Assessing the Increase in Exposure to Flood Hazard of Critical River Systems Due to Climate Change by Integrating Predicted Change in Rainfall Scenarios Based on Global Circulation Models

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Key words: flood hazard, risk management, climate change

SUMMARY

The DOSTGIA-funded (Department of Science and Technology-Grant In Aid) Disaster Risk and Exposure Assessment for Mitigation (DREAM) program have proven the advantage of the use of high-resolution Light Detection And Ranging (LiDAR) digital elevation models for the production of detailed flood hazard maps for riverine type flooding. Detailed flood hazard maps have been produced for critical river systems, for extreme rainfall events characterized by various rain intensity duration frequencies. Together with the hazard maps, an initial exposure database was also generated to be used as an invaluable tool not only for risk assessment, but also for the creation of comprehensive land use plans and master plans of local government units possibly affected by the floods in the areas mentioned. However, for these land use plans to be effective and forward looking, not only should they address the hazards in the current setting, but also the change in the severity of future hazards due to climate change. This research aims to integrate the output of statistically downscaled General Circulation Models (GCMs) to the production of flood hazard maps for identified critical river systems. The CCAFS project output is comprised of downscaled climate scenarios that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The output is global in nature, and each of the climate projections includes maximum daily precipitation estimates for the periods from 2030 through 2080. The spatial resolution of the dataset is roughly 1 km x 1 km, which is sufficient for modelling the critical river systems mentioned above. After the production of the new hazard maps, the exposure dataset will be revisited, and the change in the number of exposed elements will be quantified and reported. This report aims to provide climate proofed baseline information that will serve as guidance in producing better local government master plans and land use plans in the future.

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1. INTRODUCTION

On the average, the Philippines is visited by twenty typhoons on a yearly basis, which often leads to widespread flooding. These floods claim many lives in their wake, and result in billions of pesos in damage to agriculture and infrastructure. The national government, in its effort to mitigate these disasters, sought the aid of the Department of Science and Technology, which inaugurated the Grant in Aid-funded project dubbed the Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) program in 2012. Through the use of Lidar technology, the DREAM program finished the production of highly detailed flood hazard maps for the floodplains of the 22 critical river systems in the country, which at the time was not only unprecedented in accuracy, but also in the scale of acquisition. Hazard maps were produced for different extreme rainfall scenarios characterized by the rainfall intensity duration frequency (RIDF) curves, so that the local government units using the hazard maps will correspond their level of action to the estimated intensity of the rainfall event.

With the pressing discussions on the effect of climate change to the intensity of extreme rainfall events, this paper puts forward the application of statistically downscaled general circulation models in producing new RIDFs, and applying this new RIDF to the hydrologic model used by the DREAM program, and rerunning the hydraulic simulation over the floodplain to see the effect of the change in rainfall characteristic to the extent of inundation. This paper extends the work done by the DREAM program, focusing on the Cagayan de Oro River System.

2. RELATED LITERATURE ON THE CDO RIVER SYSTEM

2.1 Soil Cover Complex

The Cagayan de Oro (CDO) River System is one of the critical river systems targeted by the DREAM program for the production of hazard maps for different rain return periods. It is located in the northern coast of Mindanao, and is the sixteenth largest river basin in the Philippines, with an estimated basin area of 1,521 square kilometers. The location of the Cagayan de Oro River Basin is as shown in Figure 1. The hydrologic model of CDO was developed in the software Watershed Modeling System (WMS) version 9.1, by combining the available land cover data from the National Mapping and Resource Information Authority (NAMRIA) and the soil map made available by Bureau of Soils and Water Management (BSWM). The soil cover complex was in turn converted into a hydrologic model that uses the SCS Curve Number method for its Loss Rate model, and Clark's UH for its Transform model (UPTCAGP, 2015).

2.2 Elevation Datasets Used

Synthetic Aperture Radar Digital Elevation Model (SAR DEM) was used as input in determining the extent of the delineated water basin, and for extracting geometric parameters for the model. The SAR DEM has a 10 meter spatial resolution, with vertical accuracy of 6m, expressed in linear error of 90% (LE90). LiDAR surveys were executed to obtain a more accurate representation of terrain in the floodplain areas. The LiDAR DEM had a 1-meter resolution, with a root mean square error (RMSE) of 7.4 cm, when compared to select ground surveys performed in the area (UPTCAGP, 2015).

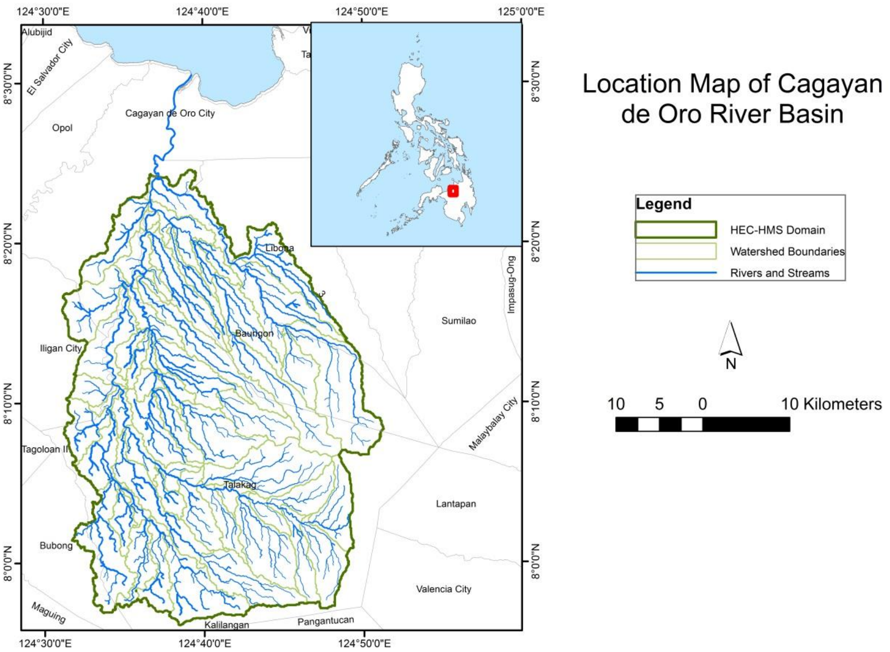


Figure 1 Cagayan de Oro River Basin Location Map

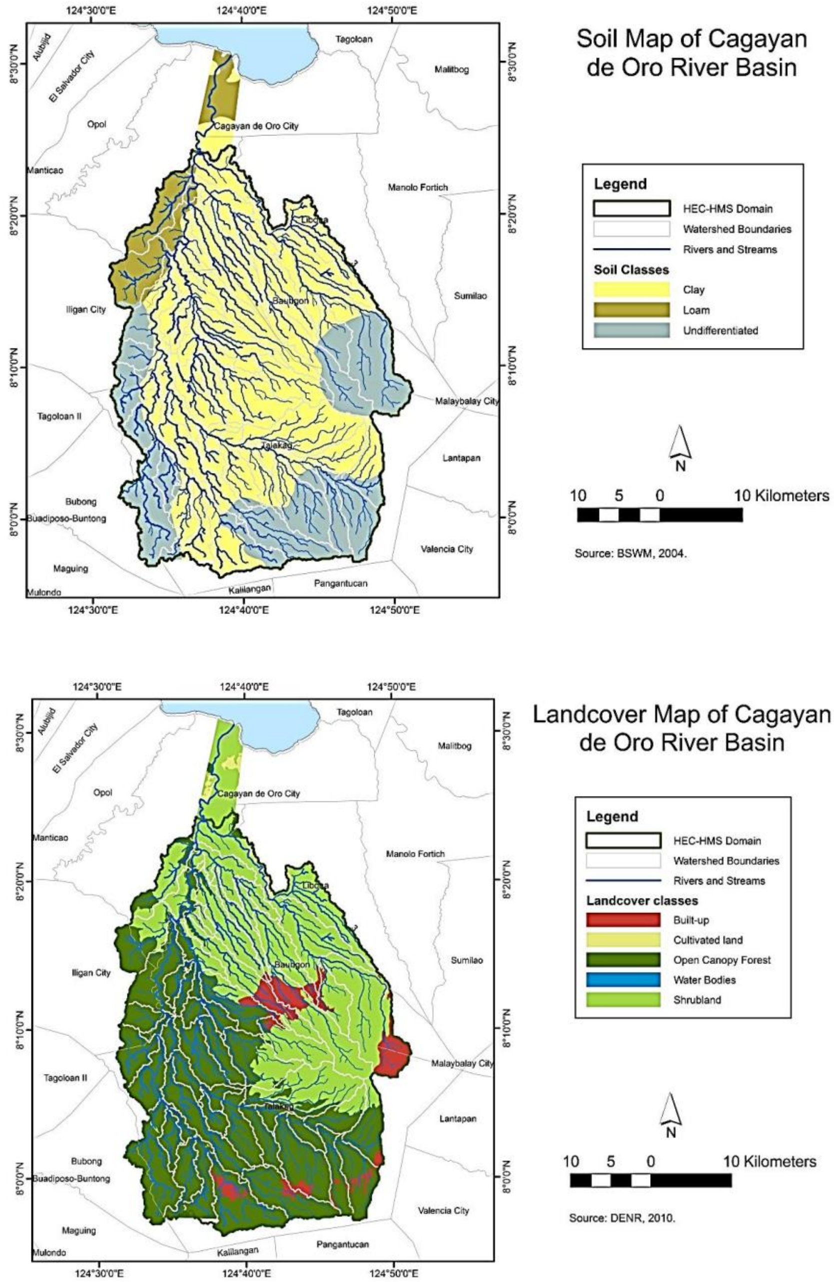


Figure 2. Soil and land cover maps for CDO

2.3 Hydrologic Model Performance

The hydrologic model made using WMS was exported to Hydrologic Modeling System (HEC-HMS) version 3.5, a software made by the Hydrologic Engineering Center of the US Army Corps of Engineers, to create the final rainfall-runoff model. Precipitation data was taken from three automatic rain gauges (ARGs) installed by the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI). These were the Bubunawan, Libona and Talakag ARGs. The Typhoon Quinta event was used for calibrating the model in HEC-HMS, and its performance against flows taken in the field are seen in the graph below. A Pearson correlation coefficient (r^2) of 0.986, and a Nash-Sutcliffe coefficient of 0.962 suggests the reliable predictive power of the model (UPTCAGP, 2015).

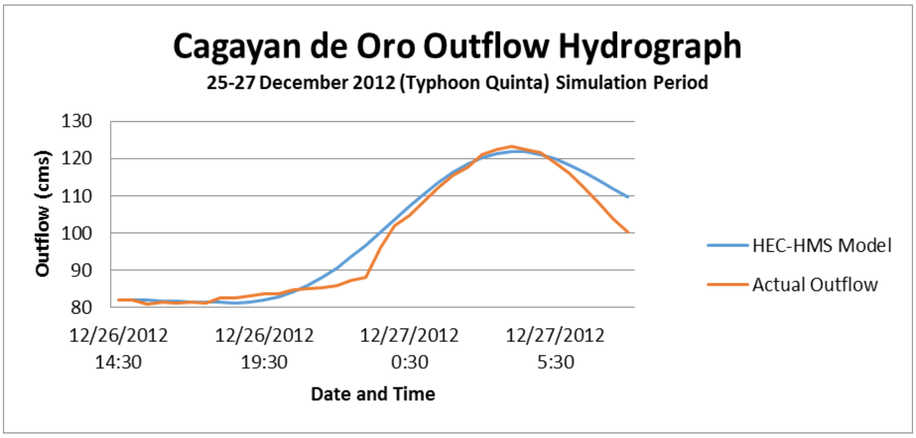


Figure 3. Comparison of modeled and actual hydrograph for CDO River

The calibrated hydrologic model was then used to compute the discharge resulting from various rain-intensity duration frequency (RIDF) scenarios, provided by the local weather bureau, the Philippines Atmospheric Geophysical and Astronomical Services Administration (PAGASA). This consists of the 5-yr, 10-yr, 25-yr, 50-yr and 100-yr RIDFs computed from 56 years of rainfall data gathered from PAGASA's Lumbia station. It is worthy to note that this station is situated near the floodplain of the river system. Based on its observation, the 100-yr RIDF for Lumbia is 255mm of precipitation in one day. The discharge values from the hydrologic model was used as input to the hydraulic model that will map the inundation in the floodplain, using the free software Lisflood.

3. METHODOLOGY

3.1 General Circulation Models (GCMs) dataset

To predict the future change in extreme precipitation over the river system, general circulation model datasets were obtained. Specifically, the precipitation data was obtained from spatially-downscaled GCMs in the Climate Change, Agriculture and Food Security (CCAFS) website. CCAFS is a 10-year research initiative of the CGIAR and the Earth System Science Partnership (ESSP). Global Circulation Models (GCMs) are large-scale representations of the atmosphere and its processes. A GCM reproduces, with certain accuracy, mass and energy fluxes and storages that occur within the atmosphere, by using an analysis unit, or is often referred to as a cell. The heavy computing requirements restrict the resolution of these cells to 100-300 km. Statistical downscaling provides a rapid method for developing high resolution climate change surfaces for high resolution regional climate change impact assessment studies, which allow researchers to obtain regional predictions of climatic changes, by smoothing and interpolation of GCM anomalies.

For the study area, the available precipitation data was obtained from the statistical downscaling Delta Method CMIP5 datasets. The method was applied to 32 GCMs based on the IPCC Fifth Assessment Report (ARP5), and produced 30"x30" resolution maximum daily precipitation over the Philippines and Southeast Asian region, for the periods 2030s, 2050s, 2070s and 2080s. The scenario which was chosen was Representative Concentration Pathways 8.5 (RCP8.5), which is characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels.

3.2 Frequency Analysis

After the various precipitation data was collated, frequency analysis was then applied to compute the magnitude of extreme events based on their return period or frequency of occurrence. Since the dataset are made up of annual precipitation exceedances, the Gumbel distribution was used to characterize the predicted precipitation and compute the future 100-yr RIDF. The Gumbel distribution uses Equation 1, to solve the exceedance value x_T of a certain return period T_r, from the sample mean and standard deviation.

$$x_T = \bar{x} + K_T s \text{, where}$$

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}$$

Equation 1. Computation of exceedance level using Gumbel distribution

The computed 100-yr RIDF value will then be applied to the hydrologic model before to obtain new discharge values for the future scenario. By using the same hydrologic model, we are assuming no change in the land cover and soil characteristics in the future over the river system.

4. RESULTS AND DISCUSSION

4.1 Comparison of GCMs

Shown below in Figure 4 is a sample of the maximum daily precipitation produced by a model on a yearly basis. The data below represents the mean value of precipitation over the entire watershed. The close correspondence between the chosen models are seen, and the mean for each year and for each model can be computed accordingly. For example, from the given period described in the methodology, the mean for the BCC circulation model is 198mm, for the Lumbia station, while the mean for the entire river system over the same period is 229mm. In fact, it can be shown that the precipitation over the Lumbia station, where the RIDFs are based, are generally lower than the mean precipitation over the river system, as shown in Figure 5. For that particular circulation model, the precipitation over the watershed is higher by 37mm over the precipitation that might be recorded in the station. The value is significant, since in PAGASA's current RIDF values, the difference between a 50-yr and 100-yr rain is 25mm, which is lower than the 37mm difference seen in the model. This could likely mean that the precipitation observed in the station near the floodplain is different from the mean precipitation going into the watershed, in the past. Figure 6 shows the topography of the basin, and the rainfall distribution over the area, possibly indicating that the mountainous areas are expected to experience heavier rainfall than the low lying areas.

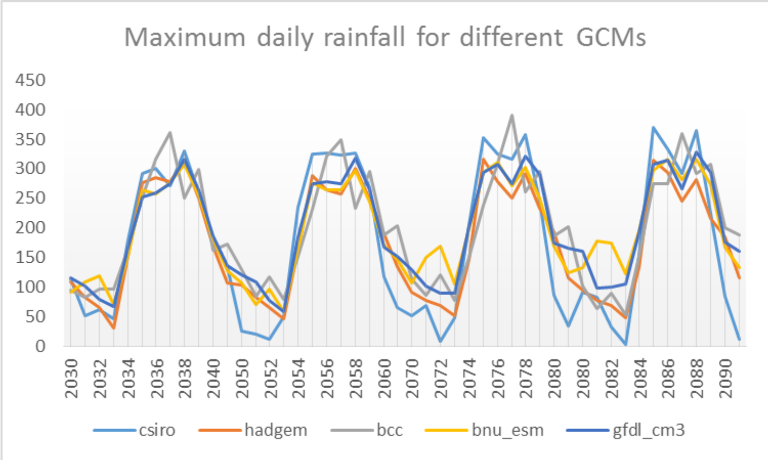


Figure 4. Maximum daily precipitation per year for selected GCMs

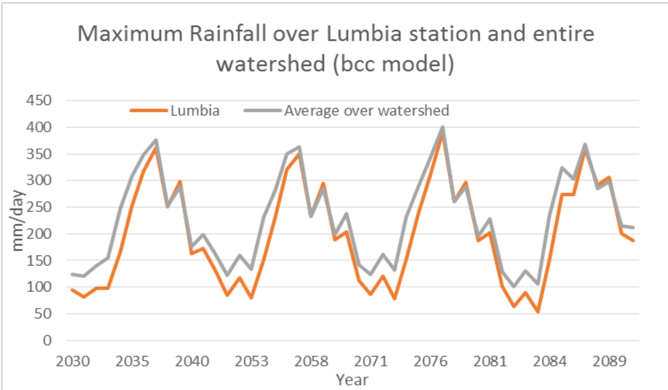
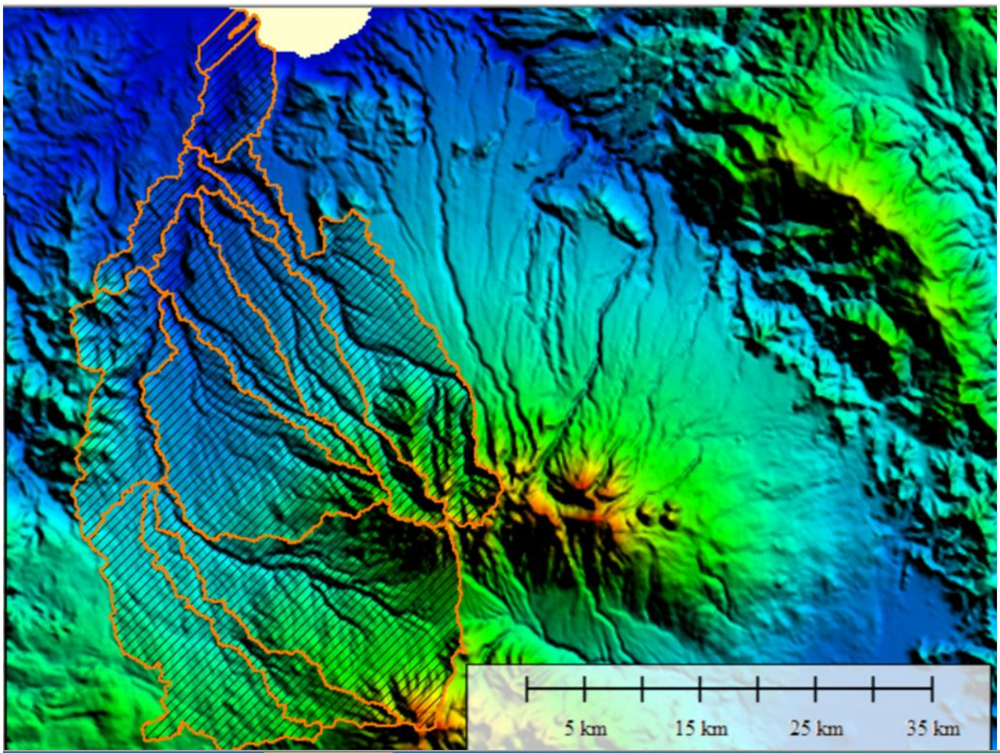


Figure 5. comparison of precipitation over Lumbia station and the entire watershed

4.2 Comparison of Discharge and Inundation

The increase in precipitation for the extreme event of 100yr RIDF resulted in the increase in the discharge coming out of the watershed, as seen in Figure 6, which leads to increase in flood inundation felt in the floodplain area. Figures 7 and 8 show the flood inundation over portions of the floodplains of CDO. The increase from 255mm to 466 mm has increased the extent of affected areas.



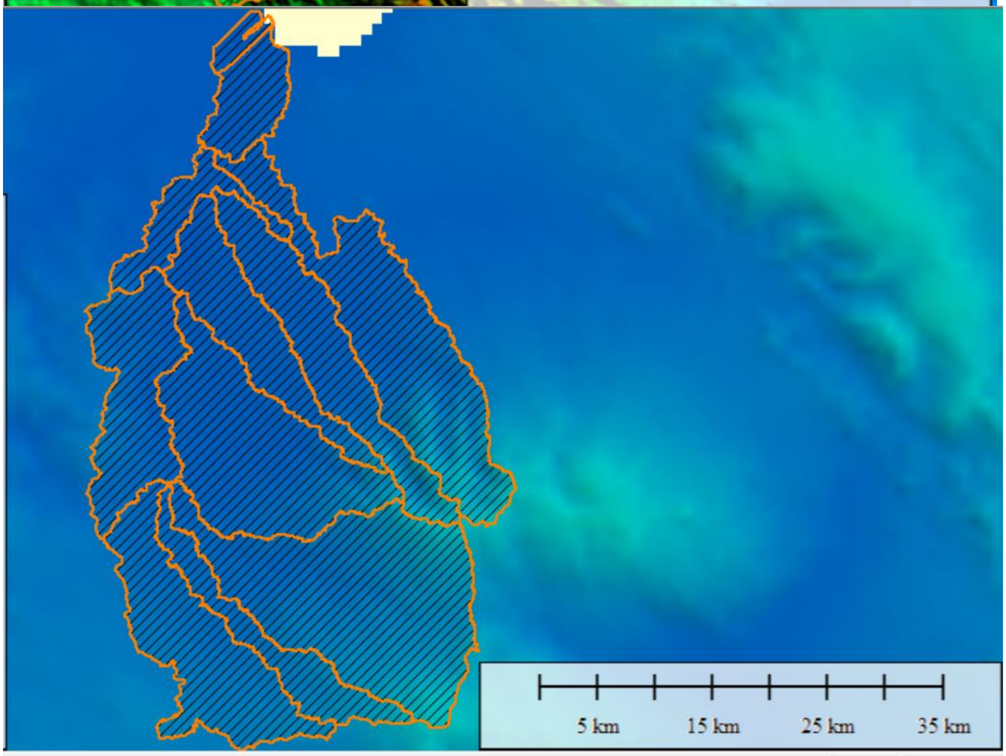


Figure 6. topography of the river basin (above), and rainfall distribution over the basin for the

BCC circulation model (below).

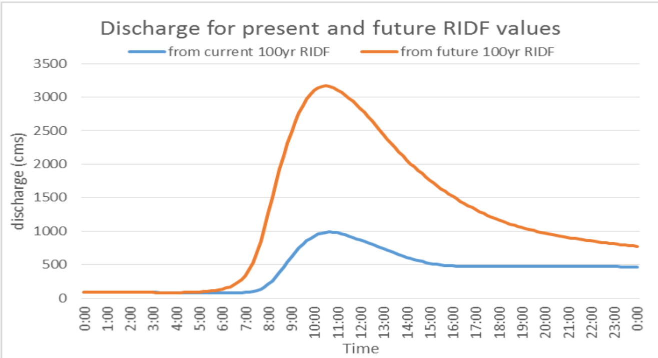


Figure 7. Change in discharge from the two scenarios

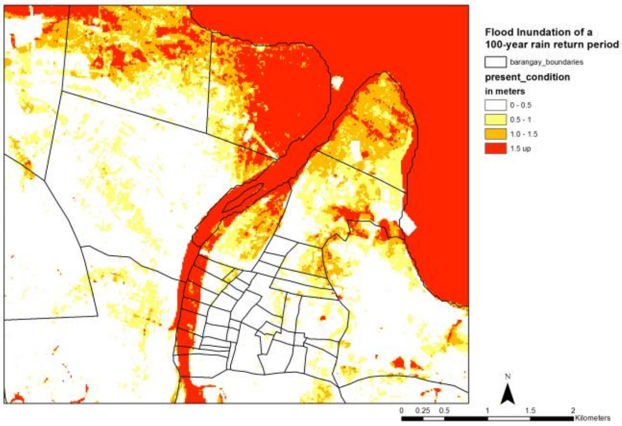


Figure 8. Inundation scenario for present 100yr RIDF

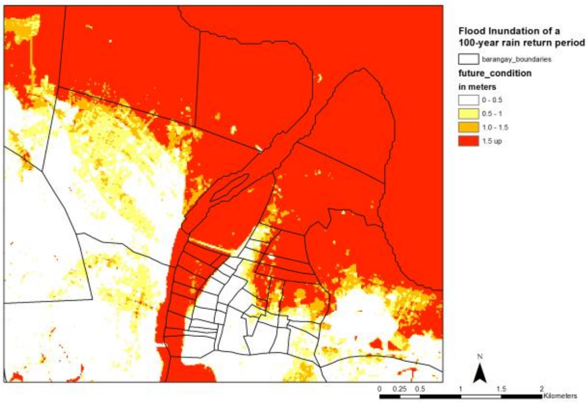


Figure 9. Inundation scenario for future 100yr RIDF

4.3 Increase in Hazard Exposure

By overlaying the exposure dataset derived from LiDAR DEM, we can then compute the increase in flood exposure for the river system, for various categories. This exposure dataset is derived from manual delineation of building footprints, and putting a building attribute in it to signify its use. In the floodplain of CDO, the increase in flood inundation exposed an additional 4290 residential buildings to flood, and an additional 170 infrastructure salient to flood disaster risk reduction, which might include medical facilities, religious facilities, warehouses, telecommunication facilities, and the likes.

5. CONCLUSION

This paper presented the data and methodology that can be used to extend the analysis of flood hazard mapping to include changes in precipitation characteristics brought about by climate change. The same analysis can now be extended into the other river systems that has been studied by the DREAM program. Inclusion of various climate scenarios of greenhouse gas emissions could also be used to give decision makers and local planning agencies options in maximizing climate change adaptation schemes. Further, it was also shown that the use of gridded precipitation data could lead us to more in-depth analysis about the spatial trend of precipitation over a large river system. As of writing, the analysis has been done only on the Cagayan de Oro river system. It is the wish of the authors that the analysis be expanded to include other river systems as well.

REFERENCES

Bedient, P.;Huber, W.; Vieux, B. 2008, Hydrology and Floodplain Analysis: International Edition, 4/E. Pearson, Ch. 3.

Ramirez, J.; Jarvis, A. 2008. High Resolution Statistically Downscaled Future Climate Surfaces. International Center for Tropical Agriculture (CIAT); CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Cali, Colombia.

UP TCAGP (2015), Flood Forecasting and Flood Hazard Mapping for Cagayan de Oro River Basin, Disaster Risk And Exposure Assessment for Mitigation Program, DOST Grants-in-Aid Program, 60 pp.

UP TCAGP (2015), DREAM LiDAR Data Acquisition and Processing for Cagayan de Oro-Iponan River Floodplains, Disaster Risk And Exposure Assessment for Mitigation Program, DOST Grants-in-Aid Program, 57 pp.

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