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NUMERICAL MODEL SIMULATIONS AND GEOSPATIAL ANALYSIS OF FLOODING IMPACTS OF *AGATON* AND *SENIANG* IN CABADBARAN RIVER BASIN, MINDANAO, PHILIPPINES

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Abstract: In 2014, heavy to torrential rains brought by tropical storms *Agaton* and *Seniang* triggered massive flooding and caused fatalities particularly in Caraga Region in northeastern Mindanao. To better understand and differentiate the impacts of heavy rains brought by these tropical storms to the extent of flooding, we reconstructed the two flooding events through numerical model simulations, and evaluated the differences through geospatial analysis. We focused on the Cabadbaran River Basin (CBR) and adjoining watersheds in Agusan del Norte, Caraga Region as our case study area. Results of the study have some practical implications to climate change impact and mitigation studies on the aspect that studying how the current weather and climate scenarios are affecting us (e.g., in terms of flooding) can help us understand and make necessary preparations for a future weather or climate scenario.

Key words: Tropical Storms, Flooding, Impacts, Numerical Simulation, Analysis

1 INTRODUCTION

1.1 Background

Flooding is a disastrous natural phenomenon whose frequency of occurrence in the Philippines has become more pronounced in recent years. Its occurrence is usually associated with the presence of tropical storms and low pressure systems which bring along rains of varying duration, volume and intensity. An infamous example would be that of Tropical Storm (TS) *Ondoy* (International name: Ketsana; September 2007) which dumped a month's worth of rain in less than 24 hours and caused flooding in Metro Manila, killing at least 300 people and displacing another 700,000 (Cheng, 2009). Since then, similar flooding occurrences associated with tropical storms became frequent and more intense, and has continued to negatively impact and bring costly damages to human lives and properties.

Two of such occurrences are the flooding caused by tropical storms *Agaton* (International name: Lingling) and *Seniang* (International name: Jangmi) in Mindanao, Philippines in the year 2014. TS *Agaton* brought considerable volume of rainfall over several days, approximately between January 10-20, 2014, to Mindanao that caused flooding and landslide incidents despite not making landfall as a tropical cyclone on the Philippines (NDRRMC, 2014). TS *Seniang*, on the other hand, made landfall over the town of Hinatuan in the province of Surigao del Sur. Like *Agaton*, heavy to torrential rains associated with *Seniang* triggered massive flooding and caused fatalities in many localities, particularly in Caraga Region in northeastern Mindanao (NDRRMC, 2015). Although figures and statistics describing the impacts of flooding caused by *Agaton* and *Seniang* are available (e.g., NDRRMC, 2014; 2015), much remains to be understood, such as: (i) how much rain did *Agaton* and *Seniang* brought that caused rivers to overflow?; (ii) how different are the flooding impacts of these storm-induced rainfall in terms of extent, hazard level, and affected infrastructures?; and (iii) how can we learn from these flooding events should a similar scenario happen again in the future?

1.2 Objectives and Significance

In this paper, we present our attempt to understand and differentiate the impacts of flooding caused by *Agaton* and *Seniang* by reconstructing the flooding events through numerical model simulations. We then used geospatial analysis to quantify the impacts in terms of flooding extent, level of hazards, and the number of infrastructures affected. This study is anchored upon the concept that identifying and quantifying the impacts of flooding is important not only for the purpose of establishing a baseline information where government and non-government agencies can make a reference to when doing post-disaster management and recovery efforts, but also for getting a detailed picture of how and why such kind of flooding occurred, that can then be used in figuring out strategies that can minimize, or even avoid, the impacts should similar events occur again in the future. On the other hand, this study is important in the context of climate change impact, adaptation and mitigation studies. As a changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012), studying how the current weather and climate scenarios are affecting us (e.g., in terms of flooding) can help us understand and make necessary preparations for a future weather or climate scenario.

1.3 Study Area

We focused on the Cabadbaran River Basin (CRB) and the nearby Pandanon River and Caasinan River Watersheds in Agusan del Norte, Caraga Region as our case study area (Fig. 1). With a total area of 238 km^2, these river basins and watersheds cover a major portion of Cabadbaran City which was reported to be one of those affected by flooding during the onslaught of *Agaton* and *Seniang*.

2 METHODOLOGY

2.1 Analysis of the Differences in Rainfall Depth Brought by *Agaton* and *Seniang*

We first conducted a time series analysis of depth of rainfall brought by *Agaton* and *Seniang* using data recorded by rain gauges installed by the Advanced Science and Technology Institute - Department of Science and Technology (ASTI DOST) in Cabadbaran City Hall and in Dugyaman-Anticala, Agusan del Norte (see Fig 1 for their locations). The data was obtained from the Philippine Real-Time Environment Data Acquisition and Interpretation for Climate-Related Tragedy Prevention and Mitigation website (PREDICT, 2014). The time periods considered in the analysis were the following: January 10-20, 2014 for *Agaton*; and December 27, 2014 – January 1, 2015 for *Seniang*.

2.2 Flood Reconstruction Through Numerical Model Simulations

The use of numerical simulation models for the flood reconstruction process consisted of developing a hydrologic model of the river basin, and a two-dimensional (2D) hydraulic model of the main river and its floodplain.

2.2.1 Hydrologic Model Development

The hydrologic model was developed using Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) Version 3.5. The model simulates the basic watershed hydrologic processes of runoff generation from rainfall, its transformation and combination with baseflow, and its routing along the channels towards the watershed's outlet (USACE, 2000).

The purpose of the hydrologic model was to determine the volume of water coming from the various sub-basins (also called watersheds) due to rainfall brought by the tropical storms. Rainfall depths recorded by rain gauges within and in the vicinity of the river basin were used as input into the hydrologic model to compute discharge hydrographs for specific locations in the river basin, specifically at those locations where the upstream watersheds ends and the floodplain portions begin. The discharge hydrographs depict the volume of water per unit time (in m^3/s) that drains into the main river at these locations. These hydrographs, together with rainfall data, were then used as inputs into the 2D hydraulic model to simulate various processes such as the movement of water from the upstream watersheds into the main river, as well as how its overflows from the rivers and travels into the flood plains.

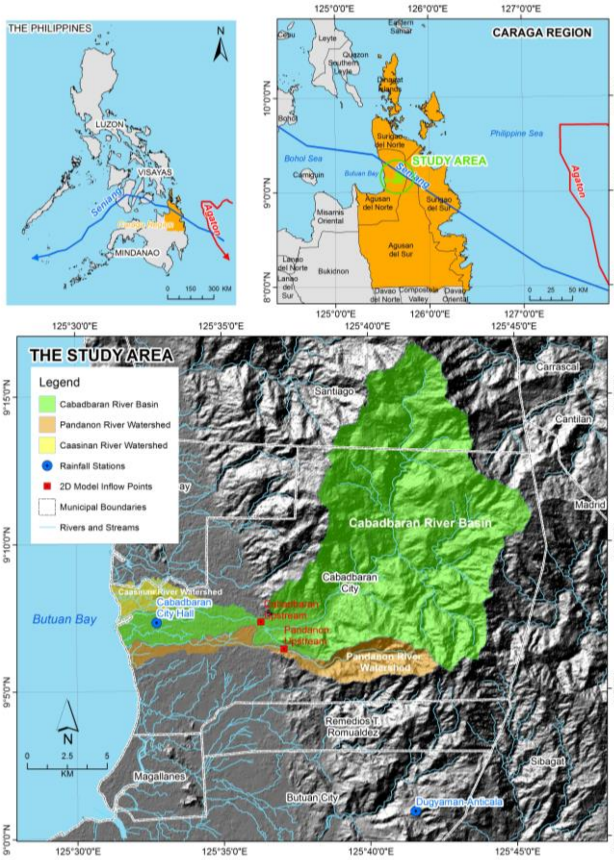

Fig. 1 Series of maps showing the study area which consists of Cabadbaran River Basin and the watersheds of Pandanon and Caasinan Rivers in Agusan del Norte, Caraga Region, Mindanao, Philippines. The tracks of TS *Agaton* and *Seniang* are also shown, including the locations of rain gauges whose data was used in the analysis.

Using the HEC HMS model, two hydrologic simulations were implemented corresponding to the period of occurrence of *Agaton* and *Seniang*. Discharge hydrographs at the Cabadbaran Upstream, and Pandanon Upstream (see Fig. 1 for their locations) were extracted from the model simulation results and used in the analysis, and as inputs into the 2D hydraulic model.

2.2.2 Hydraulic Model Development

We used a trial version of Flood Modeller Pro (CH2M Hill, 2015) in the 2D simulation of flooding during Agaton and Seniang. The 2D model computational domain (~45.53 km^2) covered the floodplains of Cabadbaran, Pandanon and Caasinan Rivers (i.e., all areas downstream of CBR Upstream and Pandanon Upstream as shown in Fig. 1) including a portion of Butuan Bay. The purpose of the 2D model was to route the discharge hydrograph from the upstream watersheds into the main rivers and floodplains. Rain falling in the floodplain was likewise routed. The model was used to determine whether the volume of water coming from the upstream watersheds will cause overflowing of the main rivers, and if it overflows, where it will go and for how long. In the case of rain falling in the floodplain, the model was also used to determine whether rainwater will get infiltrated, or get stagnant (e.g., in a depression), or continue to flow toward areas of lower elevation. Technical details on how Flood Modeller Pro does the 2D simulation are available in the software's website at http://www.floodmodeller.com. The 2D model was used to generate hourly flood depth and extent for the *Agaton* and *Seniang* events. Based on the hourly outputs, maximum flood depth and extent grids were generated at 1-m spatial resolution.

2.2.3 Datasets Used

Various geospatial datasets were utilized in the development of the numerical simulation models. In hydrologic model development, a 10-m Synthetic Aperture Radar (SAR) Digital Elevation Model (DEM) was used for sub-basin delineations and for derivation of topography-related parameters of the model such as slope and elevation. Images acquired by the Landsat 8 satellite were also utilized to derive a landcover map using Maximum Likelihood classification. The landcover map is necessary for the derivation of land-cover-related model parameters such as surface roughness coefficient, and runoff/infiltration capacities. River width and cross-section data obtained from field surveys as well as those extracted from 1-m resolution LiDAR-derived Digital Terrain Model (DTM) were also used to estimate the channel routing parameters of the model.

For the 2D hydraulic model, river bed topography (obtained from bathymetric surveys), sea bed topography (obtained from a NAMRIA topographic map), LiDAR DTM, building footprints (with top elevation) extracted from LiDAR Digital Surface Model (DSM), and the same landcover map derived from Landsat 8 OLI satellite image were used as major inputs. The river and sea bed topographic datasets and building footprints were integrated into the LiDAR DTM to ensure that the 2D model can account for the effects of river and sea bed topography as well as for the presence of buildings in flow simulation (e.g., in computing depth, speed and direction of flow). In the absence of observed tidal data, predicted tidal data at Butuan Bay was also used as boundary condition input into the 2D model to account for the effects of tide.

2.2.4 Geospatial Analysis of the Differences in Simulated Hydrologic and Flooding Characteristics during *Agaton* and *Seniang*

The discharge hydrographs and the flood depth maps were geospatially analyzed and compared to see the differences in flood characteristics and extent during *Agaton* and *Seniang*. All our geospatial analysis utilized Geographic Information System (GIS) tools and techniques. In particular, we used ArcGIS 10 GIS software to generate maximum flood depth and hazard maps based on the numerical model simulation results. The maximum flood depth maps were further analyzed to categorize depths into flood hazard levels (low, medium and high). Low flood hazards are those areas with maximum flood depths ranging from 0.10 − 0.50 m; medium: 0.5 < depth ≤ 1.50; and high: depth > 1.50 m). The differences in the flooded areas according to hazard levels were then determined for *Agaton* and *Seniang* events. The bay/sea portion of the 2D model domain was not included in the computation of the flooded area statistics (i.e., the area considered in the computation is only 34.61 km^2 out of the 45.53 km^2). We also estimated the number of buildings affected by flooding caused by *Agaton* and *Seniang*. For both events, we identified and counted those buildings that lies within those areas classified to have low, medium and high flood hazard levels.

3 RESULTS AND DISCUSSION

3.1 Rainfall Depth during *Agaton* and *Seniang*

Rainfall data recorded by the Dugyaman-Anticala Station (located approximately 600 m above Mean Sea Level (MSL)) from January 10-20, 2014 showed that the *Agaton* brought a total rainfall of 932 mm, of which 221 mm where recorded on January 19 alone (Fig. 2), a day before it dissipated to the southeast of the Philippines. It is on this day that rainfall during *Agaton* peak in its highest intensity. Data from the Cabadbaran City Hall station (located approximately 7 m above MSL) showed a lesser (but still significant) accumulated rainfall of 628 mm during the same period, with 155 mm of rainfall recorded on January 19.

On the other hand, *Seniang* brought a total rainfall of 356 mm in the upstream portions of study area as recorded by Dugyaman-Anticala station from December 27 to January 1, 2015. Rainfall intensity peaked on December 29 where 259 mm where recorded (Fig. 3). In the downstream portion, 123 mm were recorded at the Cabadbaran City Hall station, of which 80 mm where recorded on December 29.

Based on rainfall records, *Agaton* brought rains over the study area in a continuous manner over a longer period of time compared to *Seniang*. For both events, more rain was falling in the upstream than in the downstream portions of the study area. Converting these rainfall depths into rainwater volume (i.e., multiplying the total rainfall depth recorded at the Cabadbaran City Hall Station with the river basins' and watershed's total surface area of 238 km^2), we estimated that at least 149.5 million cubic meters of rainwater fell over the study area during the 11-day *Agaton* period, of which at least 37 million cubic meters were felt on January 19. In the case of *Seniang*, there was at least 29 million cubic meters of rain water that fell over the study area from December 27, 2014 to January 1, 2015, of which 19 million cubic meters was felt on December 29. How these large volumes of rainwater were converted into runoff/discharge, or became infiltrated and/or evaporated, including how they caused flooding, were figured out through the conduct of hydrological and hydraulic model simulations.

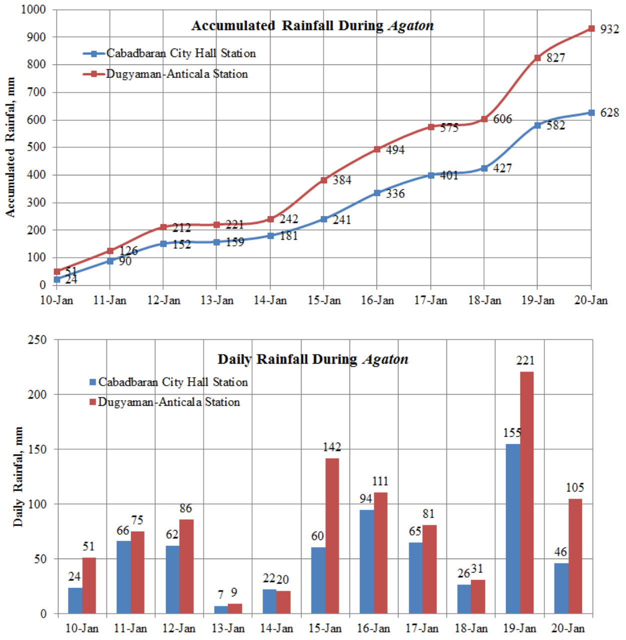

Fig. 2 Accumulated and daily rainfall depths measured by the rainfall stations during *Agaton*.

3.2 Simulated Discharge Hydrographs during *Agaton* and *Seniang*

Shown in Fig. 4 are the discharge hydrographs simulated by the HEC HMS hydrologic model for Cabadbaran Upstream and Pandanon Upstream for the *Agaton* and *Seniang* events. The model simulation results are summarized in Table 1. The hydrologic simulation results suggest that the *Seniang* event has a higher peak discharge compared to that of Agaton. However, the *Agaton* event produced more discharge than the *Seniang* event which is expected due to the higher volume of rainfall received during *Agaton*. The total volume of discharge entering the floodplains was computed by the model as 21.6 million cubic meters during *Agaton*, which is approximately 1.9 million cubic meters higher than that during *Seniang*.

Table 1 Summary of HEC HMS hydrologic model simulation of discharge for Cabadbaran Upstream and Pandanon Upstream for the *Agaton* and *Seniang* events.

Event	Peak Discharge (m3/s)		Discharge Volume, in Million cubic meters		
	Upstream Cabad-baran	Upstream Panda-non	Upstream Cabad-baran	Upstream Panda-non	Total Volume
Agaton	433	40	19.8	1.8	21.6
Seniang	483	51	17.8	1.9	19.7

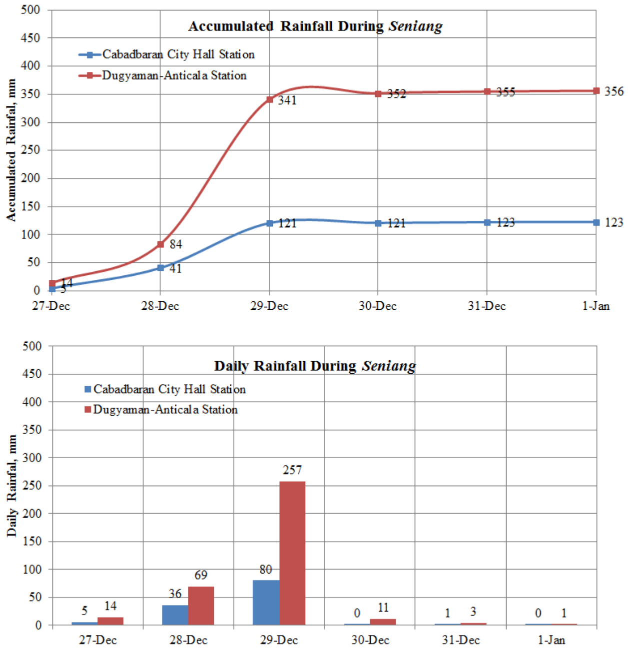

Fig. 3 Accumulated and daily rainfall depths measured by the rainfall stations during *Seniang*.

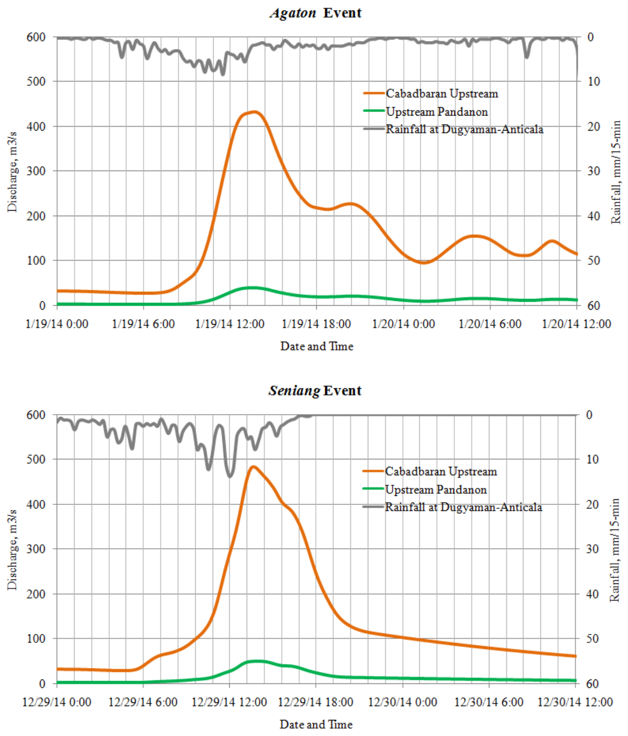

Fig. 4 Discharge hydrographs simulated by the HEC HMS hydrologic model for Cabadbaran Upstream and Pandanon Upstream for the *Agaton* and *Seniang* event.

3.3 Simulated Maximum Flood Depths and Extents during *Agaton* and *Seniang*

Shown in Fig. 5 are the maximum flood depth maps simulated by the 2D hydraulic model. These maps show the areas that have been flooded, including the maximum depth of flood within the duration of the simulation periods. It can be observed that the flooding due to *Agaton* event have a greater extent compared to that of *Seniang*. A common characteristic between the two events is that flooding in the study area was not only due to the overflowing of the Cabadbaran, Pandanon and Caasinan Rivers. Model results show that some of the flooded areas were due to storage of rainfall. This is evident in the Cabadbaran City proper.

3.4 Differences in Flood Extent and Hazard Levels during *Agaton* and *Seniang*

The maximum flood depth maps categorized into low, medium and high hazard levels are shown Fig. 6. Analysis of these maps show that the Agaton event flooded 12.23 km^2 of the 2d model domain (excluding the bay/sea portion), which is 1.27 km^2 higher than the area flooded during *Seniang*. Areas under low and medium hazard levels were also higher during *Agaton*. However, there was a similarity in areas under high hazard levels, with both events submerging approximately 1.4 km^2 of land areas with depths greater than 1.5 m.

3.5 Buildings Affected by Flooding

There were approximately 9,117 buildings in the study area. Results of the geospatial analysis for the *Agaton* event showed that about 70% of these buildings were estimated to be affected by flooding (Fig. 7). As far as numerical model simulations results are concerned, 5,217 were found to be located in low flood hazard areas while 1,150 and 48 were in medium and high flood hazard areas, respectively. In the *Seniang* event, geospatial analysis revealed over 61% of buildings were affected by flooding, with the number of buildings per hazard level slightly lower compared to that during *Agaton.*

4 CONCLUSIONS

From the numerical model simulations and output flood maps, we found that the *Agaton* event produced more discharge, and caused a wider extent of flooding than the *Seniang* event. This result is consistent with the fact that rainfall during *Agaton* was greater in volume than during *Seniang*. More areas were also in low and medium flood hazard levels during *Agaton*. However, areas in high hazard levels appeared to be similar in both events. The same characteristics were observed in terms of the number of affected buildings.

One aspect not presented in this paper in on the accuracy of the numerical model simulations and flood maps generated. At present, community-level ground validation surveys are being conducted to verify the accuracy of information derived from the numerical model simulations, and those reflected in the flood maps. Nevertheless, the results of this study showed the importance of combining geospatial data and analytical techniques with numerical models to reconstruct and understand past flooding events. The flood simulations and maps derived from this study can be useful not only in mapping and assessing the flood hazards caused by *Agaton* and *Seniang*, but also as visual aids to help people understand the differences of the impacts of different

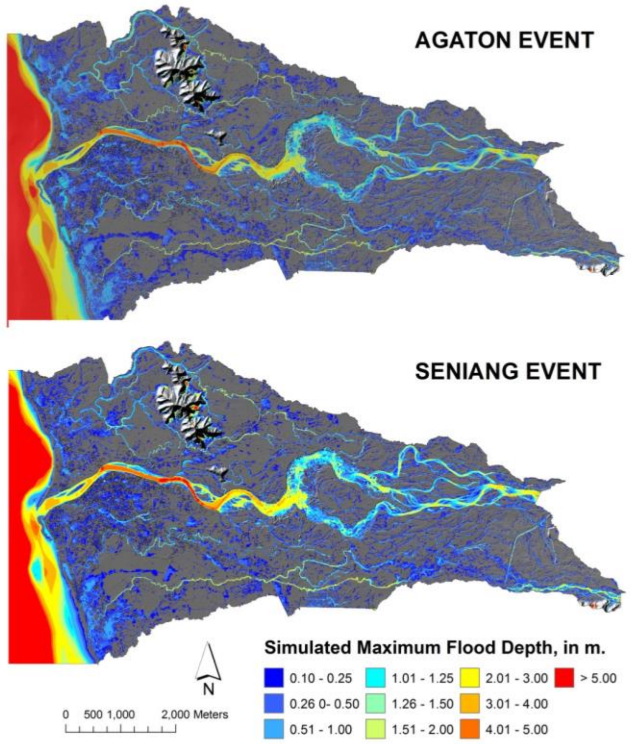

Fig. 5 Simulated maximum flood depth maps for the *Agaton* and *Seniang* events.

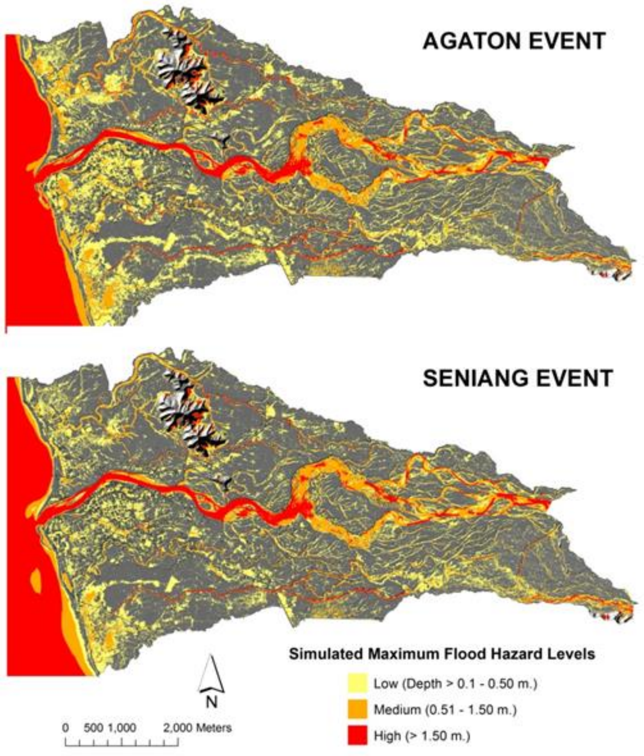

Fig. 6 Simulated maximum flood hazard maps for the *Agaton* and *Seniang* events.

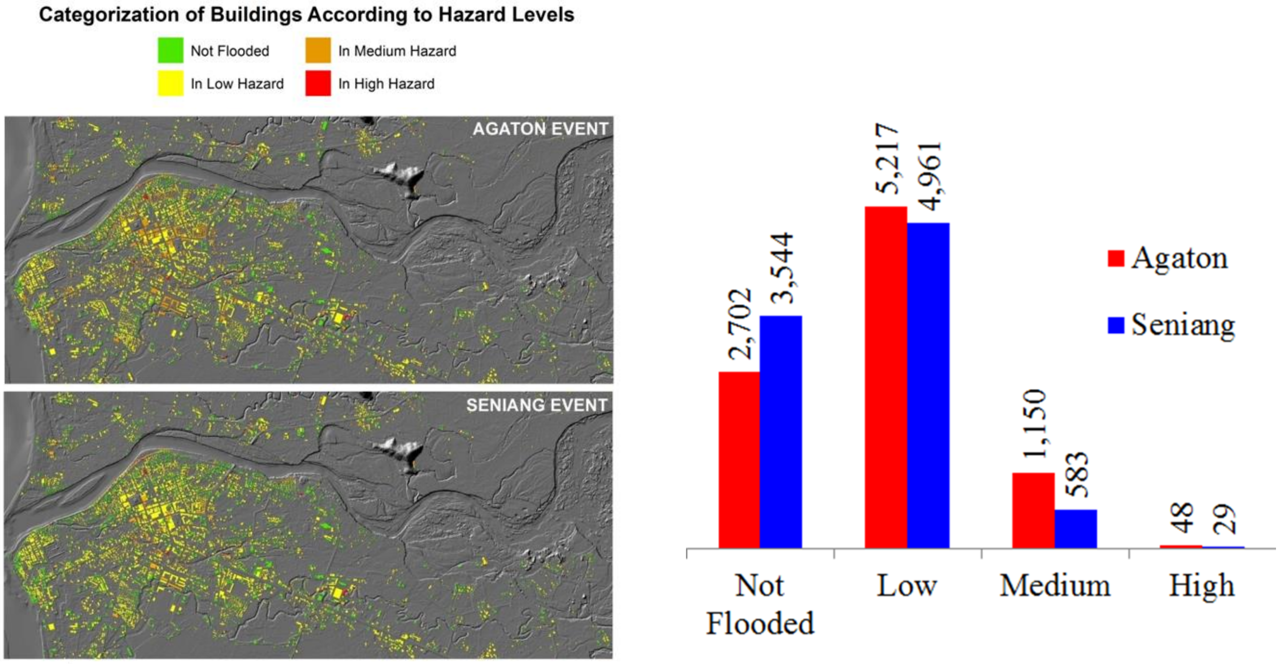

Fig. 7 Maps (left) and number (right) of buildings affected by flooding during *Agaton* and *Seniang*, categorized according to hazard levels.

tropical storms in the occurrence of flooding. The latter is very important especially now that tropical storms (and the rains that it brings along) has become fiercer in recent years, and will continue to be so due to the effects of climate change. With the knowledge learned from the numerical model simulations and geospatial analysis, the Local Government Units (LGUs) and the communities can be informed and empowered in finding ways to mitigate the negative impacts of flooding, as well as in evaluating adaptation strategies if such flooding (caused by *Agaton* and *Seniang)* or more intense events will occur again in the near future. Such flood adaptation strategies may include (i.) localized land-use planning integrating flood hazard information, (ii.) relocating communities to safe grounds, (iii.) identification and improvement of evacuation routes, and (iv.) building flood defences (specifically in areas where river overflowing occurs), among many others.

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REFERENCES

CH2M Hill (2015). Flood Modeller Pro. http://www.floodmodeller.com/

Cheng, M.H. (2009). Natural disasters highlight gaps in preparedness. The Lancet, Vol. 374, No. 969, pp. 1317-1318.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen,M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK,and New York, NY, USA, 582 pp.

NDRRMC (2014). NDRRMC Updates Sitrep No. 33 re: Effects of Tropical Depression Agaton. National Disaster Risk Reduction and Management Council. February 1, 2014. Available online at http://www.ndrrmc.gov.ph/.

NDRRMC (2015). SitRep No. 22 re Effects of Tropical Storm SENIANG". National Disaster Risk Reduction and Management Council. January 10, 2015. Available online at http://www.ndrrmc.gov.ph/.

PREDICT (2014). Rainfall Data of Dugyaman-Anticala and Cabadbaran City Hall Stations, Agusan del Norte. Department of Science and Technology, Philippines. Available online at http://repo.pscigrid.gov.ph/predict.

USACE (2000). Hydrologic Modeling System HEC-HMS Technical Reference Manual, United States Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.