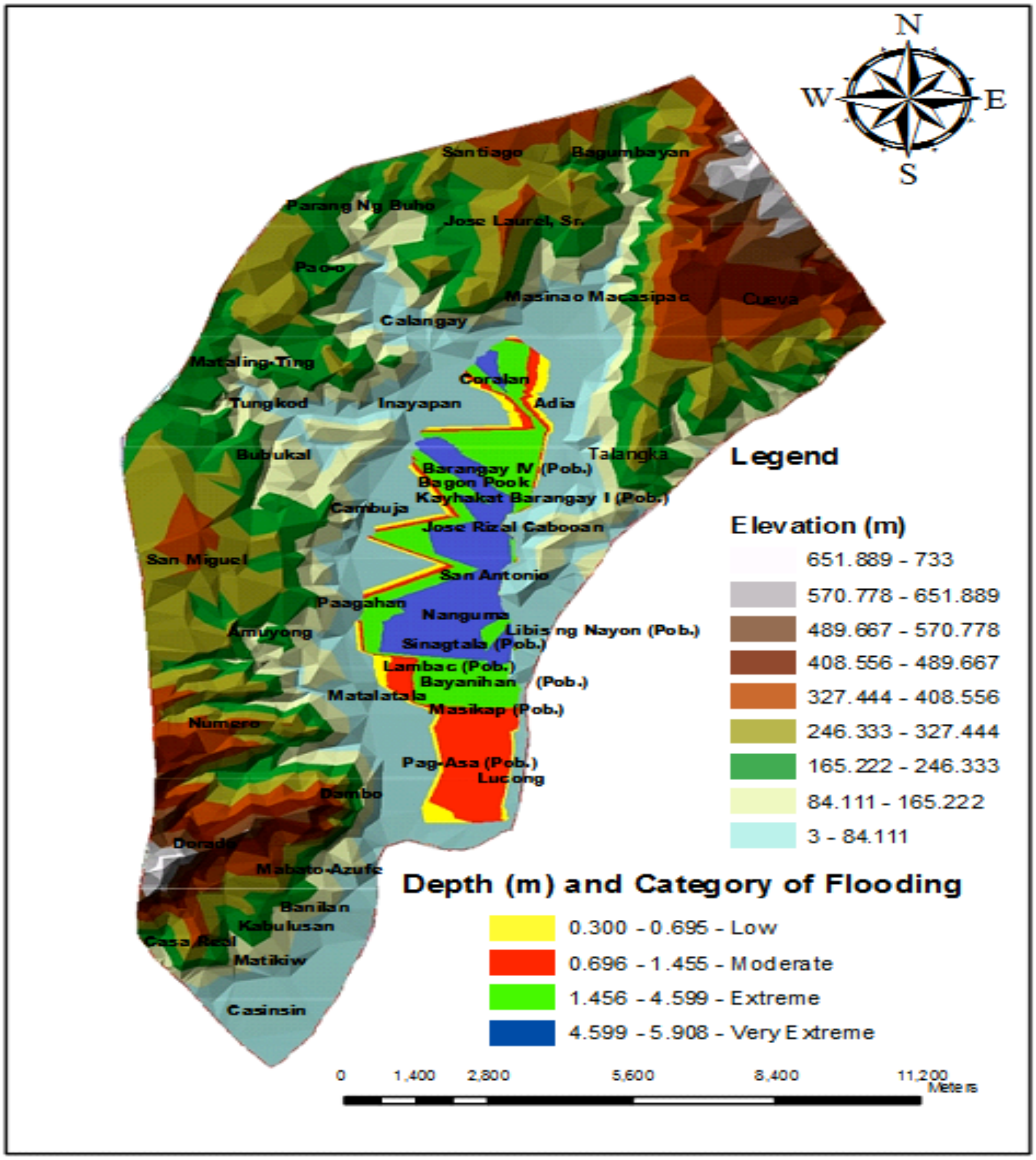

Figure 7. Depths and extent of flooding of a 20-year storm return period of extreme rainfall event.

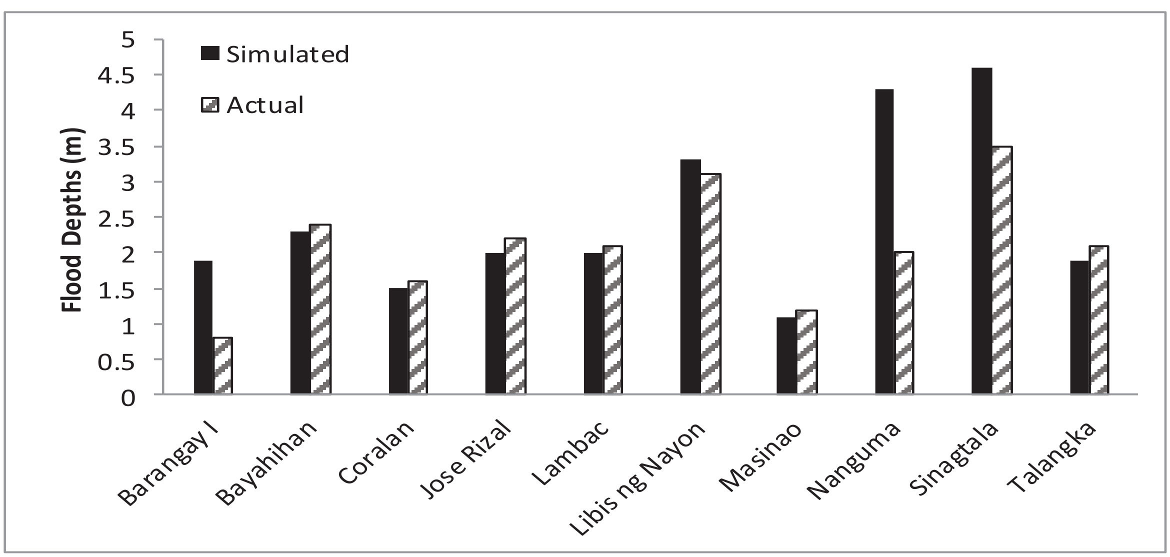

Figure 8. Simulated and actual flood depths in Mabitac and Santa Maria, Laguna.

Overall social vulnerability index of Mabitac and Santa Maria, Laguna

The social vulnerability indices in **Table 6** show the potential vulnerability of a community as a function of general demographic indicators, socio-economic indicators, resource dependence and infrastructure status. The overall social vulnerability indices of the different barangays in Mabitac, ranged from 3.429 to 3.770. This showed that the flood-prone barangays in Mabitac were socially vulnerable to flooding (**Table 6**).

Except for the infrastructure, the other social vulnerability factors were all considerably high especially the socio-economic index. Most of the respondents had no permanent jobs and low monthly family incomes. The financially deprived families generally have lesser income and resources to use or spend on preventative measures, emergency supplies, and recovery efforts, especially during the aftermath of a flood event.

The infrastructure index on the other hand was comparatively better due to good roads, available public service and communication systems. Health services were also accessible due to the proximity of the flood-prone barangays to the municipal health center.

The computed overall social vulnerability indices of the different barangays in the town of Santa Maria (**Table 7**) were more variable compared to the overall social vulnerability indices of the different barangays in Mabitac.

Barangays 4 and 2 of Santa Maria had indices lower than 2.5. The lower indices in these two barangays were attributed to their better demographic and infrastructure indices and these made them the least vulnerable barangays in Santa Maria.

There were barangays which had relatively higher social vulnerability. These were Barangays Adia, Coralan, Masinao and Jose Rizal. Barangay Masinao is located in the outskirts of the town and most of the people relies in agriculture for their income. Barangays Adia, Jose Rizal and Coralan on the other hand were highly vulnerable to floods because many residents did not have permanent jobs and most of them had low family incomes.

Overall vulnerability analysis of the towns of Mabitac and Santa Maria, Laguna

The overall vulnerability of each barangay is a function of flooding and social factors derived from the normalized indices of socio-economic, demographic, natural resource dependence and infrastructure factors together with the estimated flood depths and extents (**Figure 9**).

Table 6. Social vulnerability indices of the different barangays in Mabitac, Laguna.

Barangay	Demographic Index	Socio-economic Index	Resource dependence Index	Infrastructure Index	Social Vulnerability Index
San Antonio	3.748	4.158	3.580	2.422	3.688
Nanguma	3.739	4.199	3.588	2.622	3.733
Libis ng Nayon	3.379	3.965	3.559	2.512	3.510
Lambac	3.737	4.267	3.723	2.557	3.770
Pag-asa	3.710	4.022	3.246	2.436	3.574
Bayanihan	3.581	3.998	3.136	2.646	3.541
Sinagtala	3.500	3.694	3.429	2.580	3.429

Note: 1- low vulnerability; 5 –very high vulnerability

Table 7. Social vulnerability indices of the different Barangays in Santa Maria, Laguna.

Barangay	Demographic Index	Socio-economic Index	Resource dependence Index	Infrastructure Index	Social Vulnerability Index
Talangka	2.957	3.415	3.323	2.388	3.064
Adia	3.652	3.866	2.475	2.758	3.406
Masinao	3.018	3.878	4.132	3.197	3.470
Coralan	3.441	4.047	3.027	2.826	3.468
Bagong Pook	2.431	3.115	2.024	2.021	2.514
Barangay 1	2.824	3.611	2.297	2.374	2.914
Barangay 2	1.794	3.201	2.500	2.044	2.360
Barangay 3	2.555	3.524	3.138	2.200	2.880
Barangay 4	2.173	2.592	2.972	1.856	2.371
Jose Rizal	3.472	4.205	2.697	2.633	3.450
Kayhakat	3.129	3.557	2.565	2.403	3.0641

Note: 1- low vulnerability; 5 –very high vulnerability

Most of the flood-prone barangays of the two towns have severe to very severe overall flooding vulnerabilities. These are also the areas where most of residential houses and commercial establishments are located.

The most notable barangays that were classified as very severely vulnerable to flooding were Jose Rizal in Santa Maria and barangays San Antonio, Nanguma, Sinagtala, Lambac and Bayanihan in Mabitac.

On the other hand, the areas that were classified as low to moderately vulnerable are mostly found in the outskirts of the two towns. Ground truthing revealed that these areas are mostly rice fields and fallow land.

CONCLUSION

The simulated peak discharges of the different river networks in the different sub-basins increased as the rainfall intensity increased from 68.1 to 80.0 mm hr^{-1}. The highest simulated discharge of 74.5 m^3s^{-1} was obtained immediately after the intersection of the tributary and the middle reach (R330).

The river cross-section and simulated peak flow in combination with Triangulated Irregular Network as input to the HEC-RAS modelling system predicted the flood depths and delineated the inundated barangays of the two towns. Simulated flooding using peak river cross-section discharges derived from a 20-year return period of daily extreme rainfall using HEC-RAS model were almost equal to the observed flood depths of the communities in 7 out of 10 flood-prone barangays in the two towns.

The study revealed environment-related issues needed to be done to reduce the impacts of flooding. First, implement environmental programs that will restore the original condition of the watershed in Santa Maria. Second strengthen the flood warning system and emergency response capacity through flood hazard zonation mapping.

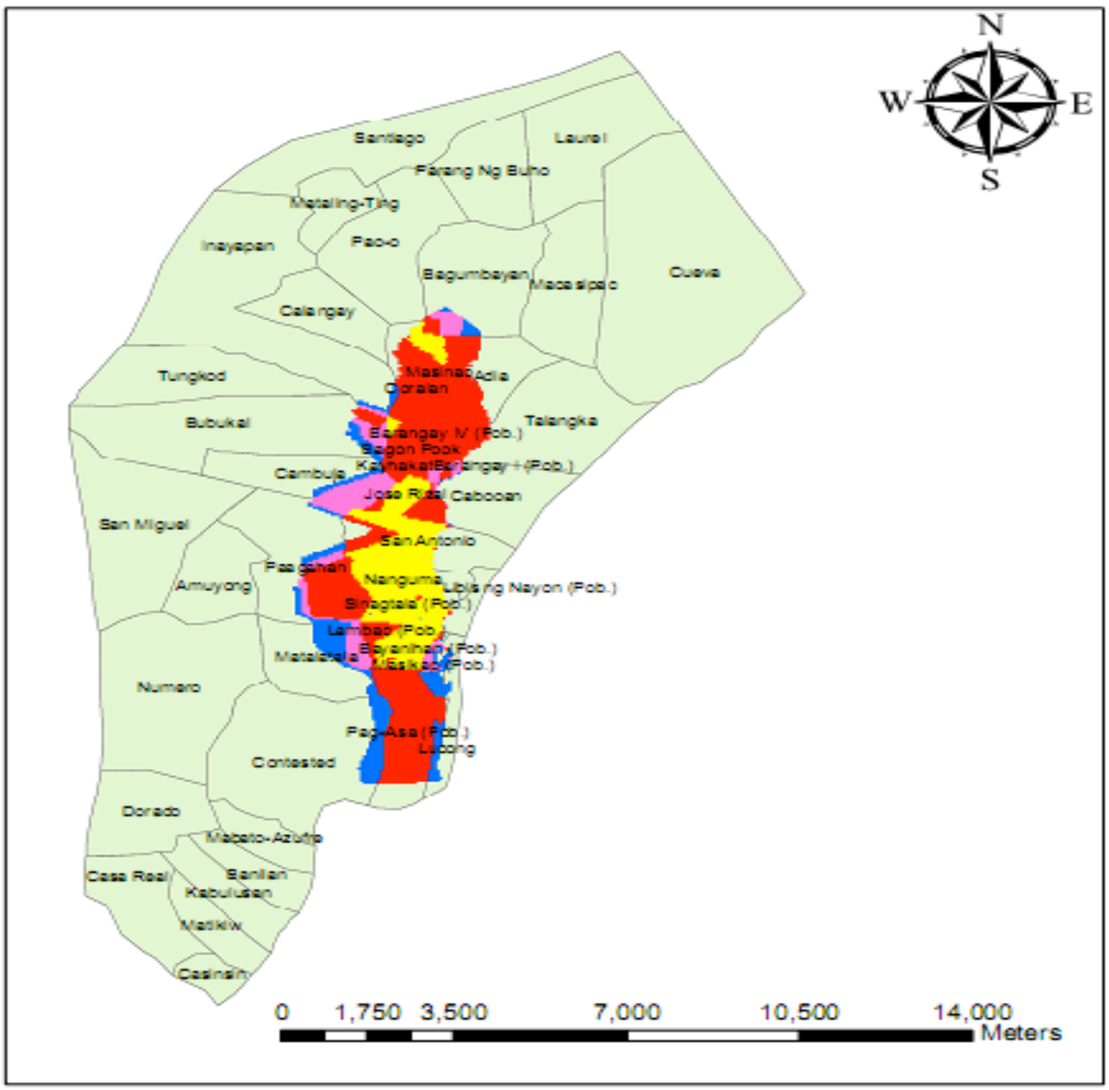

Figure 9. Overall vulnerability map of the flood-prone barangays of Santa Maria and Mabitac, Laguna using simulated flood depth of a 20-year storm return period and social vulnerability indices.

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