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Rain Barrel Implementation for Urban Runoff Mitigation

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Abstract— *Land-use change has its own set of repercussions. It impacts not only weather conditions but also runoff patterns, as permeable areas become impenetrable. Nonetheless, flooding has undoubtedly become a common phenomenon that most people have encountered. It has always been evident in some parts of the Philippines, especially in those areas which are low-lying in topography. Traditional methods to counter these effects are seen to be insufficient, as these circumstances still prevail. Kaskag, Barangay Washington, Surigao City is no exemption to these conditions. The use of a Low Impact Development technique, which is the use of rain barrels, is seen to be the course of action that this study sees as one of the feasible to address these conditions. A software called SWMM, which is software used worldwide in planning, analysis, and design related to stormwater runoff, was used to generate a hydrologic model that will simulate the post and pre-LID scenarios. After the simulation, it showed a reduction in total runoff volume, reaching the outfall by 5.73% after the installation of LID. The reduction in total runoff volume amassed an average decrease of 5.30% and a reduction in runoff peak by an average decrease of 7.72%. It can be observed that the application of LID is capable of decreasing the stormwater runoff in all seven sub-catchments. However, its capacity falls short in reducing the likelihood of flooding in the catchment of the selected study area in Kaskag, Barangay Washington, Surigao City, Philippines, especially during strong thunderstorms or continuous heavy rainfalls that may result in big flood events.*

Keywords— *ArcGIS, Rain Barrels, Flood Mitigation, Low Impact Development (LID), SWMM.*

I. INTRODUCTION

The growth of urbanization has been the center of attraction in various environmental debates for quite some time now. It is embodied as a complicated policy area where the social, political, and economic issues are interlaced with all the ecological problems. It's causing many problems like land insecurity, worsening water quality, excessive air pollution, noise, and the problems with waste disposal [1][2][3]. The expansion of these impervious shares of terrains in urban areas has brought remarkable transitions in the land properties [4][5]. Degradation of water quality, high peak flow, and excessive volume surface runoff is one of the outcomes when the continuous land development progress and the water balance [6][7][8]. Major flooding will always be associated with urbanized areas regardless of the use of dense stormwater drainage systems as a result of the peak discharge, volume, and frequency of floods increase in nearby streams [10][11][12].

Extreme weather patterns brought by climate change can cause an increase in the frequency and intensity of extreme precipitation and severe floods that further escalates these complications [13][14][15]. With all of that said, the development of urbanization and the continuous increase of the global temperature due to global warming makes productive management and designing of stormwater water systems extremely challenging [16][17][18]. The problem is aggravated using traditional, aging, and undersized stormwater infrastructure, putting communities all over the world at risk of flooding [19][20][21][22]. In many regions, existing stormwater systems are already being overrun by the current storm conditions and are already at risk of being damaged [22][23][24]. To mitigate the growing frequency of urban floods, appropriate adjustments to stormwater systems are required, including revisions and updating of conventional design processes and standards, refit of existing and old infrastructure, and building of new stormwater systems [25][26][27].

Other human activities also affect peak flood runoff by altering precipitation on land and their runoff into streams [10]. Urban flooding or pluvial flooding is a well-known natural disaster rampant in all developing countries and recent major cities [28][29]. Philippines' major cities, such as Metro Manila, Cebu City and other nearby cities are face with many environmental issues due to their fast urbanization rate growth. Metro Manila accounts for almost one-third of the entire urban population, according to the 2010 census. They account for over 13% of the Philippines' total population [13].

Outside Metro Manila, Philippines, in the Mindanao area, the growing population of Surigao City, and its barangays pose a threat to urban flooding or pluvial flooding. Surigao City, Philippines, urban barangays along Kinabutan River, Surigao City's Barangay Washington, experienced a devastating flooding year 2021 where a flash flood occurred due to heavy rain and typhoons and have always been susceptible to floods. The rivers in the city can no longer handle the level of rains, necessitating the execution of flood control projects such as river expansion and depth. These cause alarm to its residents as it creates drawbacks on their livelihood and passages. Drainage systems are already available in those areas. Yet, the same scenarios are being experienced during rainy seasons, such as the overflowing of murky waters that reach the streets and sometimes houses. [30][31][32].

The Low Impact Development (LID) technique will aid the barangays in Surigao City, Philippines with their stormwater management. The appropriate LID technique, which uses a rain barrel that is needed in that area, will be analyzed on its effectiveness and efficiency, as it will serve as support to existing catchments. With that being considered, the researcher of this study will provide their utmost effort for the betterment of the community as this will help in managing stormwater runoffs that contribute to floods.

II. METHODS

Research Design

The applied research design with model representation was used in this study. In Barangay Washington, Surigao City, Philippines, the researcher will determine the best site for the Rain Barrel facilities in the contributing catchments of the watershed. The research design chosen is acceptable since the study's goal is to assess the reduction in runoff peak and volume of the selected LID approach, which is the deployment of rain barrels in various sub-catchments to lower the risk of flooding in the watershed.

Research Environment

The research study was conducted in Kaskag, Barangay Washington, Surigao City, Philippines. Kaskag has a lower elevation and low-lying terrain. Flooding is a risk in some low-lying locations. During typhoons and protracted rain events, which are common in the area, large amounts of water are forecasted. Figure 1 below shows th site development plan.

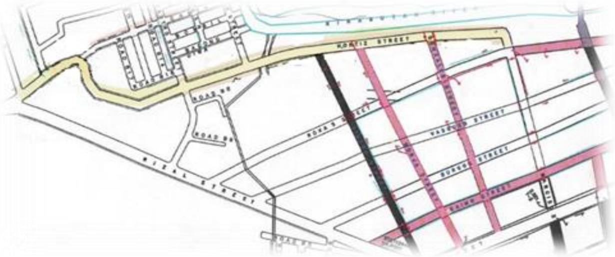

Fig. 1. Site Development Plan

The land use in this study will be classified as impermeable and pervious, with impervious representing the portion of the catchment with no commercial or residential buildings and pervious representing the area with vegetation. The catchment area of Barangay Washington is depicted in Figure 2, and the portion of the study area with higher elevations has greater pervious land than the lower portion. Because these places have substantially lower altitudes and flatter topography, the lower portion of the catchment that will be calculated is more flood-prone, especially in the areas near the outfall.

Figure 3 shows how the Digital Elevation Model of a section of Surigao City, Philippines, was utilized to generate elevation on the intended research area. The DEM was also used to determine the research area's slope, as shown in Figure 4. The DEM is also an elevation surface that depicts the naked earth and is related to a common vertical datum to show topographical features.

Fig. 2. Catchment Area of Barangay Washington

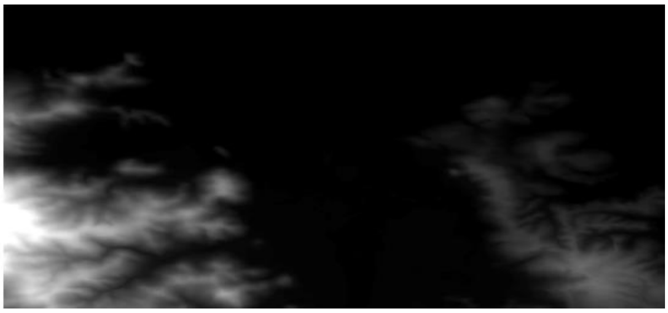

Fig. 3. Digital Elevation Model of the Study Area

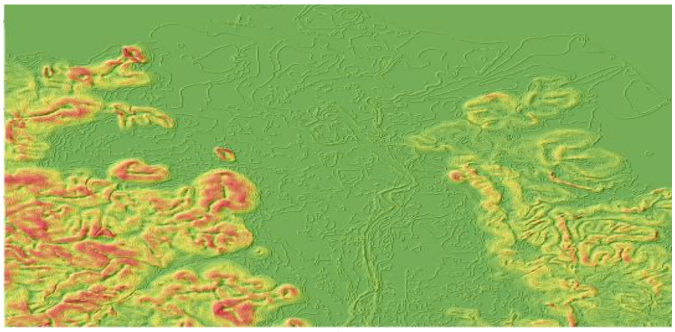

Fig. 4. Generated Slope of Surigao City, Philippines

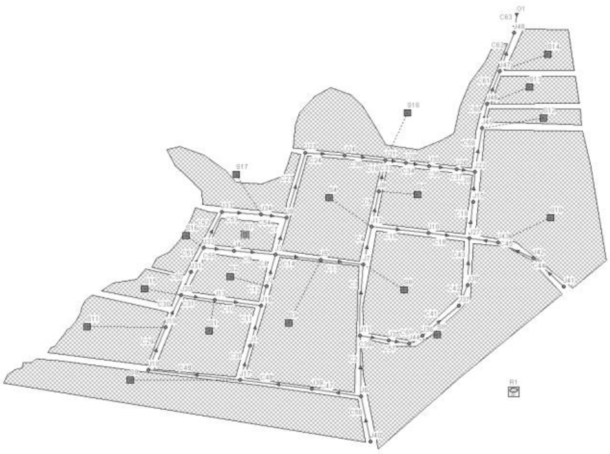

Fig. 5. Sub-catchment Representation of the Area

Figure 5 depicts the study area's sub-catchment representation; the study area was separated into distinct sub-catchments with their estimated area borders, slope, and drainage system layout.

Research Instruments

ArcGIS, a geospatial software with components such as ArcMap and ArcTool Box, which allowed the researcher to employ Data Management Tools, Spatial Analysis Tools, and Zonal Statistics, was used to aid in the creation and interpretation of the catchment area's geospatial data. The EPA's Storm Water Management Model (SWMM) was used to map out the various sub-catchments, input the existing drainage system represented by conduits and junctions, and import the study area's observed rainfall data. The SWMM is a dynamic hydrology-hydraulic water quality simulation model that can simulate runoff quantity and quality in a single event or over time from most urban areas. Finally, the program allows the researcher to select which surface runoff modeling method and infiltration loss method are suited for the study area's investigation.

Research Procedure

Letters were sent to several offices requesting specific data before administering the study instrument, including the Department of Engineering and Public Works, the Department of Public Works and Highways, and the Philippine Administration for Atmospheric, Geophysical, and Astronomical Services – Surigao Del Norte Station in Caraga Region Philippines. The data requested was the Surigao City Engineering Office's topographical map and existing drainage plan for Barangay Washington, as well as rainfall data from PAGASA-Surigao Del Norte station. Prior to that, the Surigao City boundaries were drawn out, and a shapefile was sent to LiPAD with a request for LIDAR data, which was used to create a Digital Elevation Model (DEM). The topographical surface was represented using the Digital Elevation Model. The researcher was able to explore its GIS records using ArcMap to obtain the slope, elevation, and area of the research environment. Following that, the gathered and acquired data were used as inputs for the hydrologic modeling software SWMM utilizing ArcGIS tools.

The spatial diversity in all of these processes is achieved by splitting the research area into a collection of smaller, homogeneous sub-catchment areas using the data gathered in SWMM. Each of the areas contains its own fraction of pervious and impervious sub-areas. The percentage of imperviousness was determined by doing a spatial recognition of the total impervious areas in each sub-catchment, and the roofline was the basis for the dimension of the buildings, which later on was calculated by using the tools available in ArcGIS. Overland flow can be routed between sub-areas or between entry points of a drainage system. The drainage line was then inputted to the system represented as conjunctions and conduits, wherein the dimensions used were in reference to the obtained existing drainage plan of the study area.

The researcher used a model simulation to simulate the post- and pre-LID application scenarios under the same settings in this investigation. The rain barrels were installed using SWMM's LID use editor and were placed in various parts of each sub-catchment, where they were judged to be suitable for flood mitigation. The size per unit area of the rain barrels utilized was determined by market availability in Surigao City, Philippines (a 200-liter capacity cylindrical plastic container galvanized iron container). SWWM assumes that each LID facility will handle a different fraction of the runoff from the sub-portions catchments without a LID facility, meaning that the facilities will be operational at the same time. During a simulation period, the SWMM records the amount of runoff generated in each sub-catchment, as well as the flow rate and flow depth.

III. Results and Discussion

The data presented below pertains to the contribution of each sub-catchment and the effects prior to the application of a Low Impact Development technique, which is the application of rain barrels, for the interpretation and analysis of the effectiveness and efficiency of the use of a Low Impact Development technique, which is the application of rain barrels. The information was gathered through a software simulation. The reduction in the quantity of total runoff volume that reached the outfall post, and pre-LID installation is presented in table 1 to clearly perceive the success of LID application to the entire system. The O1 in the tables denotes the total volume of runoff received by the outfall from all sub-catchments. After the application of LID, the overall runoff volume decreased by 5.73 percent.

TABLE 1. Summary of Outfall data without LID (data obtained from simulation)

Outfall Node	Flow Freq Pcnt	Avg Flow CMS	Max Flow CMS	Total Volume 10^6 liters
O1	3.31	0.395	0.458	37.912
System	3.31	0.395	0.458	37.912

TABLE 2. Summary of Outfall data with LID (data obtained from simulation)

Outfall Node	Flow Freq Pcnt	Avg Flow CMS	Max Flow CMS	Total Volume 10^6 liters
O1	3.31	0.374	0.431	35.738
System	3.31	0.374	0.431	35.738

TABLE 3. Sub-Catchment Runoff Summary without LID (data obtained from simulation)

Sub-catchment	Total Precip mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 liters	Peak Runoff CMS	Runoff Coeff
S1	256.56	10.05	246.58	0.91	0.01	0.961
S2	256.56	10.09	246.53	0.66	0.01	0.961
S3	256.56	9.84	246.79	1.35	0.02	0.962
S4	256.56	12.54	244.08	1.27	0.02	0.951
S5	256.56	16.35	240.27	1.00	0.01	0.936
S6	256.56	12.65	243.95	1.10	0.01	0.951
S7	256.56	12.55	244.07	0.57	0.01	0.951
S8	256.56	18.73	237.85	4.40	0.05	0.927
S9	256.56	12.76	243.80	3.67	0.04	0.950
S10	256.56	6.87	249.73	6.27	0.07	0.973
S11	256.56	12.12	244.49	1.26	0.02	0.953
S12	256.56	19.74	243.85	2.02	0.02	0.923
S13	256.56	12.10	244.51	1.55	0.02	0.953
S14	256.56	12.08	244.53	2.07	0.02	0.953
S15	256.56	38.68	217.87	1.12	0.01	0.849
S16	256.56	9.91	246.71	0.68	0.01	0.962
S17	256.56	12.47	244.13	2.40	0.03	0.952
S18	256.56	16.62	239.97	5.46	0.07	0.935

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The data acquired following the sub-catchment simulation is presented in tables 3 and 4 below. There were declines (in mm of total runoff) of 6.991 percent in sub-catchment 1 and 15.31 percent in sub-catchment 2 following the use of LID. Sub-catchments 3 and 4 both saw decreases in total run-off volume of 10.24 percent and 10.64 percent, respectively. The LID facilities significantly reduced overall runoff volume by 8.03 percent in sub-catchment 5. In sub-catchment 6, total runoff volume decreased by 8.99 percent. In the sub-catchment, the overall runoff volume was reduced by 10.88 percent. Sub-catchments 8, 9, and 10 saw 2.65 percent, 4.1 percent, and 3.51 percent decreases, respectively. The decreases were 9.51 percent, 8.47 percent, 10.89 percent, 5.81 percent, and 9.58 percent in sub-catchments 11, 12, 13, 14, and 15. Finally, decreases of 10.76 percent, 5.005 percent, and 2.59 percent were reported in sub-catchments 16, 17, and 18. Sub-catchment 2 has the largest decrease in runoff volume, whereas sub-catchment 18 has the smallest decrease.

TABLE 4. Sub-Catchment Runoff Summary with LID (data obtained from simulation)

Sub-catchment	Total Precip mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 liters	Peak Runoff CMS	Runoff Coeff
S1	256.56	9.35	229.34	0.85	0.01	0.894
S2	256.56	8.54	208.78	0.56	0.01	0.814
S3	256.56	8.83	221.51	1.21	0.02	0.863
S4	256.56	11.20	218.09	1.14	0.02	0.850
S5	256.56	15.03	220.91	0.92	0.01	0.861
S6	256.56	11.52	222.00	1.00	0.01	0.865
S7	256.56	10.98	213.44	0.50	0.01	0.832
S8	256.56	18.23	231.53	4.29	0.05	0.902
S9	256.56	12.76	233.80	3.67	0.04	0.950
S10	256.56	6.62	240.91	6.04	0.07	0.939
S11	256.56	10.96	221.22	1.14	0.02	0.862
S12	256.56	18.60	223.18	1.90	0.02	0.870
S13	256.56	10.78	217.87	1.38	0.02	0.849
S14	256.56	11.38	230.32	1.95	0.02	0.898
S15	256.56	34.92	196.99	1.01	0.01	0.768
S16	256.56	8.84	220.16	0.60	0.01	0.858
S17	256.56	11.84	231.91	2.28	0.03	0.904
S18	256.56	16.19	233.75	5.32	0.06	0.911

Table 5 shows that in terms of its run-off peak, sub-catchment 1 has a 6.94 percent decline from 0.2206 m^3/s to 0.2053 m^3/s, and the same is true for the remainder of the sub-catchments. Sub-catchment 2 had the biggest drop in run-off peak at 15.28 percent, while sub-catchment 3 had a reduction of 10.24 percent, and sub-catchment 4 had a reduction of 10.61 percent. There was also a 8.125 percent decrease in sub-catchment 5. The run-off peak in sub-catchment 6 was also reduced by 9.05 percent. In terms of runoff peak, the reduction in sub-catchment 7 was 12.50 percent. Sub-catchments 8, 9, and 10 saw a 2.7 percent, 4.84 percent, and 3.49 percent reduction in run-off peak, respectively. Sub-catchments 11, 12, 13, 14, and 15 saw a 9.54 percent, 5.73 percent, 10.91 percent, 5.77 percent, and 9.54 percent decrease in run-off peak, respectively. Finally, runoff peak was reduced by 10.80 percent, 5.05 percent, and 2.55 percent in sub-catchments 16, 17, and 18. Sub-catchment 18 had the smallest drop in run-off peak of all the sub-catchments studied.

TABLE 5. Run-off Peak Summary (data obtained from simulation)

Sub-catchment	Run-off Peak (CMS)	
	Pre-LID Scenario	Post-LID Scenario
S1	0.2206	0.2053
S2	0.2107	0.1785
S3	0.1493	0.1340
S4	0.1065	0.0952
S5	0.0960	0.0882
S6	0.1844	0.1677
S7	0.1672	0.1463
S8	0.5879	0.5720
S9	0.2066	0.1966
S10	0.2097	0.2024
S11	0.1100	0.0995
S12	0.3817	0.3598
S13	0.9127	0.8131
S14	0.7426	0.6997
S15	0.8965	0.8109
S16	0.3451	0.3078
S17	0.2533	0.2405
S18	0.3331	0.3246

IV. CONCLUSION

As a result of the findings, it is concluded that Rain Barrels can be employed as a Low Impact Development (LID) strategy to assist the current drainage system by reducing the quantity of runoff per sub-catchment. However, its capacity falls short in minimizing the likelihood of flooding in the Kaskag, Barangay Washington, Surigao City, Philippines basin, particularly during intense thunderstorms or persistent heavy rains that can cause large flood occurrences.

4.2 Recommendation

The following concerns were given as reccomendatons based on the study' findings and conclusions:

4.2.1. Another avenue for future research should determine the feasibility and effectiveness of the low impact development techniques to help with the flooding susch as green roofs, permeable paving, rain gardens, and infiltration trenches, bioretention gardens, bioswales, and rain harvesting.

4.2.2. Additional simulations should be conducted focusing on single rainfall events and rainfall events with a shorter return period to see whether LID can minimize the likelihood of floods.

4.2.3. To proposed to the Local Government of Surigao City, Philippines to address the flooding problem in the area while also helping to save water, the government should enact a new and enhanced cost-effective rain water city ordinances.

4.2.4. To encourage and urge the Local Government Unit of Surigao City, Philippines to consider the problem of stagnant and overflowing murky waters that reach the streets and dwellings which has been discovered in the existing drainage system. The Philippines Government Agency and the Department of Public Works and Highways should improve drainage system design in the future to manage a greater volume of surface run-off and diminish storm-water pools in the area.

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