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Assessing Flood Occurrence and Modeling Impact of Urban Drainage Structure

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ABSTRACT

This study evaluated the catchment and flood prone area by applying physical and numerical modeling. This described rainfall data and presented evidences of flooding based from extreme precipitation events. Mathematical models were derived using the definition of discharge and Manning's formula which finally were used to estimate the sufficiency of the river canal cross sectional area to transport great amount of water flow. Mt. Isarog, mountain ranges of Lagonoy and the low land area are the sources of flood water in Lagonoy River. The amount of daily precipitation is always insufficient to induce flooding except for a terrifying event that the area was heavily affected. The river canal cross sectional area is sufficient to accommodate flood water flow but the position of the moon which is indicating differences on river depth during full/new moon and first/third quartermoon, high tide and low tide, and with heavy and non-heavy rainfall.causes the flood while others are due to river bends, insufficient design of spillway and obstruction of irrigation waterway.

1. Introduction

Climate in the Philippines is influenced by complex interaction of various factors such as geography and topography. More extreme weather events are coming with more people affected by typhoon related hazards. Duration and intensity of rainfall events have changed

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that high intensity affects local waterways in terms of the generated runoff infiltrating the urban residential areas [1]. Heavy rainfall are highly localized making it difficult to estimate the probability and magnitude accurately but the intensification of extreme weather triggers the impact on the environment [2]. Bicol region in the Philippines is one of the most disaster-prone areas and high-risk environment due to geophysical location and natural hazards. The municipalities of Lagonoy and San Jose in the province of Camarines Sur are frequently visited by storms and floods putting the lives of the people in vulnerability and risk [3] specifically that majority of the population are not prepared for the hazards and are not well organized for disaster risk reduction.

2. Research objectives

The paper entitled "Assessing Flood Occurrence and Modeling Impact of Urban Drainage Structure" evaluated the catchment and flood-prone area applying physical and numerical modeling. Mathematical models were derived using the definition of discharge and Manning's formula which finally were used to estimate the sufficiency of the river canal cross-sectional area to transport a large amount of water flow.

3. Methodology

The study area are the low lying villages of San Jose and Lagonoy, Camarines Sur specifically in Sabang, Dolo, Kinalansan of San Jose and Sta. Maria, Binanuanan, Loho, San Ramon and Burabod of the municipality of Lagonoy, Camarines Sur. Some upper villages of Goa, Camarines Sur were covered for they are passages of surface water flow. The two and three dimension maps of these areas were significantly analyzed by physical modeling. Precipitation was investigated by collecting rainfall data using rain gauges in year 2018. The derivation of the mathematical model was based on discharge and Manning's formula. The highest recorded rainfall was employed in assessing flood event using the derived mathematical models which eventually was used in analyzing the adequacy of the river channel before the rainwater was discharge into the ocean. Remote sensing was applied. The

RTK COMNAV T-300 was helpful in finding significant coordinates of the river. A nomenclature table was established to facilitate understanding of the terminologies used.

4. Results and findings

4.1. The catchment and the flood prone area

The flood water sources were classified into three areas. Mt. Isarog is an area (A-1) that the precipitation water came from the slope of the mountain flowing towards Lagonoy river. The mountain ranges of Lagonoy is a catchment area (A-2) that collects rain water to flow towards Lagonoy river. In low land area (A-3), precipitation water flow in the surface down the ocean. A-1 was estimated to have an area of 90.5 km^2, while A-2 has 110.08 km^2 and A-3 as 53.71 km^2 The flood prone area has 12.24 km^2. Mapping based studies and analyses at different spatial scales was used to identify flood prone areas and estimate their vulnerability. This is the area where most effective risk mitigation measures be enforced [4] .

Table 1
Nomenclature used in this study.

Variable	Definition	Unit of measure
RTK COMNAV T-300	A surveying instrument used to determine the coordinate of significant parts of the river	
A-1	The catchment area on portion of Mt. Isarog	km^2
A-2	The catchment area on portion of mountain ranges of Lagonoy	km^2
A-3	The catchment area on lower portion of Mt. Isarog	km^2
n	The Manning's roughness coefficient in the main channel considered as with some weeds and stone, n = 0.035.	
Q_a	The discharge that the volume of precipitation water was accumulated for a period of time.	m^3/s
Q_d	The river discharge in the area of observation.	m^3/s
V	The volume of precipitation water accumulated within twenty four hours	m^3
P	The amount of precipitaion in the area of observation.	Mm
t	The time covered to accumulate water in the catchment area. It is also the time needed to discharge the accumulated precipitation water that no flooding will occur.	H
v_a	The average velocity of the rain water to flow down from surface to river canal and into the ocean.	m/s
v_1	The velocity of the surface water in A-1	m/s
v_2	The velocity of the surface water in A-2	m/s
A_c	The computed cross sectional area at the river flow	m^2
A_a	The actual cross sectional area at the opening of the river channel	m^2
R_1	The computed hydraulic radius at A-1 = 1.76 m	m
R_2	The computed hydraulic radius at A-2 = 1.83 m	m
R_3	The computed hydraulic radius at A-3 = 0.10 m	m
S_1	The slope at A-1 = 8.5%	%
S_2	The slope at A-2 = 1.6%	%
S_3	The slope at A-3 = 1.2%	%
ETHR	The estimated time that precipitation water accumulated	H
d	The lowest depth of the investigated portion of the river canal	m
P-1	The first studied portion that flooding occur.	
P-2	The second studied portion.	
P-3	The third studied portion.	

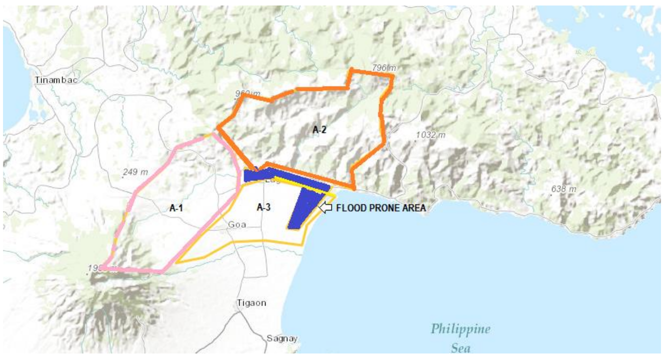

Fig. 1. The catchment and the flood prone areas.

4.2. The rainfall data

The daily precipitation was observed from January to December of year 2018. The data shown in Table 1 reveals that in most cases the daily precipitations are insufficient to induce flooding. Most of the days the precipitation are low. The lowest is zero which is happening every month. The extreme, second and third highest precipitation occurred on the month of December (298 mm on December 29, 151 mm on December 28 and 121 mm on December

23) while the fourth highest was January 12 with 144 mm precipitation. Observations on the other months do not exhibit large amount of precipitation. However, the worst flooding that happened in the area was dated January 12. It was this fourth highest precipitation event that evedencies of floodings significantly occurred. Precipitation patterns with tendency towards greater and more frequent extreme precipitation is needed to be analyzed for this can produce costly impacts in areas like flood management, hydraulic structures, water availability throughout the year, agricultural production, ecosystems, and human health [5]. Extreme precipitation is a leading cause of flash flooding and is almost exclusively convective [6].

Table 2
Daily precipitation of year 2018.

Day	Month											
	Jan	Feb	Marc h	Apri l	May	June	July	Aug	Sept	Oct	Nov	Dec
	Precipitation (mm)											
1	61	1	1	0	8	0	17	1	0	6	0	13
2	0	10.2	2	1	1	11	0	0	23	4	0	2
3	0	10.4	5	1	0	0	0	0	1	15	1	11
4	0	-	0	5	0	0	0	16	0	0	1	0
5	0	8	0	0	43	2	0	0	3	1	75	0
6	0	4	0	6	0	18	6	24	1	0	8	2
7	0	0	0	3	0	1	3	5	0	0	1	0
8	0	0	0	20	1	8	30	0	0	0	1	7
9	0	0	29	23	0	58	0	0	0	0	23	0
10	0	0	15	0	0	12	5	0	8	0	0	0
11	18	0	7	0	0	4	5	0	5	0	0	0
12	144	36	6	1	0	0	31	0	3	0	33	0
13	15	31	0	2	16	3	30	0	46	-	0	20
14	14	7	0.10	0	1	0	0	1	71	-	0	34
15	32	0	28	1	17	0	0	-	23	-	0	11
16	42	0	2	1	0	0	6	-	7	-	17	32
17	55	0	3	0	0	0	25	-	0	-	0	25
18	8	0	0	0	0	0	0	0	41	-	8	3
19	10	0	0	3	0	32	0	0	8	-	0	1
20	23	13	0	0	0	0	0	0	6	-	4	55
21	4	20	0	3	0	51	8	0	11	-	51	4
22	0	0	21	0.5	0	22	0	0	10	61	6	3
23	1	0	12	0	12	0	0	0	0	0	1	121
24	50	16	1	0	0	0	0	0	0	0	4	30
25	105	21	0	0	29	0	28	0	0	0	1	1
26	105	2	0	4	0	0	0	0	0	0	-	0
27	25	14	1	0	0	0	1	0	0	0	-	0
28	1	0	4	0	0	0	28	3	0	1	-	151
29	0	-	20	0	0	0	12	1	0	0	-	298
30	2	-	9	0	6	0	0	13	0	0	-	102
31	0	-			4	0	12	30	0	0	-	

An analysis of rainfall-runoff model is necesseary for the following reasons [7]: rainfall records are more available than streamflow records, stremflow measurement errors make the data unsatisfactory for direct frequency analysis, non stationary streamflow records can render record unsatisfactory, extrapolation of rainfall record is easier than the runoff records and physical features of catchment can be incorporated in raifall-runoff model.

4.3. Evidences of flooding

Evidences of floodings shown in Figure 2 were collected during the fourth extreme rainfall event that occurred January 12. The flooding shown in Figure 2A and 2B happened between villages of Salog, of the municipality of Goa and Malabog of the municipality of Lagonoy. Figure 2C is a flood that happened in the village of Sta. Maria that affects a national highway. In Figure 2D, local residences were rescued in the village of Burabod. Figure 2E is a flood in the village of Sabang, Figure 2F in San Roque, Figure 2H in Telegrafo and Figure 2I in Manzana of the municipality of San Jose. The images show that the area affected by flood is widespread within the coastal and riverside villages. The presented map also shows that Lagonoy river is discharging water within the coastline.

Fig. 2. The January 12, 2018 flood.

Flooding is widespread, however, it was not extraordinary dated December 29, 28 and 22 that registered the first, second and third highest precipitation event respectively in year 2018.

4.4. The discharge mathematical model

A mathematical equation was derived based from the definition of discharge:

$$Qa = \frac{V}{t} = \frac{AP}{t} \quad (1)$$

Application of physical modeling has found that the total cathcment area is 254,290.00m^2 and by substitution the previous eqation becomes:

$$A_c v = \frac{10,171.60}{t} \quad (2)$$

where Qa is the discharge that precipitation flow as surface water in the catchment area during the period of accumulation. To avoid canal overflow, the amount of river discharge shall not exceed the capacity of the river cross sectional area at a particular time. The mathematical equation was established based from other definition of discharge, which satisfies equation 2.

$$Q_d = A_c v \quad (3)$$

but:

$$Q_d = Q_a \tag{4}$$

4.5. Cross sectional area of the river canal

Mannings Equation was used to compute the velocity of the rivers running at specified slope. Discharge was calculated due to lack of field flow data which was based on peak flow from a defined cross section and hydraulic characteristics. Peak discharges are usually calculated using indirect method based on empirical hydraulic formula such as Manning's equation [8]. The Manning's equation is:

$$v = \frac{1}{n} R^{2/3} S^{1/2} \tag{5}$$

Considering the three areas of study the equation for average velocity is:

$$v_a = \frac{v_1 + v_2 + v_3}{3} \tag{6}$$

By substituting the velocity on each area the equation becomes:

$$v_a = \frac{1}{3n}\left(R_1^{2/3} S_1^{1/2} + R_2^{2/3} S_2^{1/2} + R_3^{2/3} S_3^{1/2}\right) \tag{7}$$

The Manning's roughness coefficient for main channels where there are evidences of some weeds and stone is n = 0.035. The derived mathematical equation for the fourth highest precipitation event assuming the cross sectional area of the river to be sufficient is shown below.

$$\frac{10171.6}{t} = \frac{A_c}{3(0.035)}\left(R_1^{2/3} S_1^{1/2} + R_2^{2/3} S_2^{1/2} + R_3^{2/3} S_3^{1/2}\right) \tag{8}$$

To compute for the cross sectional area, the equation was manipulated to appear as:

$$A_c = \frac{1068.02}{t\left(R_1^{2/3} S_1^{1/2} + R_2^{2/3} S_2^{1/2} + R_3^{2/3} S_3^{1/2}\right)} \tag{9}$$

Following the same process of derivation the equation of the cross sectional area for the highest precipitation event at 298mm is shown as:

$$A_c = \frac{2210.20}{t\left(R_1^{2/3} S_1^{1/2} + R_2^{2/3} S_2^{1/2} + R_3^{2/3} S_3^{1/2}\right)} \tag{10}$$

A condition was established that for a canal to be sufficient in transporting extreme precipitation water, the actual cross sectional area of the river channel shall be greater than the computed cross sectional area. If extreme precipitation events are not sufficiently represented in modeling and simulations then the observed data are not accurately represented [9].

4.6. Capacity of the river canal cross sectional area

The derived mathematical model was used to determine the sufficiency of the river canal cross sectional area at coordinates 13.722191, 123.577628 to 13.723095, 123.577282 in discharging precipitation water with assumptions that rain water was accumulated within twenty four (24) hours, six (6) hours, two (2) hours and one (1) hour. The estimated cross sectional area of the river is 1,200m^2. The result is shown in the Table 3.

Table 3
Comparison between river flow (Ac) against river channel (Aa) cross sectional area.

ETHR	144 mm precipitation event				298 mm precipitation event			
	Ac (m^2)	Aa (m^2)	Relation	Interpretation	Ac (m^2)	Aa (m^2)	Relation	Interpretation
24	69.65	1,200	Lesser	Sufficient	144.16	1,200	Lesser	Suffiicent
6	278	1,200	Lesser	Sufficient	576.65	1,200	Lesser	Sufficient
2	835.8	1,200	Lesser	Sufficient	1729.96	1,200	Lesser	Insufficient
1	1671.6	1,200	Lesser	Insufficient	3459.92	1,200	greater	Insufficient

The table reveals that the cross sectional area of the river channel is sufficient to discharge large amount of precipitation water even at shortest time of accumulation except for the highest event that for a one hour of rain water accumulation the cross sectional area is inssuficient. However, a 298 mm volume of rainwater accumulation is impossible to happen within one or two hours.. This means that there is no problem on the capacity of the river crosssectional area.

4.7. Depth of water

The depth condition of the river canal was investigated at coordinate 13.722810, 123.574030. It was found changing during high and low tide, new moon and full moon and during rainy and non-rainy days. The condition is shown in Table 4.

Table 4
River depth at high and low tide, rainy and non-rainy, full/new moon and first/third quarter moon.

Condition	Full/New moon		First/third quarter moon	
	heavy rainfall	non-heavy rainfall	heavy rainfall	non-heavy rainfall
High tide	5.00d	2.50d	2.50d	1.67d
Low tide	2.33d	1.67d	1.33d	d

At low tide and first/third quartermoon, the condition of the river depth reaches up to 1.33 times deeper than non-rainy days.but at full/new moon is reaching up to 1.67 and 2.33 times deeper on non-rainy and rainy days respectively. During high tide the river depth could reach up to 1.67 and 2.50 times deeper on non-rainy and rainy days respectively at first/.third quarter moon but is reaching up to 2.50 and 5.00 times deeper on non-rainy and rainy days respectively at full/new moon. The conditions were supported that tidal ranges varies from 1.0 to 12.0 meters [10] however the mean sea level rise which is of great importance in the analysis of coastal flooding is ranging from 0.50 to 10.00 meters [11] while it was clarified that at 12.00 meters sea level rise, the no flood level dissipitation begins to plateau while the flood level dissipitation continues to rise [12].

4.8. Causes of flood

Flooding occurs if the amount of precipitation exceeds the evaporation rate and infiltration capacity of the soil [13] however it is caused by multiple factors like human causes by putting up building structures on water ways, inappropriate disposal of waste, soil compaction due to vehicular and human movements or hydro meteorological causes such as excessive rain fall, poor drainage system, high rate of soil water holding capacity [14]. The causes of flooding in P-1 is due to river bends of Lagonoy river (See Figure 3). Exceesive amount of rainfall makes runoff water overflows to the floodplain areas. When the pressure gradient overcomes the centrifugal force in river bends, a stream is formed inside the section in transverse direction. Erosion of river walls which occurred in old rivers contributes a lot of damages in land around the river. The structures create false rivers right-of-way that consequently decreases the potential use of land [15]. Large amplitude and wavelength of river meandering resulted to large area of floodplain.

Fig. 3. Portions of Flood Affected Areas.

Other causes of flooding is the constructed spillway which is located at coordinate 13.745549, 123.502383. The structure serves as road to connect two villages. The spillway is designed to safely convey floods to the watercourse downstream [16], but is inadequate to convey large volume of water flow.

Fig. 4. River bends and the spillway.

River meandering and the effect of high tide causes flooding on the coastal villages (P-2). The sea water that enters the river canal is blocking the exit of large volume of runoff resulting water level to rise. Tides affect water levels and current speeds in rivers as they approach the ocean [17]. The effects can reach much farther inland sometimes at hundreds of kilometers than the brackish, where salty seawater mixes with fresh river water. In the local setting, the affected areas are the coastal villages of Sabang, Dolo, Kinalansan and Burabod.

Insufficient design and location of irrigation waterway causes flooding in P-3. The location that the canal have to discharge water into the sea is obstructed by houses and buildings.

Improper drainage condition is the main cause of floods that the government and local community should take necessary measure to ensure that proper drainage is built and clear during rainy season [18].

5. Discussion

Lagonoy river has sufficient catchment area to collect rainwater from Mt. Isarog, the adjoining mountain ranges of Lagonoy and from the low lying area in which urbanization is taking off. Urbanization meets the population's needs as it increased the development of paved and residential areas resulting to the alteration of time of concentration, water quantity and flow rate which significantly changed the catchment's hydrological and hydraulic characteristics suggesting that analyzes of the present and future problems is necessary to lessen the effect [19]. The daily precipitation varies as indicated by the changing amount of precipitation but there are cases that the precipitation is extraordinary resulting to widespread flooding. As building resilience in urban drainage system requires consideration of a wide range of threats that can contribute to urban flooding it was suggested that hydraulic reliability based approaches be focused on quantifying functional failure caused by extreme rainfall or dry weather flow leading to hydraulic overloading [20] . This study was able to present evidences that the area affected by flood is widespread within the coastal and riverside villages that occur within a remarkable precipitation event. Such evidences highlighted the need for experimental efforts to support the development and validation of computational models of urban floods [21]. Since, this study was focused mainly on input and output of precipitation and discharge, the mathematical models were based mainly from the definition of discharge and Mannings equation. The derived model was assumed to be useful in estimating the sufficiency of the river cross sectional area to handle extreme river discharges. However, this study does not considered the hydrologic losses in the system like evaporationn or increasing drainage capacity like retention ponds, pumping stations and flood diversion culvets [22] which requires utilization of other models. The phenomenon of urban flooding caused by surcharged sewer system could probably lead to drainage modeling [23] however they were not included on this study that the interaction between surface and water flow [24] were not emphasized. The effect of floating objects such as debris, plastic and domestic wastes were also not included. This study was able to established that the river canal is sufficient in transporting extreme precipitation water as the actual cross sectional area of the river channel is greater than the computed cross sectional area of the river flow. The established phenomenon is necessary as the socioeconomic aspects, climate characteristics, built environment and revirine process of urbanized plains subjected to flooding creates a pattern of development without predefined equilibrium state [25]. However among the causes of flooding of various villages within the vicinity of the river may be considerefd as natural and man made. Natural causes are due to river meandering and the effect of hightide associated by the position of the moon while man made causes are due to insufficient design of spillway and obstruction of irrigation waterway. The situation is experienced in other urban villages in Asia that the problem get worsed when unplanned infrastructure and urban growth are filled up in low-lying areas [26] similarly with European cities that are expereincing a steady increase in the intensity of floods due to high urban densities resulting to soil sealing that although they used piped drainage system to cope with excessive rainwater, the designs no longer have the capacity to keep pace with the on-going urbanization and impact of climate change [27] . However, aside from the new technologies that are available for flood monitoring, modelling and mitigation like the use of light detection and ranging (LIDAR) based digital elevation model (DEM) for the storm water management model (SWMM) [28] it was insisted that there are paradigms that are suggesting the adoption of greener approaches to urban storm water management [29] as resilience in cooperative operation is superior compared to structural measures such as the installation of additional drainage facilities including pump stations and detention reservoirs [30].

6. Conclusion

Three catchment areas as sources of flood water during heavy rainfall are the mountain of ranges of Lagonoy, Mt. Isarog and the low land. The catchment area is larger compared to flood affected areas. In most cases, the amount of daily precipitation is insufficient to induce flooding but there was a terrifying event that the identified area was heavily affected. A mathematical model was derived using physical modeling of a satellite map and by applying the definition of discharge and Manning’s formula. The derived model was used to prove that the river canal cross sectional area is sufficient to accommodate extreme surface water flow. Causes of flooding is attributed to the position of the moon which is evidenced by difference on river depth during full/new moon and first/third quartermoon, high tide and low tide, and with heavy and non-heavy rainfall. Other causes of floods are due to river bends, insufficient design of spillway and obstruction of irrigation waterway to discharge directly surface waterflow into the ocean.

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