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Assessment and Analysis of the Floodplain of Cagayan De Oro River Basin

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Abstract

A technical approach using 1-dimensional steady flow model, GIS and remote sensing were used to analyze the Cagayan de Oro River Basin with a catchment area of 1400 sq. km., located in the northern central part of the island of Mindanao. Precipitation frequency analysis was done for Cagayan de Oro Rainfall Station, the only station with historical records starting from the year 1950. Probable point rainfall for the said station was used in the frequency analysis for 2, 5, 10, 25, 50, and 100 years return period storms. Results from precipitation frequency analysis were then used to construct the Rainfall-Intensity-Duration-Frequency (RIDF) Curves. Design precipitation hyetograph with their respective return periods were established using the alternating block method. A hydrologic model was built in HEC-HMS using ArcGIS and HEC GeoHMS. Physical attributes of the watershed were extracted using the above-mentioned tools and then exported to the HEC-HMS model. Using the design storms calculated during the precipitation analysis, the HMS model yields peak flows for different return periods. The hydraulic model was established in the river section starting from the river delta up to 9 kilometers upstream. In ArcGIS, river geometry was extracted from Triangulated Irregular Network (TIN) derived from Digital Elevation Model and ground survey. The river geometry was then exported to HEC-RAS for hydraulic analysis. Water levels computed in the hydraulic analysis were then exported back to ArcGIS for inundation mapping. The flood inundation results show that the city of Cagayan de Oro is extremely exposed to flood hazards. It is observed that the channel capacity is only capable of handling 2-year and 5-year storms without flooding portions of the city.

Keywords: Floodplain analysis, flood inundation, hydrologic model, flood hazards, GIS, remote sensing, river basin

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1. Introduction

Rivers and river systems played a key role in the emergence of the world's ancient civilization such as ancient China, Mesopotamia and ancient Egypt. These early river-based civilizations were largely concentrated around large rivers because in those regions, opportunities for gathering and hunting for food were declining. These people depended primarily on farming and husbandry as the source of their food. This was only made possible because of river flooding. The Greek historian Herodotus wrote that "Egypt was the gift of Nile". It is because of the annual flooding which provides a fertile land. The Yellow River is also called "the cradle of Chinese civilization" because it was the birthplace of the ancient Chinese civilization and at the same time called "China's Sorrow" due to its frequent devastating floods. River flooding magnifies the agricultural advantages and at the same time poses risks of property damage and deaths. Nowadays, flooding is a major natural hazard which every year affects different regions all over the world. Among the various types of natural hazards, floods have affected the largest number of people worldwide, averaging 99 million people per year between 2000 and 2008 (WDR, 2010). In Asia, countries such as India, Bangladesh, China, Thailand, Viet Nam and the Philippines are extremely vulnerable to flooding (WWAP, 2012).

The Philippines is among the countries which are relatively vulnerable to disaster risks. Situated in the western Pacific Ocean, this archipelago comprising of 7,107 islands covers almost three hundred thousand square kilometers. It is bounded by bodies of water, the Pacific Ocean on the east and West Philippine Sea on the west and situated along the Pacific Ring of Fire. The geographic location and its geologic characteristics make the Philippines prone to natural hazards such as earthquakes and typhoons. On average, the Philippines is hit by 15 astride typhoon belt and five to six cyclonic storms each year, most of which hit Luzon and Visayas regions. Aside from this hydrological condition, rapid and unplanned urbanization, man-made obstructions in the flood path, such as wires, bridge piers, floating debris, and dam breaks cause serious flooding. The problem of flood hazard is particularly eminent in cities near the river deltas which are lying only up to a few meters above sea level.

Cagayan de Oro is located along the central coast of Mindanao and the capital city of the Province of Misamis Oriental. Serving as a regional center for Northern Mindanao, the city has an estimated population of more than

622,000 as of 2011. In the heart of the city traverses Cagayan River or often called as Cagayan de Oro River. It is one of the major rivers in Mindanao having its headwaters in Kalatungan Mountain Range in the central Province of Bukidnon, then picking up tributaries along the way as it traverses the Municipalities of Talakag, Baungon, Libona and finally emptying into the Macajalar Bay at Cagayan de Oro. This catchment of having an area of more or less 1400 km² can discharge huge amount of water during a heavy downpour. The flat slope and swallowing of the channel as it approaches the delta poses risk of flooding to the densely populated riverside of Cagayan de Oro city. In the last five years, the city suffered heavy losses due to flooding. Therefore, consideration of appropriate mitigation measure is imperative.

Mindanao, the second biggest Island, has only an average of one tropical cyclone per year based on statistics from 1883-1990. However, Mindanao was hit with seven tropical cyclones in the last fifteen years. In 2011, Tropical Storm Sendong (International name: WASHI) hit the island of Mindanao. Cagayan de Oro city and other neighboring municipalities were among which suffered the hardest hit. The tropical storm Sendong in December 2011 exposed the city’s vulnerability to flooding. According to Lumbia’s PAGASA, the weather station, which is situated few kilometers from the city center recorded 180.9 mm one-day rainfall which exceeds the monthly average of only 117 mm. With this heavy downpour in a short period of time Cagayan de Oro River watershed discharges almost 2,500 m^3/s at water level 9.86m which is 60 times more than the normal water of 2.0m. Coupled with high tide and high velocity, this high volume of water resulted in flash floods in the city. Aside from this hydrological condition, unplanned urbanization of the city also contributed to the flooding problem. The rapid population growth due to migration resulted in informal settlements along the riverbanks and floodplains. The presence of this unplanned settlement which is only made up of light materials and sub-standard construction makes the fatalities higher. Urbanization generally increases the size and frequency of floods and may expose communities to increasing flood hazards (USGS, 2003). This tropical storm left 1,206 dead, 6,036 injured, 162 missing and an estimated damage of PhP 12,086,284,000 (Philippine Peso, 2011) for all sectors (PDNA, 2012).

This tragic experience prompts urgent need to investigate and analyze the flooding problem and provide effective structural and non-structural countermeasures. This study used Hydrologic Engineering Center (HEC) tools to achieve the research objectives. Hydrologic Engineering Center –

Hydrologic Modeling System (HEC-HMS) together with ArcGIS Advanced and HEC-GeoHMS are used to build the hydrologic model. Hydraulic analysis is done using the Hydrologic Engineering Center –Hydrologic Modeling System (HEC-RAS), a one dimensional model. This study used the above mentioned tools to investigate flooding potential of Cagayan de Oro City as a result of extreme rainfall events, as well as to evaluate the potential non-structural mitigation options. The specific objectives include a) assessment of flood frequency for the assessment of flooding potential of Cagayan de Oro City; b) build hydrologic model for the Cagayan de Oro River Basin; c) analyze the floodplain using steady flow one-dimensional model; and d) create flood inundation map.Figure 1 shows the location map of the study area.

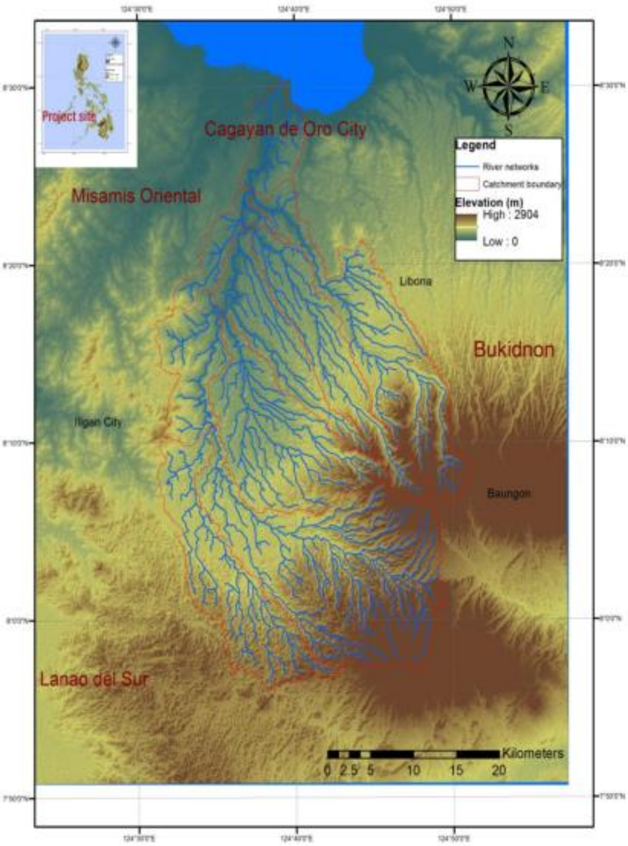

Figure 1. Location map of the study area

2. Methodology

Frequency analysis of precipitation data is essentially important to river hydrology. It is a consistent, statistical method for denoting the probability of occurrence of rainfall at a specific point in a catchment area USACE, (1993). The frequency distribution of the precipitation data was determined using analytical techniques. Theoretical distributions such as Log-Pearson Type III, Normal, Log Normal, and Extreme Value (Gumbel) distribution were used to evaluate the distribution functions at various points of interests.

In this study, two models were generated, namely; a hydrologic model and hydraulic model. The automated basin processing and hydrologic model building used ArcGIS (Environmental Systems Research Institute, 1990) and HEC-HMS. The HEC-HMS requires three primary input parameters: precipitation loss method, transform method and routing method (HEC, 2010a & e).There are several methods available in HMS to determine precipitation loss for overland flow that accounts for infiltration losses. These includes the Initial and Constant, Deficit and Constant, Exponential, SCS Curve Number, Green-Ampt, Smith Parlange and Soil Moisture Accounting. The second main input process parameter, Transform Method, simulates the process of direct runoff of excess precipitation on a watershed. There are two available options available in HEC-HMS. These are the empirical models (theoretical models) and conceptual models. Once excess precipitation has been transformed into overland flow and routed to the outlet of the sub-watershed, it enters the stream and its added to the flow routed from the upstream. There are several routing methods available in HEC-HMS including the Kinematic Wave, Lag, Modified Puls, Muskingum, and Straddle Stagger. In this study, the Muskingum-Cunge method or model was selected because observed data were not available. This model is physically-based routing and it is easier to set-up and apply with some confidence compared to other empirical models.

On the other hand, the automated floodplain analysis used ArcGIS and HEC-RAS.The methods used for floodplain analysis consisted of the following steps:

- Preparation of Triangular Irregular Networks (TIN) in ArcGIS for Desktop Basic
- Developing the RAS GIS Import File using HEC-GeoRAS
- Running HEC-RAS

- Post-processing of HEC-RAS results in HEC-GeoRAS for floodplain analysis

The approach for floodplain analysis used one-dimensional model using HEC-GeoRAS, ArcGIS, and HEC-RAS.

2.1 GeoRAS Preprocessing

2.1.1 River Digitization

The procedure for extracting geometric data in HEC-GeoRAS (HEC, 2010f) is as follows:

- Add the TIN dataset then in RAS Geometry tab in the GeoRAS toolbar select Layer Setup and under Required Surface select the TIN dataset
- Create empty GIS layers for the Stream Centerline, Flow Path Centerlines, Bank lines and XS Cut Lines.
- In the editor mode, manually digitize the centerline of the river from upstream to the downstream using Sketch Tool. Geo-referenced Landsat images are helpful guides to pinpoint the path of a stream.
- In the RAS Geometry tab, select Stream Centerline Attributes commands to populate the missing field of the new layer.
- Similarly in the editor mode using the sketch tool, manually digitize the Flow Path Centerlines, Bank Lines and XS Cut Lines(see Fig. 2).
- Complete their attributes commands in the RAS Geometry tab to populate the missing fields of the new layers.
- Bank Lines defines the main channel flow from flow in the overbanks. Flowpath center lines are used to identify the hydraulic flow path in the left overbank, main channel and right overbank.
- Manning’s n values can be assigned to cross-sections using land use data along with Manning’s n value for different land use types. This is not a compulsory step as it can also be performed manually in HEC-RAS.
- Select Export RAS Data in RAS Geometry tab to create the GIS Import File for HEC-RAS

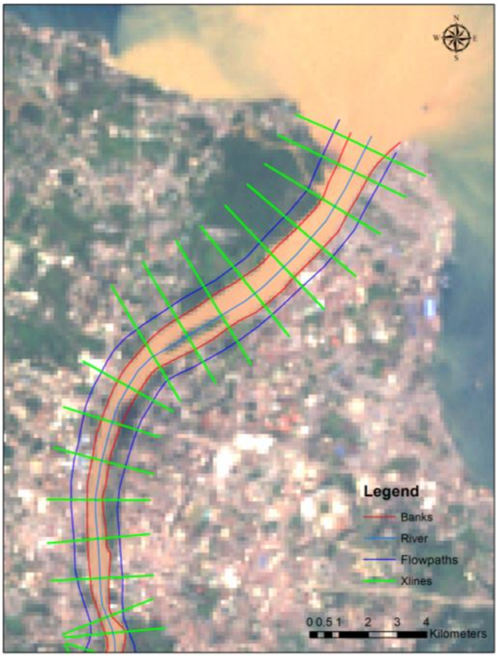

Figure 2. A snapshot of the river, river banks, flowpath centerlines, and cross-section overlaid on top of geo-referenced Landsat image for Cagayan de Oro

2.2 HEC-RAS

To build a floodplain model, the import file created in GeoRAS was imported to the Geometric Editor within HEC-RAS (HEC, 2010b& c). The river geometry was represented by river stations or cross-sections. These were numbered beginning from downstream to the upstream side. Flood discharges for different return periods obtained from hydrological model were entered in steady flow data. The flow data entered in the steady flow data editor consists of six return periods, namely; 2-year, 5-year, 10-year, 25-year, 50-year and 100-year.

The upper cross section RS+9000 were taken as the upstream boundary. Both upstream and downstream cross-sections have critical depth as the boundary condition. A subcritical depth analysis was done in the steady flow analysis. The resulting water surface profiles were then exported back to GeoRAS by creating the RAS GIS export file.

2.3 Georas Post-Processing

Simulation results from HEC-RAS were exported back to GeoRAS (HEC, 2010f) for floodplain mapping. Floodplain boundary and inundation depth data sets were created from exported cross-sectional water surface elevations. The process of exporting HEC-RAS results are as follows:

- Importing the RAS GIS Export File
- Inundation Mapping

2.4 Importing the RAS GIS Export File

HEC-GeoRAS does not read directly the spatial data format.*RASExport.sdf* written by HEC-RAS. It must be converted first into XML format. To convert an SDF file to XML, select the *Convert RAS SDF to XML File* button on GeoRAS interface. After converting the data from the SDF file to XML format the data is read into the GS and HEC-RAS results are processed.

2.5 Inundation Mapping

After the conversion of the data, initial datasets are created. The stream network, cross-section data, bank station data and bounding polygon data will be read and shape files are automatically created. Based on the water surface elevation attached to each cross-section, a water surface TIN is generated. Floodplain delineation then will use this water surface TIN and terrain model to calculate the floodplain boundary and inundation depths.

The floodplain delineation method rasterizes the water surface TIN using the *Rasterization Cell Size* and compares it to the DTMGRID. The flood plain is calculated where the water surface grid is higher than the terrain grid. Inundation depth grid is the result from the water surface and terrain grid comparison.

3. Results and Discussion

3.1 Precipitation Frequency Analysis

Two rainfall stations which are located in Cagayan de Oro River Basin were selected for Precipitation Frequency Analysis. These stations are under PAGASA and listed in Table 1.

Table 1. Rainfall stations for probable analysis

Station Code	Name	Location		Period of Observation
		Longitude	Latitude	
748	Cagayan de Oro	124°38’00”	8°29’22”	Jan.1950 to Dec.2000
747	Lumbia Airport	124°33’18”	8°24’12”	Jan.1977 to Present

Annual maximum point rainfalls at Cagayan de Oro Rainfall Station were used for precipitation frequency analysis. Using Gumbel, Log Normal and Log Pearson III distribution the probable point rainfalls were obtained. Among the results of these methods, the probable rainfall was selected considering the goodness of fit described by Kolmogorov-Smirnov (KS). Data are presented in Table 2 to Table 4 with corresponding graphical representations shown in Figures 3 to 8.

Table 2. Probable point 1, 2 and 3 -hour rainfall at Cagayan de Oro Station in millimeters

Return Period	Gumbel			Log Normal			Log Pearson III		
	1-hr	2-hr	3-hr	1-hr	2-hr	3-hr	1-hr	2-hr	3-hr
2	47.70	61.00	68.04	48.064	62.2	80.121	48.030	60.20	76.744
5	61.05	81.74	89.75	61.766	81.4	103.403	61.752	80.20	101.277
10	69.89	95.48	104.12	70.419	93.7	118.403	70.450	95.10	120.190
25	81.06	112.83	122.28	80.990	108.8	136.207	81.060	115.90	147.298
50	89.35	125.71	135.75	88.640	119.8	149.312	88.840	132.80	169.965
100	97.57	138.49	149.12	96.140	130.7	162.173	96.450	151.00	194.879
200	105.77	151.22	162.45	103.560	141.6	174.912	103.980	170.80	222.370
KS	0.10013	0.11205	0.110212	0.10013	0.15171	0.013328	0.10556	0.11712	0.09745

Table 3. Probable point 6 and 12-hour rainfall at Cagayan de Oro Station in millimeters

Return Period	Gumbel		Log Normal		Log Pearson III	
	6-hr	12-hr	6-hr	12-hr	6-hr	12-hr
2	61.00	90.76	62.2	89.43	60.20	85.212
5	81.74	124.86	81.4	118.069	80.20	115.317
10	95.48	147.43	93.7	136.523	95.10	139.119
25	112.83	175.96	108.8	159.389	115.90	173.967
50	125.71	197.12	119.8	176.159	132.80	203.672
100	138.49	218.12	130.7	192.746	151.00	236.836
200	151.22	239.05	141.6	209.291	170.80	273.985
KS	0.11205	0.08159	0.15171	014918	0.11712	0.09715

Table 4. Probable point 24 and 48-hour rainfall at Cagayan de Oro Station in millimeters

Return Period	Gumbel		Log Normal		Log Pearson III	
	24-hr	48-hr	24-hr	48-hr	24-hr	48-hr
2	95.54	120.85	97.905	121.651	96.066	116.832
5	127.18	165.75	129.761	161.867	128.858	158.945
10	148.13	195.48	150.346	187.930	151.903	191.282
25	174.59	233.04	175.907	220.364	182.586	237.553
50	194.23	260.91	194.686	244.235	206.608	276.199
100	213.72	288.56	213.285	267.907	231.648	318.641
200	233.14	316.12	231.859	291.578	257.911	365.435
KS	0.12941	0.09721	0.15979	0.15372	0.13796	0.10589

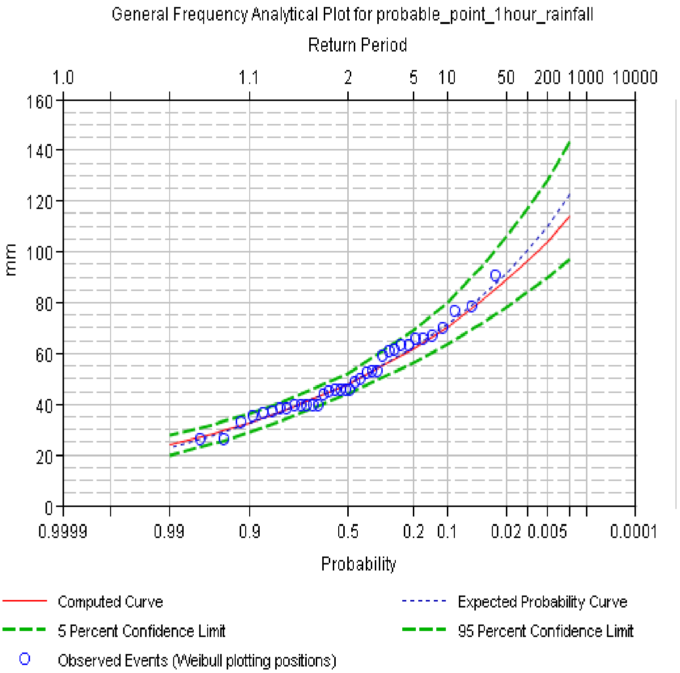

Figure 3. Probable 1-hour rainfall

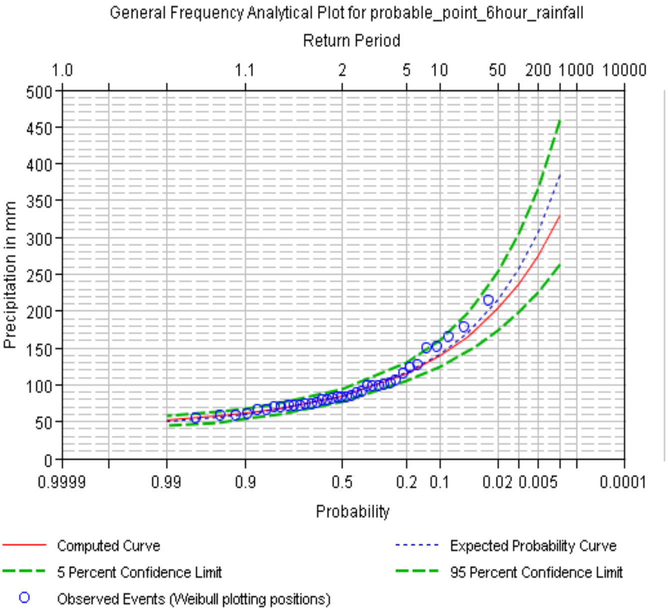

Figure 6. Probable 6-hour rainfall

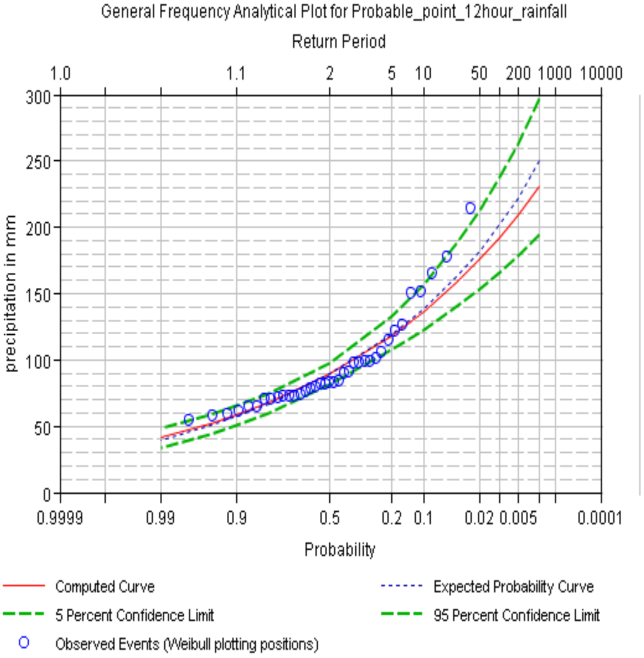

Figure 7. Probable 12-hour rainfall

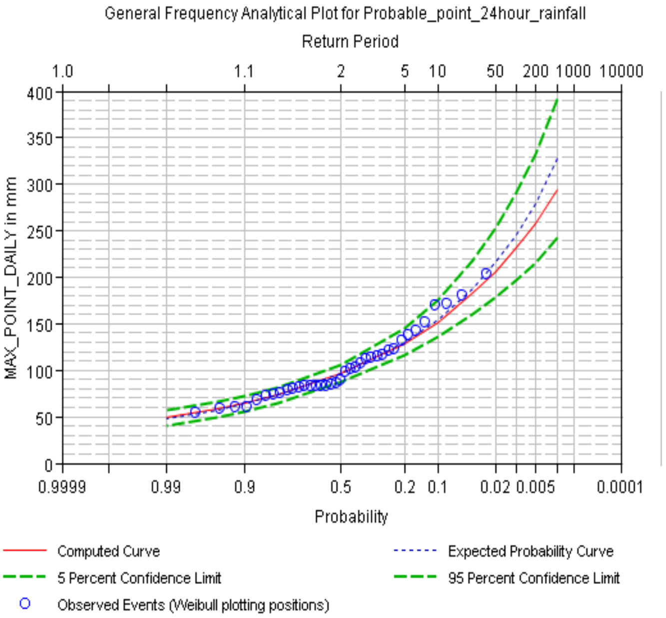

Figure 8. Probable 24-hour rainfall

3.2 Plots of Probable Point Rainfall in Cagayan de Oro Station

3.2.1 Rainfall-Intensity-Duration-Frequency Curve

Using the probable rainfall for 1-hour to 48-hour rainfall obtained from Cagayan de Oro Station, the Rainfall-Intensity-Duration-Frequency-Curve (RIDF) was prepared for 2-yr, 5-yr, 10yr, 25yr, 50yr, and 100yr return period (See Fig. 9). RIDF's were separated into short duration (10 min to 1 hour) and long duration (1 hour to 1-day). The following RIDF equations for long duration were compared for analysis:

$$I = \frac{a}{t+b} \quad \text{………} \quad \text{Type I} \qquad\qquad I = \frac{a}{\sqrt{t} \pm b} \quad \text{………Type III}$$

$$I = \frac{a}{t^{n}} \quad \text{…………} \quad \text{Type II} \qquad\qquad I = \frac{a}{(t+c)^{b}} \quad \text{……….Type IV}$$

Where, I = rainfall intensity in mm/hr and t= rainfall duration (hr)

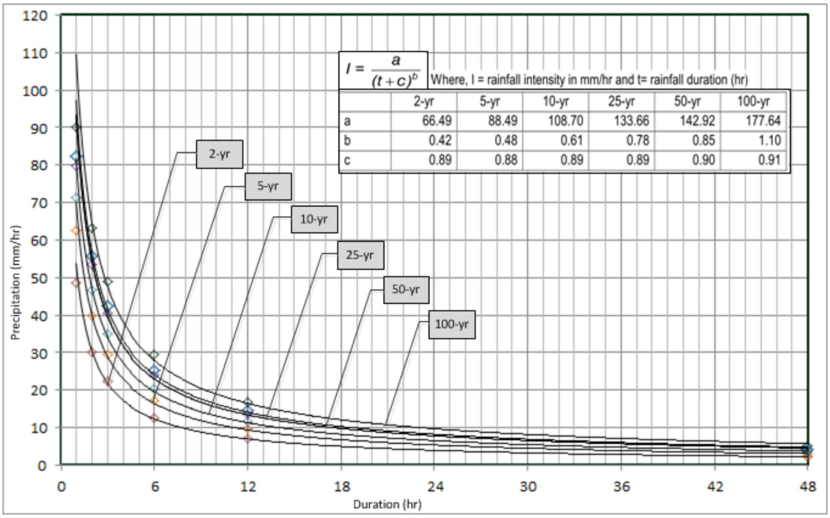

Figure 9. RIDF for 2 days at Cagayan de Oro Station

The parameters for the RIDFequations were fitted by optimizing the Nash–Sutcliffe model efficiency coefficient. Through comparison, Type IV was selected as the RIDF function for Cagayan de Oro Station. Table5 shows the values of the optimized parameters.

Table 5. Parameters for RIDF Type IV

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
a	66.49	88.49	108.70	133.66	142.92	177.64
b	0.42	0.48	0.61	0.78	0.85	1.10
c	0.89	0.88	0.89	0.89	0.90	0.91

3.3 Design Precipitation Hyetograph

Sample design storms with their return periods of 2 and 5 years are shown in Figures10 and 11, respectively considering the following:

- Temporal distribution of rainfall was measured using the alternating block method
- 48-hour rainfall amount was assumed equal to the probable mean rainfall

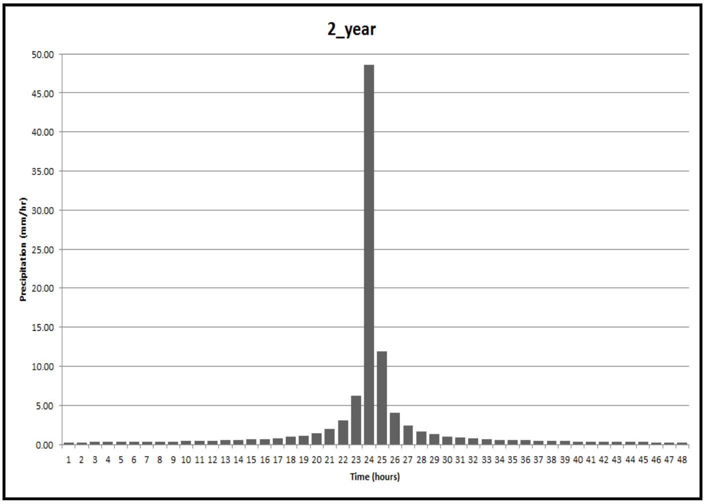

Figure 10. 2-year return period

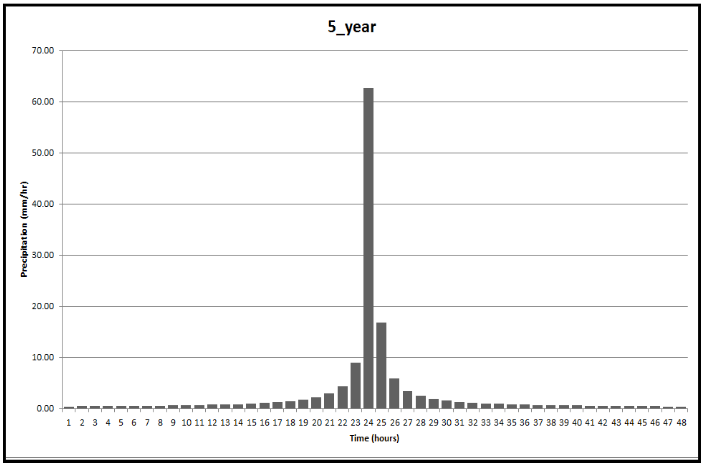

Figure 11. 5-year return period

3.4 Runoff Model

Modeling and Basin Subdivision

The 1400 km^2 Cagayan de Oro River Basin was divided into 23 subbasins and 12 channels as shown in Figure 12, and modeled as shown in Figure 13

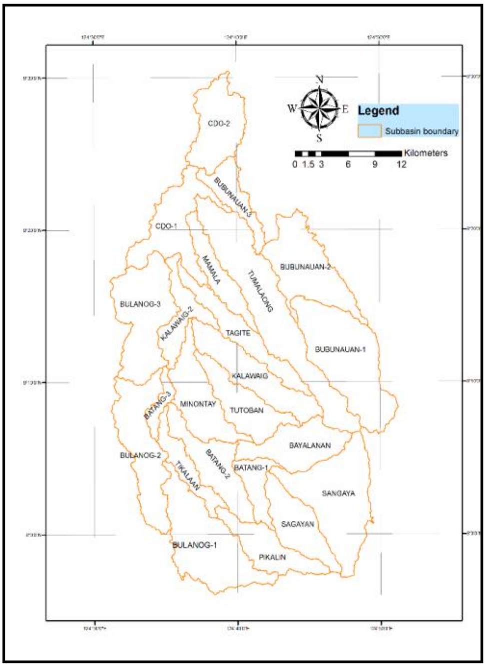

Figure 12. Basin subdivision for Cagayan de Oro River Basin

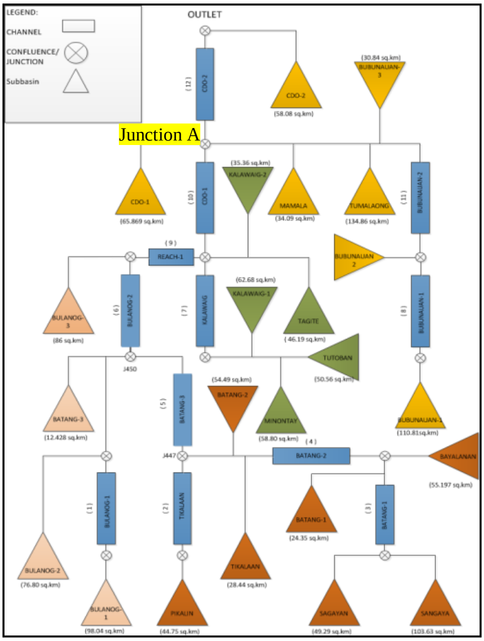

Figure 13. Runoff model structure

consideration of the various river features and basin characteristics for which peak discharge is necessary. Parameters required by the HEC-HMS related to the physical attributes of the river and basin elements such as River Length, catchment area, Basin Slope (S), Longest Flowpath, CentroidalFlowpath and Lag Time are presented in Table 6aand Table 6b.

Table 6a. Parameters for Channel

Name	Length (km)	Elevation upstream (m above sea level)	Elevation downstream (m above sea level)
(1) BULANOG-1	10.83	853.20	716.08
(2) TIKALAAN	18.58	868.44	480.44
(3) BATANG-1	6.28	808.51	656.16
(4) BATANG-2	14.30	656.16	480.44
(5) BATANG-3	6.53	480.23	402.23
(6) BULANOG-2	21.49	402.23	140.18
(7) KALAWAIG	22.10	498.72	129.00
(8) BUBUNAUAN-1	8.64	484.50	360.59
(9) REACH-1	3.22	274.25	129.00
(10) CDO-1	15.98	129.00	59.94
(11) BUBUNAUAN-2	17.36	360.59	59.94
(12) CDO-2	16.09	59.94	-03.04

3.5 Simulation Results

Figure 14 shows the estimated probable discharge of 2, 5, 10, 25, 50 and 100 year return period at Junction A (See Figure 13).

3.6 Hydraulic Model

3.6.1 Preparation of TIN

The 30m x 30m DEM obtained from the GDEM (Global digital elevation model established in 2007 by the National Aeronautics and Space Agency) was used to generate Triangulated Irregular Network (TIN) for the subbasin named CDO-2, the study area for floodplain analysis.

Table 6b. Parameters for Subbasin

Name	Area (km^2)	Longest Flowpath (km)	Centroidal Flowpath (km)	Slope (%)	CN	Lag (min)
SANGAYA	103.630	23.481	11.186	15.125	68.973	217.310
SAGAYAN	49.290	18.659	15.732	14.582	66.666	195.760
BAYALANAN	55.197	19.049	10.868	19.391	73.201	144.620
BATANG-1	24.352	12.190	5.200	12.295	67.625	148.090
BATANG-2	54.489	24.287	12.097	9.947	67.943	282.950
TIKALAAN	24.438	20.742	11.340	8.852	68.000	263.980
PIKALIN	44.746	20.310	10.723	12.24	68.562	217.440
BATANG-3	12.428	12.969	7.098	8.896	69.507	173.730
BULANOG-2	76.801	27.830	13.218	8.897	65.749	353.430
BULANOG-1	98.037	26.230	13.924	9.339	70.960	286.360
BULANOG-3	86.000	27.133	10.844	16.582	59.539	297.490
MINONTAY	58.803	22.353	6.092	6.834	72.986	278.530
KALAWAIG	62.677	25.333	13.043	15.914	72.704	203.340
TUTOBAN	50.560	19.772	11.136	9.236	71.594	225.740
TAGITE	46.185	28.753	15.300	14.510	71.575	243.130
KALAWAIG-2	35.360	20.528	11.947	9.227	75.843	206.420
BUBUNAUAN-2	78.831	20.495	7.370	8.435	77.027	208.250
BUBUNAUAN-1	110.81	28.273	16.474	25.060	72.339	178.720
TUMALAONG	134.86	18.201	23.373	14.834	72.821	325.370
MAMALA	34.088	19.774	9.206	8.757	67.396	259.570
BUBUNAUAN-3	30.835	28.723	7.086	11.796	70.740	191.390
CDO-1	65.869	16.183	5.086	11.987	55.829	320.330
CDO-2	58.076	16.813	8.010	8.431	66.162	240.010

During the creation of TIN in ArcGIS for Desktop, the elevation range was classified into nine classes from 314-353, 274-314, 235-274, 195-234, 155-195, 116-155, 76-116, 37-76, and -3-37m.

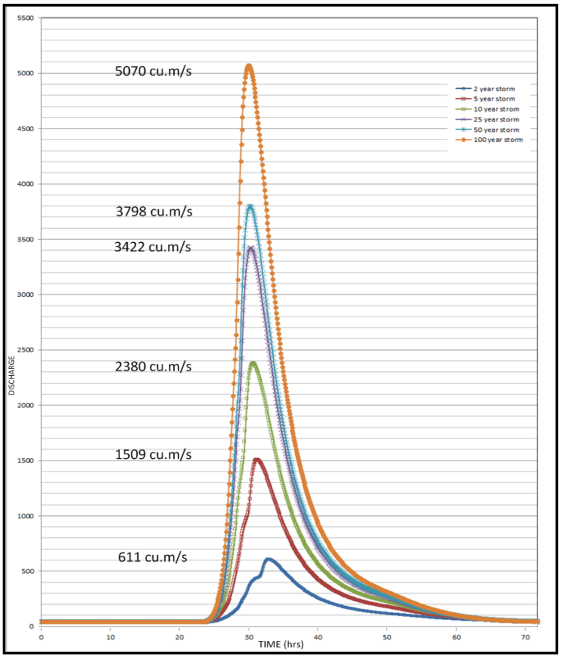

Figure 14. Estimated probable discharge

Figure 15 shows that the elevation at the middle part is relatively flat and the river channel is not clearly recognizable. As mentioned, ground survey data were to be used together with the created TIN to provide more geomorphological details of the river channel and floodplain. Bathymetry points obtained from the river sounding were used to update the river cross section extracted by HEC-GeoRAS.

3.7 Cagayan de Oro River Water Elevations

The estimates of the peak runoff from the HMS model for different storm recurrence interval are used in the hydraulic model built in HEC-RAS. The RAS model was then simulated to obtain water elevation results. The extent of the inundation can be calculated and modeled in HEC-GeoRAS using the RAS model results. In Figure16, the extent of inundation and the vulnerable segments of the river basin where flooding is likely to occur can be calculated and identified in GeoRAS. The flooding occurrence and inundation in a given year are presented in Figures17 to 22.

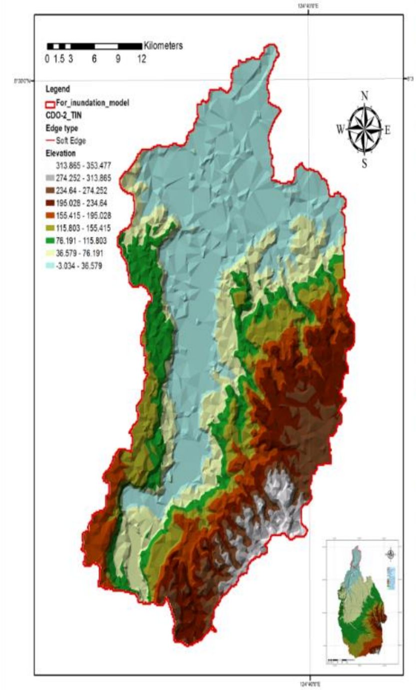

Figure 15. TIN for Inundation model

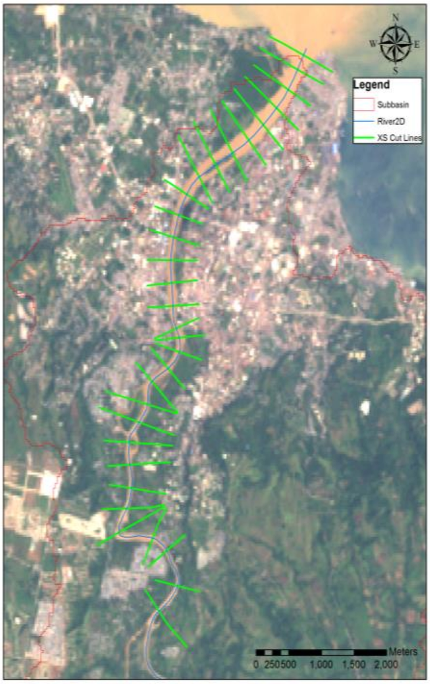

Figure 16. Cross-section cut lines for hydraulic model in HEC-RAS

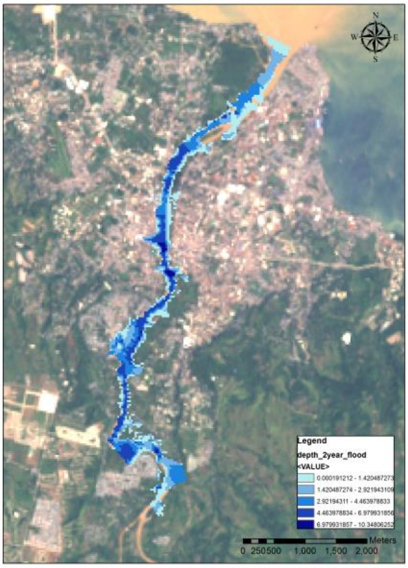

Figure 17. 2-year flood depth

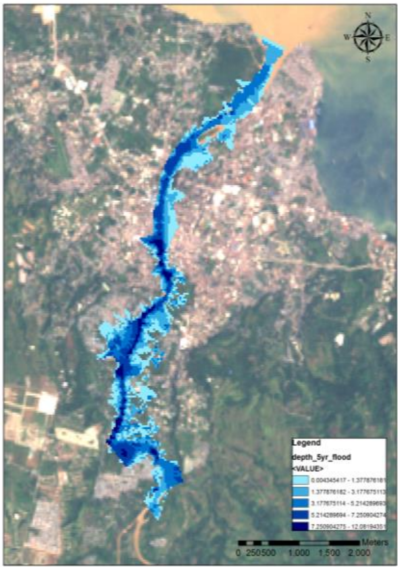

Figure 18. 5-year flood depth

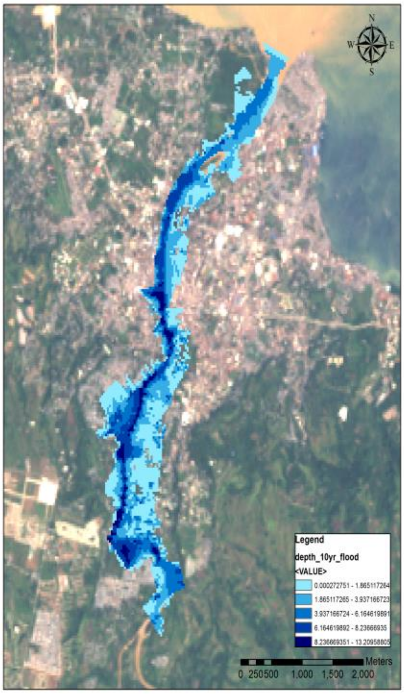

Figure 19. 10-year flood depth

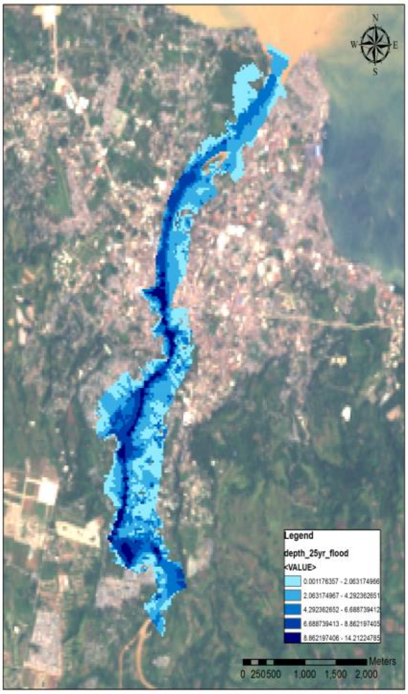

Figure 20. 25-year flood depth

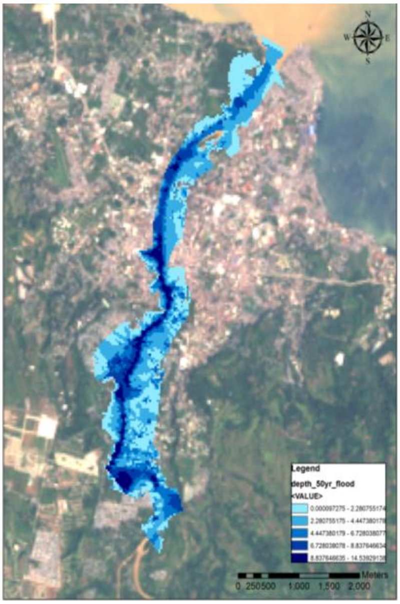

Figure 21. 50-year flood depth

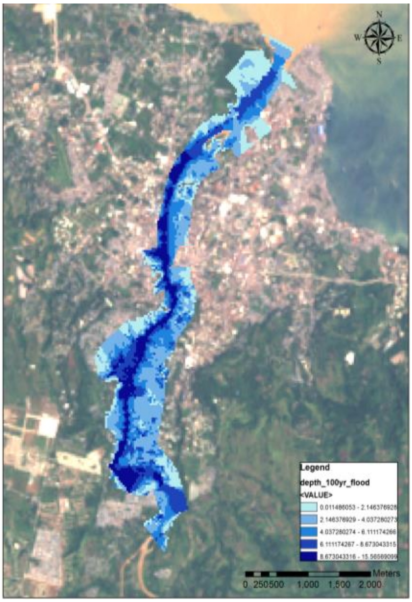

Figure 22. 100-year flood depth

The results show that with the increasing storm depth, the flood inundation also increases along the right banks. The inundation area results for the different storm scenarios are shown in Table 7.

Table 7. Inundation Area

Inundation area (km) for different storm scenarios	
Return period	Area (km)
2	0.12
5	1.95
10	2.79
25	3.25
50	3.35
100	3.73

The applications of hydrologic and hydraulic models together with GIS for floodplain analysis are very limited in the Philippines due to the scarcity of river geometric, topographic and hydrologic data. Therefore, this floodplain analysis and modeling are subject to the following sets of constraints.

- HEC-HMS, HEC-GeoRAS and ArcGIS were the primary software used to build the hydrological model.
- HEC-RAS, HEC-GeoRAS and ArcGIS were the primary software used for hydraulic analysis.
- Landuse/landcover used for generating Curve Number were derived from satellite images
- During the model run in HEC-HMS and HEC-RAS, several assumptions are made and needs to be verified.

According to the hydraulic model result, considerable flooding starts at 5-year flood event. River cross sections in the middle reach to the delta are observed to be shallower than the cross-sections upstream. Inundation map shows that the right banks of Cagayan de Oro are most likely to overflow if a 5-year event or higher will occur. These areas need immediate countermeasures because the level of hazard is high.

With the present river condition of the Cagayan de Oro River, structural countermeasures are necessary but not the long term solution to the flooding problem. With no possibilities of widening the river sections and increase conveyance, a mitigation measure has to be made further upstream. A retention basin or a dam could help manage river discharge, but needs further studies.

Floodplain analysis is one of the interests of land developers, design engineers and urban planners. The result of the floodplain analysis provides good information for floodplain management program on the area. Below are some of the potential applications of this study:

- The hydrologic model can be used to test impacts of land use changes and rainfall prediction in the Cagayan de Oro River Basin
- The results of floodplain analysis can be used for the design of flood control structures such as dikes, embankments, retention ponds, etc.
- The results can also provide information for the design of other hydraulic structures such as weirs and bridges.
- The results of this study could be a basis for non-structural measure for flood protection such as floodplain zoning.

4. Conclusions and Recommendations

This study presents a systematic approach on conducting floodplain analysis using 1-Dimensional steady flow models and GIS. The Cagayan de Oro River Basin was modeled using numerical models in combination with remote sensing techniques to determine the vulnerability of flooding of Cagayan de Oro City. A hydrologic model was built in HEC-HMS and ArcGIS. Design storms with different return periods for the whole basin were then simulated. Peak flows for the design storms generated by the HMS model were used to run the RAS model. The RAS model, then generates estimates of water elevations and flood inundation extents for the different design storms.

- The use of GIS and remote sensing in providing unavailable ground data proves to be a valuable tool in this study.
- The automated basin processing and hydrologic model building using ArcGIS and HEC-HMS saves time and resources while providing reliable results at the same time.

- The automated floodplain analysis using ArcGIS and HEC-RAS provides results that will help decision-makers better understand the flooding problem.

The flood inundation results show that the city of Cagayan de Oro is exposed to a high level of flooding hazard. It is observed that channel capacity is only capable of handling 2-year or 5-year storms without having considerable floodplain. With little possibility for channel modification, mitigation measures have to be made upstream. With the high probability that the city will be flooded again in the next five years, it is imperative that short-term and long-term mitigation measures have to be performed.

This study was conducted under the major constraint of limited data availability. The following recommendations are made for further studies in the future:

- Precipitation data: One of the major parameters for the hydrologic model, precipitation data in and around the catchment, is needed for establishment of design hyetographs.Precipitation data series are also needed for calibration and validation of the model
- Topographical data. For flood routing in hydrologic models, topographic data should be provided to fully represent the channel. For modeling flows in overbank, topographic data of high resolution are needed to fully represent the floodplain
- Flow data: A major hydrologic parameter, long time series, are necessary for the calibration and validation of models.
- River cross sections should be measured through topographic survey because the river morphology has changed drastically during previous major flood event.

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