RAINWATER RETENTION SITE ASSESSMENT FOR URBAN FLOOD RISK REDUCTION AND FLOOD DEFENCE IN MANDAUE CITY, PHILIPPINES

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KEY WORDS: Rainwater Retention, Geographic Information System (GIS), Rainwater Harvesting, Flood Interventions, Surface Runoff, Flood Management

ABSTRACT: This study utilized a geospatial approach to identify suitable sites for rainwater retention areas in Mandaue City, a highly urbanized city in Cebu, Philippines. Based on the integrated use of remote sensing and Geographic Information System (GIS), ideal sites for rainwater retention were produced to divert surface water runoff from flooding the streets and obstructing traffic. Ideally, the chosen sites should have low infiltration capacity and be within open spaces. For the hydrological planning of the study, we considered the amount of surface runoff, elevation, soil characteristics, land use, and present drainage status of the study area. The Digital Elevation Model (DEM) derived from LiDAR technology is used to obtain the slope raster and generate small streams. Land cover and curve number (CN) of the area were used to compute the surface runoff. The soil textures were converted based on their infiltration rate and runoff potential. Finally, the weighted overlay tool in GIS created a layer identifying potential areas for rainwater retention sites. The findings indicate that 54.8% of the research area was ideal for water harvesting, with open land areas making up 2.3% of the best locations. In addition, a major portion of the appropriate locations lies in clay loam soils and within 0-25 meters in elevation. These results will hugely benefit policymakers and urban planners in helping create solutions to the city's flooding problem and the looming water crisis.

1. INTRODUCTION

The increasing number of extreme rainfall events resulting in heavy precipitation is causing – and will continue to cause – increased urban flooding unless steps are taken to mitigate their effects. Urban flooding is a growing source of significant economic loss, social disruption, and environmental hazards in a highly urbanized city like Mandaue in Metropolitan Cebu, Philippines. Nestled in the metro, the city is also a major hub for trade, industry, tourism, and education. As a result, it has experienced consistent growth and development at a rapid rate of urbanization. The persistent flooding of the metropolitan area during heavy rains, however, has recently become a serious issue that demands immediate attention (Ramalho, 2019).

Unfortunately, Mandaue City rests in the downstream drainage basin amalgamating the water runoff from the neighboring towns upstream and from the tributaries of the river nestled in adjacent towns. In addition, the city faces serious dilemmas like impaired and flawed drainage systems as of 2012 documents, impassable roads during flood events and over 3,500 households located in flood-prone areas labeled as "danger zones" (Mahoney & Klitgaard, 2019).

Previous drainage studies were conducted to help the city overcome its flooding woes through drainage master plans in 1983, 1995 and 2005. These resulted in identifying critical flood-prone areas in Mandaue city and its neighboring towns as well as outlined recommendations for drainage systems for the affected areas. Unfortunately, none of the recommendations were attended to and no guidelines for regulating run-off were implemented, hence the flooding problem was exacerbated even further (Jaque et al, 2017). Rapid land development, coupled with aging and inadequate infrastructure, increased the amount of storm runoff that was directed into already overburdened drainage systems, resulting in pockets of flooding in underdeveloped and vulnerable neighborhoods.

Today, the flooding issue has reached a critical and alarming level, resulting in loss and damage to property, loss of man-hours as residents' mobility is disrupted, and increased fuel consumption brought on by heavy traffic during heavy rains (Jaque et al., 2017). Since many of the urban wastewater and stormwater systems that serve as the backbone of urban flood mitigation are insufficient or in poor condition, solutions require strong support from various government offices, units, and cooperation from all towns involved. Unfortunately, the necessary human and financial resources to address urban flooding are not always available at the required levels. Urban flooding challenges have been difficult to address in many communities due to a lack of funding, a division of duties among various departments, and a reluctance to deal with the effects of more frequent and intense precipitation and climate change (Galloway et al., 2018).

Although constructing sewage systems is a conventional method of treating urban flooding, alternative approaches must be developed due to their high cost in the light of the present financial crisis, particularly in local governments (Ishimatsu, 2016). Rainwater retention cells, a type of low-impact development, have recently been recommended in Europe and North America as a best management practice for stormwater runoff treatment (Dietz and Clausen 2005; Davis 2007; Li et al. 2009; Kazemi et al. 2011; Autixier et al. 2014; Shuster et al. 2017).

Urban waterlogging is caused by impervious surface coverage and increasing rainfall intensity due to climate change and variability, which means storm water cannot easily infiltrate the ground and excessive surface runoff causes urban flooding. Since there are fewer green spaces in highly urbanized cities like Mandaue, resulting in a lack of important rainwater infiltration in the city, necessitating the reduction of impervious area and increased coverage of green spaces (Li et al, 2018; Zhang et al, 2020). By using design strategies to produce a functionally equivalent hydrologic landscape, low-impact developments like rainwater retention sites can preserve or replicate the hydrologic regimes that existed before they were developed. Such development is based on careful site design for stormwater control at the source through the use of rain gardens/bioretention technology, green roofs, swales/bioswales, and other resources (Zhang et al, 2020). A rain garden is a shallow land depression planted with trees and/or shrubs and mulched with bark or ground cover. Such gardens are recommended as part of best management practice for urban storm runoff because of their functions of reducing surface runoff, recharging groundwater, and retaining contaminants (Zhang et al, 2020).

In this study, a geospatial approach has been utilized to identify suitable sites for rainwater retention areas in Mandaue City, a highly urbanized city in Cebu, Philippines. Based on an integrated use of remote sensing and Geographic Information System (GIS), ideal sites for rainwater retention are produced in order to divert surface water runoff from flooding the streets and obstructing the traffic. Ideally, the chosen sites should have high infiltration capacity and be located in open spaces.

2. STUDY AREA

Mandaue City, Cebu, (10.3321° N and 123.9357° E) is a high-income urbanized city in the Philippines. It is part of the Cebu Metropolitan area located in the Central-Eastern coastal region of Cebu, as shown in Figure 1, and is the second-largest city in the province. Historically, the city was the center for trade with other countries to the locals in the province and presently provides social, recreational, and economic opportunities to locals throughout Cebu and its neighboring provinces. The city has one major waterway, the downstream portion of the Butuanon river, and also serves as a catchment area for a number of rivers and streams from a neighboring heavily populated city (Cortes et al., 2022). Due to its proximity to the equator, the country only experiences rainy and sunny seasons characterized by the Coronas climate type 3 classification with the rainy season lasting from June to November. Out of that, the city has an average annual precipitation of 1,570 millimeters (JICA, 2010).

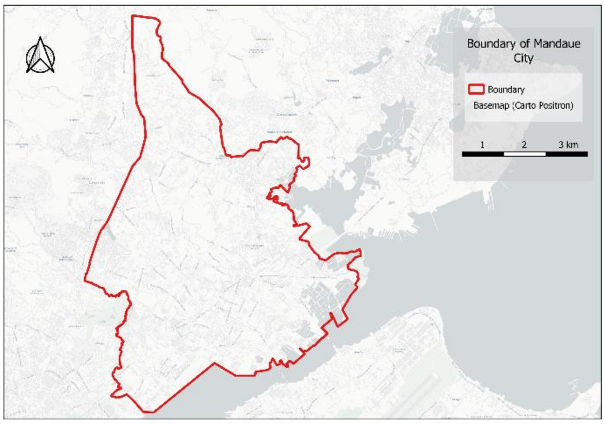

Figure 1. Mandaue City, in Cebu Province

3. MATERIALS AND METHODS

3.1. Datasets

The basic datasets used in this study include; the LiDAR-derived Digital Elevation Model (DEM), land cover data from the National Mapping and Resource Information Authority (NAMRIA) as well as soil type and land use data from the study area's City Planning Office.

3.2. Data Processing

3.2.1. Slope and Drainage: The available DEM data covers a part of the Cebu province which was clipped to extract only the portion of the study area. Figure 2 shows the clipped elevation raster, highlighting the site's low elevation interspersed with multiple river networks and streams. Consequently, the slope map was created using this DEM and extracted through the Slope tool in the ArcGIS Spatial Analyst environment.

In order to properly delineate basins and streams, the Hydrologic Engineering Center's Geospatial Hydrologic Modeling Extension (HEC-geoHMS) toolbar was utilized for DEM reconditioning and fill sinks. DEM reconditioning is the process of adjusting the DEM so that elevations direct drainage towards the vector information on stream position, and sinks should be filled to ensure proper delineation of basins and streams.

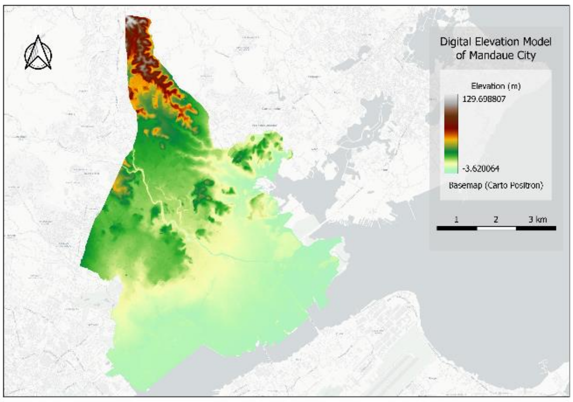

Figure 2. Digital elevation model of Mandaue City

3.2.2. Soil: The soil classes for the study were reclassified based on its texture, runoff and infiltration rate. It was then distributed into its corresponding Hydrologic Soil Group (HSG) with the SCS soil scientists' reports serving as the basis for defining the HSG class type (USDA, 1986).

The following information on soil groups (A, B, C, and D), based on the USDA (2007) paper describes Group A as soils that have high infiltration rate and low runoff. These soils consist of deep, well to excessively drained sands or gravels. Examples of these types of soils are sand, loamy sand, or sandy loam soils. Group B soils are those that have moderate infiltration rate. This group consists chiefly of deep well drained soils with a moderately fine to moderately coarse texture and a moderate rate of water transmission this includes loam, silt loam, and other silt soils. Group C soils have a slow infiltration rate. This group consists of soils with a layer that impedes the downward movement of water or fine textured soils and a slow rate of water transmission. Lastly, Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils.

3.2.3 Land Cover: Along with NAMRIA's 2015 land cover, open spaces and parks from the city's 2021 land use plan were included in the classification. Inquiries were conducted with the City Planning Office regarding the current usage of their classified open areas and parks' current condition and situation. According to the established discussions, open spaces and parks are the greatest places for rerouting flood water from the streets

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because, in addition to causing the least amount of property damage, the soil and trees can absorb and store the runoff water.

3.2.4. Surface Runoff: The surface runoff variable for this study was produced with the use of the 'Generate CN Grid' tool from HEC-GeoHMS toolbar. This method is used to compute for the surface runoff, after consideration of the soil's infiltration rate. In order for the tool to function, soil land cover data, and the curne number lookup of soil data were required.

Raster	% Influence	Scale
Runoff Depth	35	3; 4; 8; 9; 9
Slope	24	9; 7; 6; 5; 3; 1
Soil Texture	16	9; 7; 8; 3
Drainage Density	10	4; 7; 9; 8
Land use/cover	6	4; 6;4; 7; 9; 8; 1
Lineament Density	9	9; 7; 5; 3

Table 1. Weighted overlay analysis and % influence of parameters by Mugo et al. (2019)

3.2.5. Weighted Overlay Analysis: In order to come up with the suitable areas for rainwater retention sites, the prepared datasets were first converted into rasters to become valid parameters for the weighted overlay tool. The weighted overlay tool is used to address multi-criteria issues including site selection and suitability models. In the suitability analysis, a weight is given to each raster layer. Values in the rasters were then reclassified to a common suitability scale. Consequently, the suitability value is derived by overlaying raster layers, dividing each raster cell's suitability value by its layer weight, and summing up the results.

For the selection of appropriate rainwater retention sites, not all parameters were equally significant. As a result, various weights for each criteria were determined. These criterions used for the study are tabularized in table 2. The slope dataset was one of the key criterion used because different slope classes affect runoff volume and infiltration, with the type of slope having a significant impact on rainwater retention (Munyao, 2010). Land cover was also taken into account, with open spaces and parks regarded to be suitable locations for retention sites while built-up and agriculturally productive regions were deemed unfit. Despite the fact that the majority of pertinent studies take the density of lineaments into account when performing their analyses and Maina and Raude (2016) highlighting its significance because these could significantly affect the retention whether the runoff is for surface storage or ground water recharge purposes, no lineaments were found inside the study region. As seen Figure 3, showing the existing lineaments for the province provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), no lineaments are located within the study area. Table 1 illustrates the influences applied to each factor based on a previous study by Mugo et al. (2019). Given that lineaments are not taken into account in this study, the distribution of the original influence on other factors can be seen in Table 2.

Figure 3. Lineaments near Mandaue City

Criteria	*Influence (%)*
RUNOFF MODEL	37
SLOPE	26
SOIL GROUP	18
DRAINAGE	12
LAND COVER	7

Table 2. Updated criteria for weighted overlay analysis and their corresponding influence

4. RESULTS AND DISCUSSIONS

4.1. Surface Runoff

The most important consideration when choosing the best locations for rainwater retention is surface runoff. The distribution of surface runoff across the city is shown in Figure 4. For specific soil and land use/ land cover, the runoff parameters are defined by its corresponding curve number (CN). CN is the estimate of the precipitation excess of soil cover, land use and antecedent moisture. This value is hereby used as an input factor in the service runoff equation.

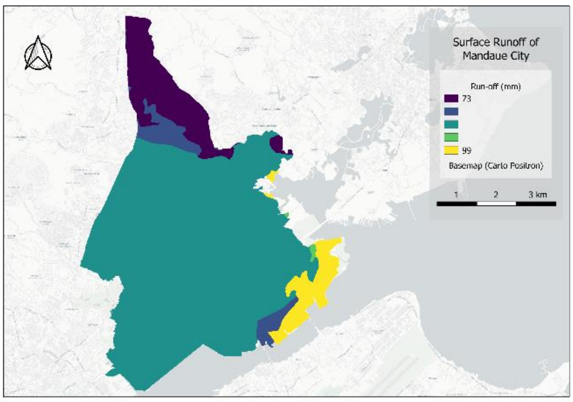

Figure 4. Surface Runoff map of Mandaue City, Cebu

4.2. Slope

The slope classification map in Figure 5 shows that the majority of the area belongs within an elevation between 0 – 25 meters. Part of these slope classes belongs to level (< 3%), undulating (3-8%), and rolling (8-18%) slope classification. This aforementioned group comprises 73.87% of the area, which proves that Mandaue City is indeed a low-lying area and demonstrates why it is a natural catchment basin. The hilly to mountainous classification, which is 26.13% of the area, completes the slope classification of the city.

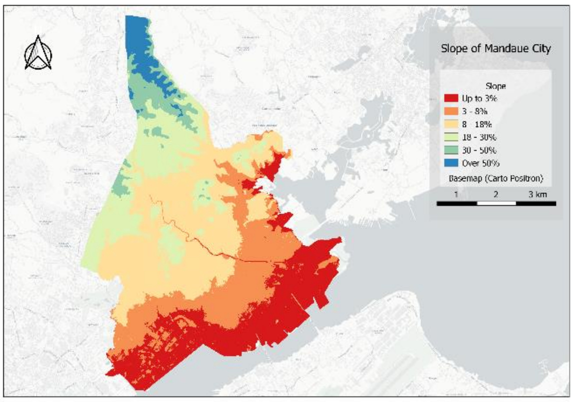

Figure 5. Slope map of Mandaue City, Cebu

4.3. Drainage

The stream network, in Figure 6, was used to evaluate the delineation density produced in the drainage density map in Figure 7. A large portion of the south to southwest region of the study area has high drainage density, which is a probable cause for the area to generate a lot of runoff. The low density regions are mostly located in the south to southeastern portions of the city.

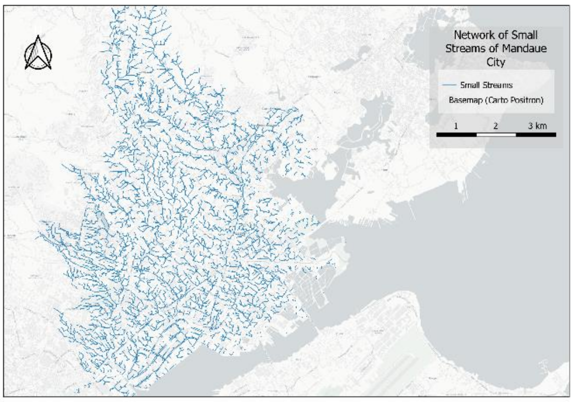

Figure 6. Network of small streams

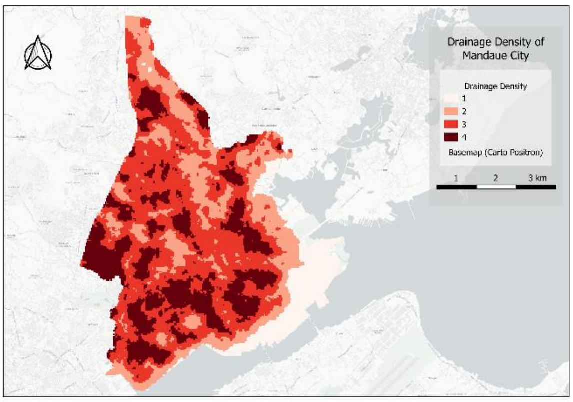

Figure 7. Drainage density map of Mandaue City, Cebu

4.4. Soil Group

Mandaue's soil classification consists of Faraon clays, Hydrosols, and Mandawe clay loams as seen in Figure 8. Clay loam is a mixture that contains more clay than other types of soil, which embodies 77.32% of the study area. For Mandaue City's hydrologic soil classification, Hydrosols are in Group A, Mandawe Clay Loams are in Group C, and Faraon Clays are in Group D.

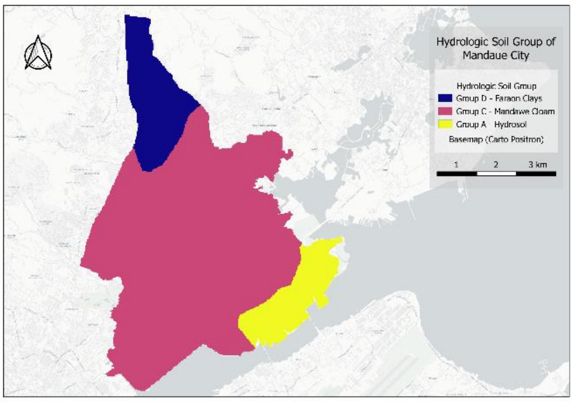

Figure 8. Soil group map of Mandaue City, Cebu

4.5. Land Cover

Mandaue City is a densely populated city, therefore the built-up area accounts for 88.54% of the total land area. Open areas for the land use/land cover raster consists of 3.58% of the region. Since they cause minor environmental harm, these open spaces have enormous potential as places to divert rainwater and potential flood waters. Other land use classes found in the city are brushland, fishpond, grassland, inland water, mangrove forest, and perennial crop as presented in Figure 9.

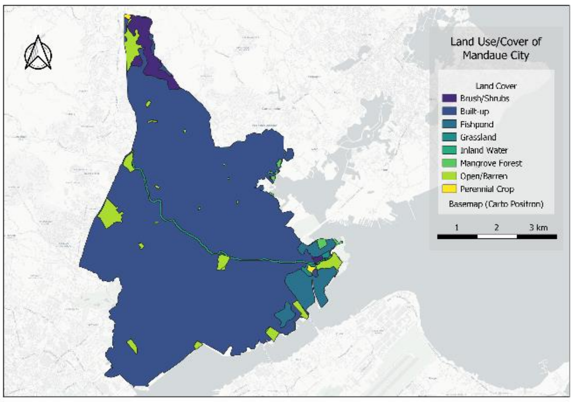

Figure 9. Land cover map of Mandaue City

4.6. Rainwater Retention Suitability Map

The study area is divided into areas that are suitable for rainwater retention sites. This is achieved by classifying the ranked factors into most suitable to least suitable areas as shown in Figure 10. Out of the overall study region, 54.8% is thought to be the most suitable places for rainwater retention, of that figure 2.3% is made up of open land and park areas which were previously determined by the city planning office to be the best locations for rainwater retention cells. Additionally, clay loam soils are found in the majority of suitable regions which are mostly found on low-elevation slopes between 0 - 25 meters. Only 0.72% of the study area are considered as least suitable.

Visible in Figure 10, we can see that most of the suitable areas are in the coastal plain of the study area. Areas which are most suitable for rainwater retention, visualized as dark green shades, can be assessed to be rain gardens and other rainwater retention cells based on the land area and availability. Pertinent road and street networks located in these green areas can also be evaluated for the creation of bioswales in their inner islands and adjacent strips.

Figure 11 shows our rainwater suitability map interspersed with orthophotos of the area to show the actual vegetation cover and land area of some of the most suitable sites evaluated by the study. From these, we can see the huge potential of these sites to be converted into rainwater retention cells like a possible rain garden, although management interventions like these would yet to be discussed with local agencies and government units for feasibility and viability.

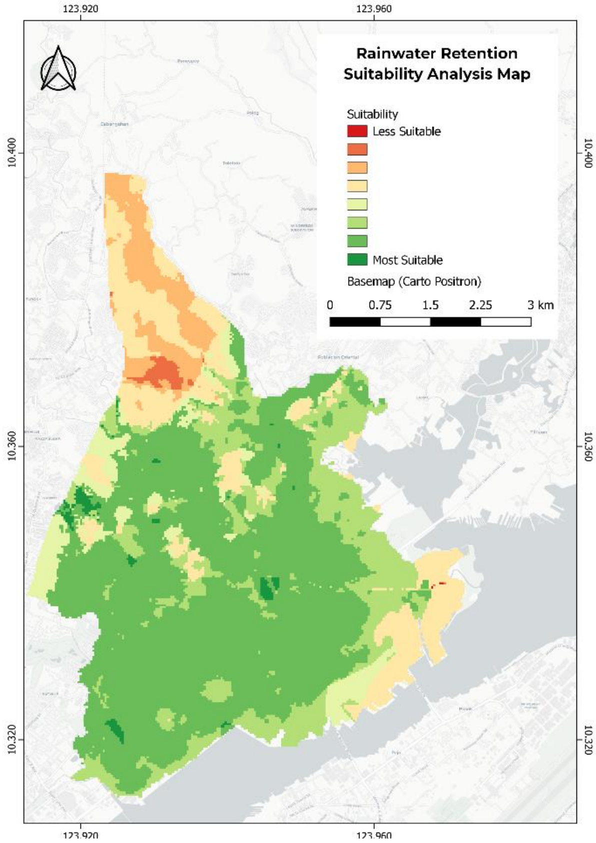

Figure 10. Rainwater retention suitability

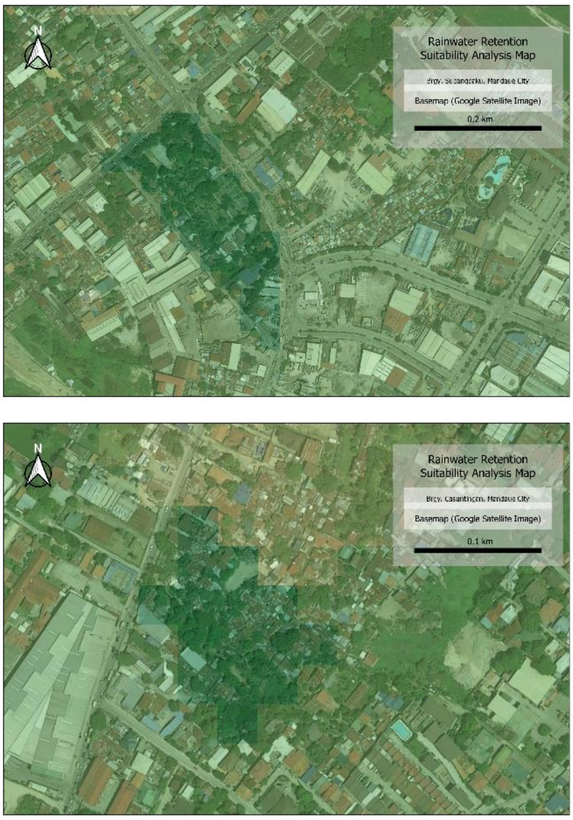

Figure 11. Sample suitable areas

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5. CONCLUSION AND RECOMMENDATION

Urban areas, like Mandaue City, face serious concerns about flooding from urbanization and climate change. Urbanization increases the amount of impervious surface in a given area, which often slows down infiltration time and subsequently, raises the danger of flooding. This study and similar ones show that the use of remote sensing and GIS is necessary for planning and managing water resources, particularly in developing countries like the Philippines (Sayl et al., 2020). This study has shown that minor resources can be used to produce a rainwater retention suitability map and come up with ideal sites to divert surface water runoff from flooding the streets and obstructing traffic during rain events. The study has determined 54.8% of the study area as ideal for rainwater harvesting, with open land areas making up 2.3% of the best locations.

In addition, a major portion of the appropriate locations lies in clay loam soils, which has low infiltration capacity and within 0-25 meters in elevation. These results will hugely benefit policymakers and urban planners in helping create solutions to the city's flooding problem and the looming water crisis.

The result of this study will hugely benefit policymakers and urban planners from the Local Government Unit in their attempts to reduce the flooding in the city by determining and selecting the most appropriate areas to redirect flood and sites that will retain the flood water. Through efforts in redirecting the flood water to these sites, damages to properties and traffic in the streets will be minimized, and the water stored in these open areas and parks will be beneficial to the soil and the plants in the vicinity.

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