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Original Article

Photogrammetric Assessment of Urban Rainwater Catchment Systems in Cebu City, Philippines: Implications for Water Resource Optimization and Flood Mitigation

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Abstract

Background: *In many developed cities, freshwater scarcity and recurrent flooding are significant concerns, particularly in rapidly urbanizing areas. Cebu City, a major urban center in Cebu, Philippines, is facing similar challenges. Literature highlights the value of integrated water management systems, including rainwater harvesting (RWH), in responding to these overlapping issues.*

Methods: *This study examines the nuances of urban flooding in two flood-prone locations in Cebu City, assesses the applicability of RWH as an integrated strategy to mitigate floods. Photogrammetry techniques were employed to collect spatial and ground information from satellite images and geohazard maps, facilitating the identification of flood occurrences and the estimation of potential rainwater capture volumes.*

Results: *Findings reveal that only a small fraction of catchment areas remains unpaved, limiting natural infiltration. Calculations show that approximately 1.45 million cubic meters of floodwater accumulate annually across the two study sites. To address this, the study suggests a large-capacity underground rainwater detention tank under the specific streets to capture runoff without disrupting urban space.*

Conclusion: *The results demonstrate that integrating RWH into flood control systems offers a practical and resilient approach to mitigating floods while supporting sustainable water resource management in dense urban environments.*

Keywords

rainwater harvesting, urban flooding, photogrammetric analysis, integrated water management, SDG 6, sustainability, Cebu City, landslide and flood susceptibility map of Cebu, Geohazard Maps, GIS Map

INTRODUCTION

In many developed cities, the issues of water scarcity and frequent flooding are common occurrences. Often, these are a direct result of rapid concretization and high population density. The ensuing competition for limited resources drives severe shortages, a problem that is especially critical for developing countries burdened by inadequate infrastructure (Heidari et al., 2021; McDonald et al., 2014; Ssekyanzi et al., 2024; Tzanakakis et al., 2020). Flooding is a persistent problem that is exacerbated by climate change. This phenomenon leads to knee-deep waters in several city locations (Erram, 2024b; Espina, 2016; Seblos, 2024).

The interplay between water scarcity and flooding underscores the need for integrated water management strategies that address both scarcity and excess water, thereby ensuring the sustainable use of resources (Silva, 2023; Ssekyanzi et al., 2024). This study aims to investigate the feasibility of sustainable urban rainwater capture as a means to mitigate flooding and promote sustainable water management in Cebu City.

Water shortage is a serious global issue that creates multiple problems (Klobucista & Robinson, 2023; Salazar & Petralba, 2015; UN-Water, n.d.). Population expansion, climate change, and poor water management all contribute to the problem. Over two billion people in arid and semi-arid regions, accounting for more than 40% of the world's population, face water scarcity issues (Klobucista & Robinson, 2023; Tzanakakis et al., 2020).

Urban water resource management is crucial in addressing the challenges posed by increasing population density and climate change. Management strategies must incorporate both traditional and innovative approaches to enhance resilience and sustainability in urban areas effectively. In Brazil, urban water management practices are evolving to include more sustainable solutions that address water scarcity and flooding, ensuring a reliable water supply for urban populations (Ssekyanzi et al., 2024; Tzanakakis et al., 2020).

Cebu City, known as the "Queen City of the South," is located in the Central Visayas region of the Philippine archipelago, specifically in Region 7. It has become a prime destination for those seeking a better quality of life and promising investment opportunities (Olinares, 2024). Cebu City has a total land area of 315 km^2 (Espina, 2016). A recent study ranked Cebu City 436th among global cities in terms of livability, highlighting its efforts to improve quality-of-life metrics while noting its commitment to environmental sustainability (Erram, 2024a).

Cebu City's increasing urbanization creates significant challenges, including traffic congestion, pollution, and flooding. Despite ongoing efforts to improve its infrastructure and livability, residents continue to face issues related to inadequate drainage systems and water management, particularly during heavy rain seasons. The city's governance is under scrutiny as it seeks to balance development with the pressing need for effective flood management and urban resilience strategies (Erram, 2024b; Verdejo, 2024).

Water is a renewable resource that replenishes itself through precipitation. However, flooding also occurs when rainfall exceeds the ground's absorption capacity, particularly in areas with impermeable surfaces that hinder proper water infiltration (Aqua-Barrier, 2021; Lai, 2023). Strategic management is needed to address water scarcity and reduce susceptibility to flooding. Deploying urban rainwater harvesting systems in highly urbanized and flood-prone locations creates a dual-purpose technology that can reduce floods while increasing the city's clean water supply. These technologies are not new. Several developed and developing countries have used large-scale versions of this concept. Drawing on best practices from around the world and conducting a photogrammetric and spatial analysis in Cebu City's urban area can provide a reliable calculation of the amount of water involved in this kind of project.

Urban Flood Risks and Water Management Approaches

Globally, there is an urgent need for planned action to manage water resources effectively and combat water scarcity. This shift should focus on the fundamental concepts of urban water management, which include interventions in the municipal water cycle. Consider how water is used and reused, and increase the application of natural structures for water and wastewater treatment (Khatri & Vairavamoorthy, 2007). People project that by 2025, one-third of the population in the developing world will face severe water shortages, with significant portions of the population lacking access to safe drinking water and sanitation facilities (UN-Water, n.d.). This scarcity is further compounded by the deterioration of existing infrastructure and the impacts of climate change on water availability (Ssekyanzi et al., 2024; UN-Water, n.d.), and due to the high concentration of people living in these areas (Salazar & Petralba, 2015).

Integrating freshwater management into the flood control systems has become a standard solution among many cities. Part of the strategy on integrated water management is the use of rainwater harvesting (RWH) (Klobucista & Robinson, 2023; Slater, 2019). RWH actively removes rainwater from the streets and stormwater drains, reducing the incidence of flooding. Experts designed these systems to handle varying rainfall intensities, manage storm water, and they are part of a larger infrastructure that promotes sustainable water use in urban environments (Teston et al., 2022).

Some prominent projects include Singapore's nationwide flood monitoring system. It includes RWH components that work in conjunction with other flood management strategies. This system effectively monitors and manages stormwater, providing real-time data to mitigate flooding risks across the city during heavy rainfall and urban flooding (Linkwise Technology, 2015).

The Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur, Malaysia (Stormwater Management and Road Tunnel, n.d.), and the Kasukabe Underground Flood Protection Tank in Saitama, Japan, (Ortiz, 2018; World-Class Underground Discharge Channel, 2013) are mainly built for flood control, but these are good demonstration of how much freshwater exists and how strong is the need to mitigate economic loses cause by the same flood. These large infrastructure projects have shown the significant investment needed for flood mitigation purposes.

Table 1 presents a consolidated synthesis of current literature on the interrelated themes of urban flooding, sustainable water management technologies, and initiatives. The table summarizes the published articles discussing the causes and challenges of urban flooding, the application and limitations of rainwater harvesting systems, the principles of integrated urban water management, and the role of community awareness and engagement in enhancing the effectiveness and sustainability of these interventions.

Together, these insights provide the foundation for understanding the environmental pressures faced by rapidly urbanizing areas, as well as the technical and social strategies proposed to address flood risk and water scarcity. The governance and management of rainwater, methods of water collection, and the role of the community in awareness and participation in water management. This synthesized literature serves as an analytical backdrop in contextualizing the policy recommendations developed in this study.

Table 1. *Thematic Matrix of Urban Flooding and Water Management Literatures*

Urban Flooding and Water Management	Descriptions	Pros	Cons
Urban Flooding Causes and Challenges	Heavy rains, rapid urbanization, inadequate drainage, and climate change exacerbate flooding in Cebu.	Highlights the urgency of updating infrastructure and incorporating climate resilience	Persistent drainage system neglect and land impermeability worsen flood risk
Rainwater Harvesting (RWH) Systems	Collection of rainwater from rooftops or surface runoff as a sustainable water resource and flood mitigation strategy.	Reduces demand on municipal supply, mitigates runoff and floods, and improves water sustainability	Limited space in urban areas for large-scale systems; upfront costs; maintenance needed
Integrated Urban Water Management	Combining water reuse, natural water treatment, and infrastructure to address scarcity and flooding.	Promotes sustainability and resilience; addresses water scarcity and flooding synergistically	Requires coordinated governance, significant planning, and investment
Community Awareness and Participation	Importance of involving local communities in managing water resources and flood mitigation.	Enhances the sustainability of measures; empowers residents	May require significant outreach efforts; varied community engagement levels

Global Approaches to Urban Flooding and Water Management

The following thematic matrix, Table 2, synthesizes findings from several published studies and documented case applications addressing urban flooding challenges and water management interventions across different global cities. The summarized literature highlights the varying degrees of flood risk, driven by rapid urbanization, heavy rainfall events, and inadequate drainage systems, as well as the corresponding solutions, including large-scale flood diversion tunnels, integrated water management systems, and rainwater harvesting technologies.

By presenting the issues, implemented strategies, associated costs, and observed impacts side by side, this matrix provides a concise comparative overview of how different localities have addressed similar hydrological pressures. This synthesized table serves as a foundational reference for understanding effective models of urban flood mitigation and water resource management.

Table 2. *Matrix of International Urban Flooding and Water Management Case Studies*
(ITS International, 2012; Organisation for Economic Co-operation and Development [OECD], 2009; Organization of American States, n.d.)

City	Flooding, freshwater scarcity Issues	Solutions Implemented	Project Cost (if available)	Before and After Results / Impact
Tokyo, Japan	Severe urban flooding risk from heavy rains and typhoons; limited surface space for drainage.	Metropolitan Area Outer Underground Discharge Channel ("Underground Cathedral"): Massive underground flood control facility storing and diverting excess storm water.	Construction cost approx. USD 2 billion; completed 1993-2006.	Dramatic reduction of surface flooding during typhoons and heavy rain; protects millions of residents; enhances urban resilience.
Singapore	Frequent flash floods are primarily caused by urbanization. Heavy rainfall overwhelms the drainage.	Integrated water management system, including Rainwater Harvesting (RWH), and a nationwide flood monitoring system.	Not explicitly listed; Singapore invests heavily in urban infrastructure and innovative water management.	Significant reduction in flood incidences; improved drainage capacity; effective real-time flood management
Kuala Lumpur, Malaysia	Flooding caused by inadequate drainage and rapid development	Dual-purpose flood tunnel to divert excess storm water	Estimated MYR 1.3 billion (approx. USD 300 million) for tunnel construction	Significant drop in Flooding frequency; the tunnel reduces peak flood levels substantially
Nanjing, China	Urban flash floods occur when flood volumes are high due to the monsoon and the presence of impermeable urban surfaces.	Installation of rainwater harvesting tanks reduces floodwater volumes by up to 57.7%.	Cost details are not specified in the source.	Marked decrease in Flood peak flow by around 57.7%, enhanced urban flood resilience.
Genoa, Italy	Heavy rainfall is causing urban floods on an aging infrastructure.	Rainwater harvesting systems reduce flooding peak flow by 33%.	No specific expenditure mentioned	Achieved 33% average reduction in peak storm water flow, mitigating flood risk.
Sicily, Italy	Regional vulnerability to floods from heavy rainfall.	Urban resilience initiatives focusing on rainwater harvesting and retention measures	Not specified	Improved flood resilience, particularly in flood-sensitive urban areas.
Honduras	Rainwater harvesting is implemented to mitigate flood and water scarcity issues.	Adapted rainwater harvesting installations to local rainfall patterns.	Cost data not noted, but low-tech RWH emphasized.	Adequate supplemental water supply during floods and dry seasons.

METHODS

To provide a better perspective and a point of reference for this study, the researchers reviewed similar urban issues. Aside from persistent flooding and water crises, the criteria include highly urbanized cities, dense populations, and actions taken by cities to solve or mitigate their own crises.

To investigate urban sprawl and development, the researchers used photogrammetry to assess how this urban development affects and contributes to the persistent occurrence of flooding in specific city locations. Photogrammetry is the science and technique of obtaining accurate measurements and spatial information about objects and environments by analyzing high-definition aerial images and digital data from drones and satellites (Aber et al., 2010; AccuPixel Ltd, n.d.; Houck et al., 2018; Puerta et al., 2020).

Photogrammetry enables the recovery of exact surface points to create maps, drawings, or three-dimensional (3D) models. Dating back to the mid-19th century, photogrammetry has been crucial for mapping, including military uses in World War II, and continues to advance with technologies like UAVs (Remote Aerial Surveys, 2017). Its ease of use, low cost, and non-intrusive methods make it valuable in fields like archaeology, architecture, surveying, and underwater studies (Puerta et al., 2020).

The objective of this analysis is to assess the current urban features that significantly impact flooding patterns and to explore possible interventions and strategies to mitigate persistent flooding, while also developing solutions to address the water crisis (Rong et al., 2020; Zazo et al., 2018).

Tools

For proper analysis, the researchers utilized aerial images of Cebu City, along with a geological hazard map and actual pictures of street flooding.

a. Google Maps images, Figure 1, are geospatial images that are a composite of registered imagery of the Earth taken by satellites. These are free, readily available images that can be used in the study. Accordingly, the horizontal positional accuracy of Google Maps may vary significantly in different locations. However, these images are more precise, especially in the urban areas, and have a precision of around 1-5 meters. For remote regions, the image resolution may be as low as 20 meters (Guo et al., 2021).
b. GeoHazard Maps Figure 2: These are readily available GIS maps that were overlaid with the hazard data. These maps can be downloaded from the government websites. GIS is a vital tool for geohazard mapping because it allows for the integration and analysis of multiple types of spatial data, which are then combined to assess risk and create comprehensive maps.
c. Actual ground-level pictures of street flooding.

Variables

Google Maps provides urban development digital data through images, which will serve as the basis for measures such as distance, area of green spaces, and concretized grounds, buildings, gated compounds, and streets.

The Geohazard map provides both the topographical data and the flood hazard map. It demonstrates the different levels of the ground through the color gradients. The deep red oranges are the lowest and most vulnerable locations to flooding, and the lighter-colored edges, which transition to standard map color, represent the higher grounds. Figure 1 shows how the area of the map is measured in Google Maps tools, and Figure 2 shows the general flood flow directions. The dotted red line is the area under study for downtown Cebu City.

Figure 1. *Measuring area in Google Maps*

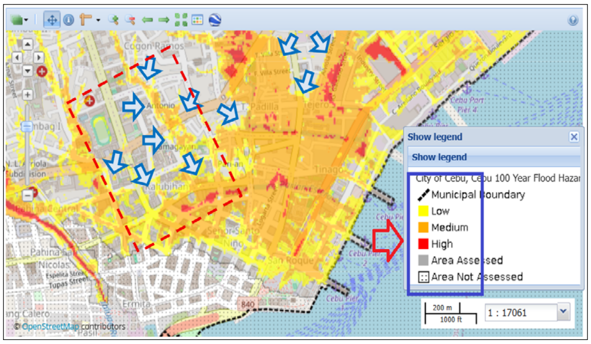

Figure 2. *Determining Flood Directions using Color Graph Intensities*

Data Processing and Parameters

The researchers processed the data through visual inspection, with a particular focus on urban features visible in the images. The other part of the analysis involves quantitative measures of area, distance, and elevations through map metadata, color schemes, and direct map measurements of identified urban features presented in the image.

Items to look for in the analysis include street orientation and buildings, which form barriers and guide surface runoff, helping to explain flood flow dynamics. The other is the urban terrain and elevations of low-lying areas, flood-prone locations, and catchment areas for floodwaters (Mines and Geosciences Bureau Region Office VII, n.d.-a).

Data considerations for the viability of rainwater capture and its location include the directions and locations of runoffs, as well as the volume of rainwater that can be directed and harvested. The size and volume of the water detention tanks, as well as the feasibility of installing this water detention facility in an urban setting, along with the relative expense and benefits derived from the project, are taken into consideration.

Other dimensions include the amount of precipitation. In this study, the researchers utilized the Climate Normal data, which is a 30-year average of Cebu Rainfall (in millimeters per month) (Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA], n.d.). Rainwater volumes are calculated based on the number of establishments in the area.

RESULTS

The following are the data sets (images) and data analysis to provide a detailed description of the urban scenario.

Cebu Land Slide and Flood-Prone Areas

Figure 3 shows the landslide and flood susceptibility map of Cebu Province (Japan International Cooperation Agency & Metro Cebu Development and Coordination Board, 2015; Mines and Geosciences Bureau Region Office VII, n.d.-a). In this image, the color purple represents the flood-prone areas. Within Cebu Province, the identified flood-prone areas include those around Balamban, Pinamungajan, Lilo-an, Pardo, Cebu City, and Lapu-Lapu.

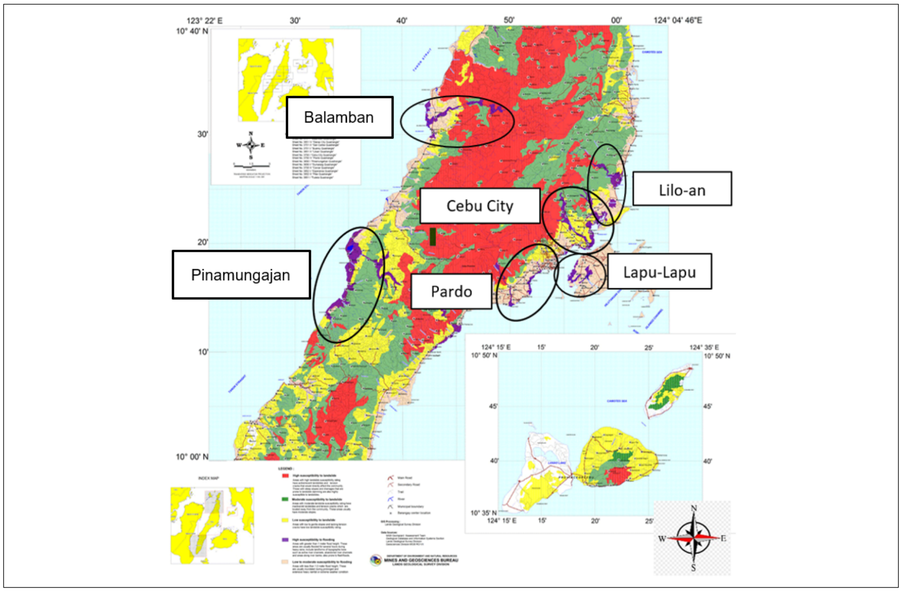

Figure 3. *Landslide and Flood Susceptibility Map of Cebu Province (Mines and Geosciences Bureau Region Office VII, n.d.-a)*

Cebu City Urban Flood Landscape Analysis

Cebu City has a total land area of 315 km2. Figures 4 and 5 present the details of Cebu City's flood-prone areas. In the assessment, 19 streets are identified as flood-prone. Among the 19 identified flood-prone streets in Cebu City, four (4) of which are shared with Mandaue, these are P. Remedio St., A.S. Fortuna St., Banilad Town Center, and Country Mall. There are five (5) flood-prone streets from the downtown area: Colon Street, Bonifacio St., S. Osmena Boulevard, Elizabeth Mall, Point 16, and Manalili Cor. Jakosalem. Another five (5) flood-prone streets were identified within the North Reclamation Area. These are A. Soriano, J. De Vera, M.J. Cuenco cor. T Padilla, Cebu-Mandaue Boundary, and North Bus Terminal. In the Mabolo Area, the Cebu Business Park and F. Cabahug St., SRP are additional attractions (Mines and Geosciences Bureau Region Office VII, n.d.-b).

Figure 6 contains images of actual flooding incidence in the different locations of Cebu City (DOST-UP DREAM and Phil-LiDAR Program, 2017). The red areas are highly susceptible to flooding. The leftmost is Barangay Mambaling, and the other is Mabolo at the North Reclamation Area (DOST-UP DREAM and Phil-LiDAR Program, 2017).

Figure 4. *Cebu City Flood-prone Areas (DOST-UP DREAM and Phil-LiDAR Program, 2017)*

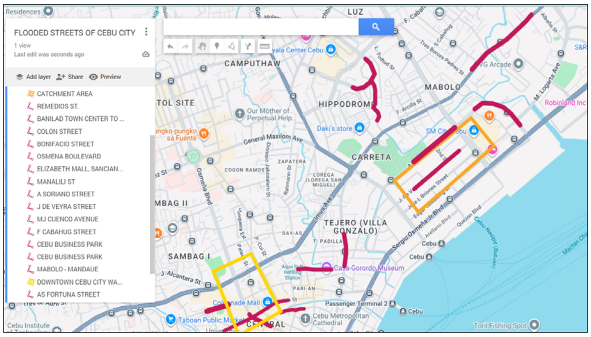

Figure 5. *Cebu City Map and persistently flooded streets (Google, n.d.)*

Figure 6. *Cebu City's Flood-Prone Areas (DOST-UP DREAM and Phil-LiDAR Program, 2017; Magsumbol, 2021; My Cebu Photo Blog, 2019; einstein143, 2014) are marked as red areas of high susceptibility to flooding.*

Figures 7 and 8 show the satellite view of Downtown Cebu City and the Flood Map. It is observed that downtown Cebu City is a highly dense and populated area. This is a mixed residential area on the outskirts, with a commercial district located towards the center. The yellow box represents the entire catch basin for Colon Street, highlighted by a red line, located towards the lower end and parallel to the short end of the box.

Upon actual inspection of the grounds, the said locations are significantly elevated above Colon Street and are fully paved. Only the City Sports Center, located at the upper end of the box, remains an open area. The flood map shows how the rainwater flows towards the Colon area.

Figure 9 illustrates the urban sprawl and rainwater catchment in downtown Cebu City. The north direction of the map points toward higher elevations, while the south direction, toward the bottom of the map, tends to move toward flood-prone areas. These streets include Magallanes, Borromeo, Sanciangko, and Manalili. These streets intersect with several south-direction streets (yellow arrows) from a higher elevation (DOST-UP DREAM and Phil-LiDAR Program, 2017). The orientation of the streets is such that they tend to block the natural flow of water to the south, indicated by the yellow arrows.

Figure 7. *Downtown Cebu City (Google, n.d.)*

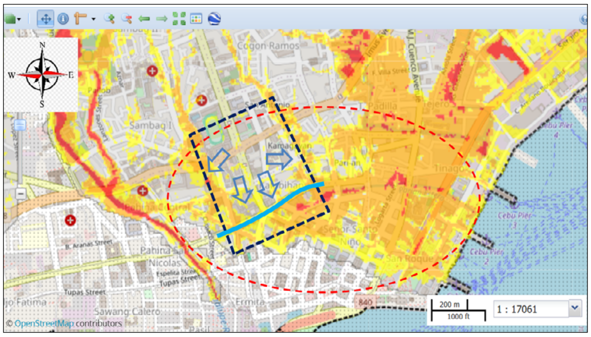

Figure 8. *Downtown Cebu City Flood Map (DOST-UP DREAM and Phil-LiDAR Program, 2017)*

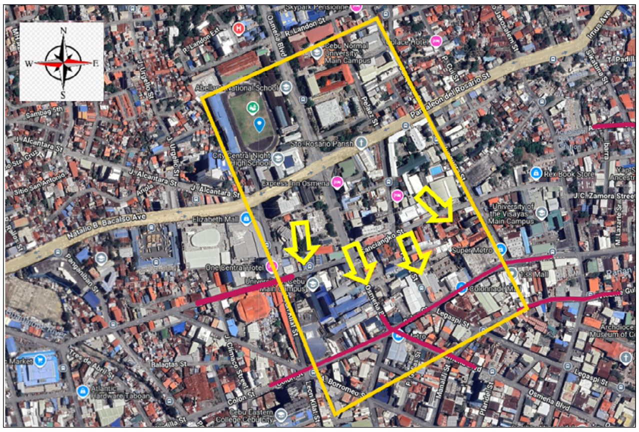

Figure 9. *Regularly flooded streets, highlighted in dark red (Google, n.d.). Yellow arrows indicate the direction of the street flooding flow.*

Figure 10. *Flooded a) Manalili (Magsumbol, 2022) and b) Colon Street, (Yburan, 2020) downtown Cebu City*

Rainfall Data and Amount of Precipitation (mm)

Table 3 presents the 30-year average rainfall precipitation (in millimeters per square meter per month) for Cebu City, as well as the average frequency of rain per month, measured as the average number of rainy days per month. These data are derived from the CLIMATE NORMALS Mactan Airport 1991 – 2020 data set. The table presents the average monthly rainfall intensities and the average frequency of rainy days. The data presented is the result of 220 million data points (PAGASA, n.d.).

Table 3. *30-year Monthly Average of Cebu Rainfall (mm) and Average Rainy Days, 1991 – 2020 data (PAGASA, n.d.)*

Month	Rainfall (mm/sqm/month)	Ave. Rainy Days	Equivalent Average Liters of rain per sqm per month
January	135.1	12	135.1
February	88.9	9	88.9
March	60.9	7	60.9
April	55.6	5	55.6
May	94.4	9	94.4
June	180.7	13	180.7
July	210.6	15	210.6
August	157.9	13	157.9
September	190.4	14	190.4
October	207.6	15	207.6
November	131	12	131
December	171.9	14	171.9
(Max., Ave., min)	**(210.6, 140.4, 55.6)**	**(MIN, MAX) (5,15)**	**(210.6, 140.4, 55.6)**

Rainwater Capture Calculations

The subject locations of this study are the downtown area of Cebu City and b) the North Reclamation of Barangay Mabolo and SM City.

Calculating the Rainwater Catch Basin Area in Downtown Cebu City

Figure 11 shows the selected establishments that were considered as possible sources for rainwater harvesting (red box). Anything in the open space and on the streets is excluded to avoid contamination.

Table 4 presents a summary of the establishments and areas measured, as shown in Figure 11.

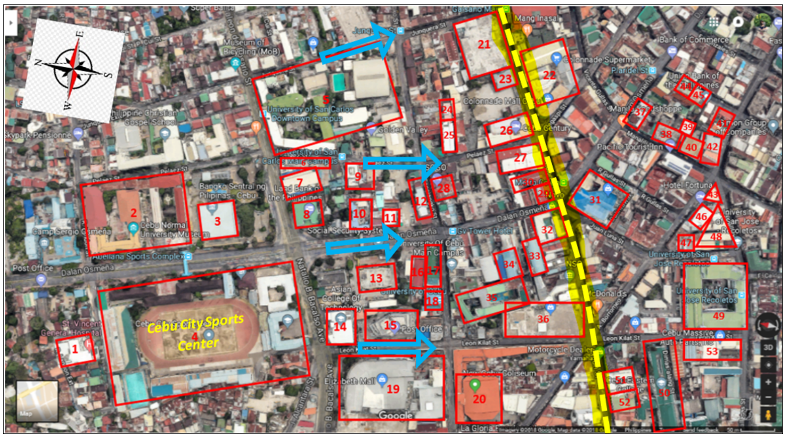

Figure 11. *Colon Street RWH Catchment Area (red boxes) (Google, n.d.)*

Table 4. *Summary of RWH Catchment Area in Colon Street (Missing entries refer to buildings that are unidentifiable on Google Maps and at specific locations.)*

Area No.	Name	Total Roof Area (m2)	Area No.	Name	Total Roof Area (m2)
1	St. Vincent General Hospital	1,379.10	27	--------	2,713.49
2	Cebu Normal University	14,474.43	28	Sogo	662.58
3	Banko Sentral	2,841.45	29	McDonalds	681.96
4	Abellana	44,224.57	30	Rose Pharmacy	846.69
5	University of San Carlos	25,591.85	31	Metro Colon	2,959.94
6	Jollibee Sanciangko	1,650.53	32	Novo	1,867.21
7	Sto. Rosario	1,825.59	33	Unitop	964.88
8	Landbank	1,782.61	34	Andok's	2,693.58
9	Sta. Rita Dormitory	1,645.75	35	University of Cebu - Main	4,893.23
10	Harmanson Electronic Center	1,030.80	36	Gaisano Capital	7,519.25
11	Sugbuanon Rural Bank	957.95	37	-	768.06
12	Big Start	969.06	38	-	959.34
13	Social Security System	4,578.13	39	-	272.06
14	Asian College of Technology	1,885.64	40	Blak fabrics	780.58
15	General Service Insurance System	4,167.40	41	Union Bank	830.25
16	PS Bank	705.12	42	Sterling Bank	1,175.98
17	GV Tower Hotel	580.28	43	BDO	263.18
18	Alorcon Eng. Review Center	779.05	44	Luym Building	548.12
19	Elizabeth Mall	12,088.23	45	Cathay	395.72
20	New Cebu Coliseum	4,783.47	46	Hotel Fortuna	652.26
21	Super Metro	4,868.11	47	Metrobank	353.70
22	Colonnade	8,586.74	48	Commercial Buildings	2,987.27
23	JRS	1,716.68	49	University of San Jose-Rec.	8,023.20
24	Mc Sherry	503.91	50	Cebu Eastern College	3,589.58
25	148 Residences	864.38	51	sun gold	1,695.84
26	Century Building	1,821.05	52	Cebu Progress	1,438.28
			53	--------	3,183.88
Approximate total surface Area (sqm)		**459,845.54**	**Total Rainwater Catchment Area (sqm)**		**200,021.99**

Table 5 presents the 2-day rainwater volume that can potentially be harvested from selected structures within the catchment area. The other data is the total volume calculated from the overall catchment area.

Table 5. *Average 2-day RWH volume for Downtown Cebu City in Liters, and the possible flood water volume for a 2-day rain*

Month	Ave. No. of rainy days / Month	Liters of rain/ sqm/month	2 days RWH volume (liters, at 43.50%)	2 days of rain, total area (liters, at 100%)	Average Monthly Floodwaters (liters, at 100%)
January	12	135.1	4,503,828.47	10,354,188.74	62,125,132.45
February	9	88.9	3,951,545.54	9,084,504.11	40,880,268.51
March	7	60.9	3,480,382.63	8,001,312.40	28,004,593.39
April	5	55.6	4,448,489.06	10,226,964.81	25,567,412.02
May	9	94.4	4,196,016.86	9,646,537.55	43,409,418.98

Table 5. *continued*

Month	Ave. No. of rainy days / Month	Liters of rain/ sqm/month	2 days RWH volume (liters, at 43.50%)	2 days of rain, total area (liters, at 100%)	Average Monthly Floodwaters (liters, at 100%)
June	13	180.7	5,560,611.32	12,783,706.01	83,094,089.08
July	15	210.6	5,616,617.48	12,912,462.76	96,843,470.72
August	13	157.9	4,858,995.73	11,170,709.35	72,609,610.77
September	14	190.4	5,440,598.13	12,507,798.69	87,554,590.82
October	15	207.6	5,536,608.68	12,728,524.55	95,463,934.10
November	12	131	4,367,146.78	10,039,960.96	60,239,765.74
December	14	171.9	4,911,968.58	11,292,492.62	79,047,448.33
				Annual Total Floodwaters	**774,839,734.90**

Calculating the Rainwater Catch Basin Area in the North Reclamation, Mabolo

Figure 12 presents the Google Map of the North Reclamation area. Table 6 presents a summary of the rainwater catchment area, including red box drawings, for the North Reclamation area.

Figure 12. *North Reclamation Area Catchment Area (red boxes)* (Google, n.d.)

Table 6. *Summary of RWH Catchment Area in North Reclamation. The missing entries are the names of the buildings that could not be identified*

Area No.	Name	Total Roof Area (m2)	Area No.	Name	Total Roof Area (m2)
1	SM City Cebu	39,554.55	24	-	2,106.06
2	Ana Baptist	842.43	25	Cebu City Police Clearance	546.51
3	CBX	1,628.37	26	-	388.62
4	BDO	1,080.76	27	-	689.46
5	Erim Express	789.74	28	-	787.52
6	-	714.23	29	-	597.05
7	Conor Express Inter.	412.78	30	-	2,430.54
8	Wheelmasters Corporation	1,991.31	31	-	645.78
9	IIEE Cebu Chapter	1,680.74	32	-	1,024.99
10	Informatics College	533.66	33	-	842.78
11	Mactan Inter. Trading	849.83	34	-	1,473.80
12	Lord Jesus Our Redeemer	631.13	35	-	726.03
13	San Marino Residences	1,385.57	36	-	519.38
14	Aie You Go Travels Phil.	355.93	37	-	767.01

Table 6. *continued*

Area No.	Name	Total Roof Area (m2)	Area No.	Name	Total Roof Area (m2)
15	Lovely Planet PH	1,008.26	38	-	938.88
16	Alternativ	760.97	39	-	375.76
17	Pacific Ocean Manning Inc.	501.97	40	-	494.92
18	Sun Gold/BDO	2,167.87	41	-	1,245.07
19	White Gold Club 1	4,361.96	42	-	826.6
20	Volkswagen	5,731.46	43	-	806.98
21	Honda Cars	4,685.38	44	-	2,725.38
22	Isuzu	1,309.43	45	-	945.44
23	-	546.51	46	-	824.88
Approximate total Surface area (sqm)		**420,777.37**	**Total Roof Catchment Area (sqm)**		**96,254.28**

The total area covered by the structure is 22.88% of the total surface area. Table 7 presents the average 2-day rainwater volume that can be harvested in the North Reclamation area.

Table 7. *Average 2-day RWH Volume for the North Reclamation Area, and the flood water volume for a 2-day rain*

Month	Ave. No. of rainy days /Month	Liters of rain/sqm/ month	2 days RWH volume (liters, at 22.88%)	2 days of rain, total area (liters, at 100%)	Average Monthly Floodwaters (liters, at 100%)
January	12	135.1	2,167,325.54	9,474,503.78	56,847,022.69
February	9	88.9	1,901,556.78	8,312,690.71	37,407,108.19
March	7	60.9	1,674,824.47	7,321,526.24	25,625,341.83
April	5	55.6	2,140,695.19	9,358,088.71	23,395,221.77
May	9	94.4	2,019,200.90	8,826,974.16	39,721,383.73
June	13	180.7	2,675,868.98	11,697,610.89	76,034,470.76
July	15	210.6	2,702,820.18	11,815,428.55	88,615,714.12
August	13	157.9	2,338,238.59	10,221,653.34	66,440,746.72
September	14	190.4	2,618,116.42	11,445,144.46	80,116,011.25
October	15	207.6	2,664,318.47	11,647,117.60	87,353,382.01
November	12	131	2,101,551.78	9,186,972.58	55,121,835.47
December	14	171.9	2,363,730.10	10,333,089.99	72,331,629.90
				Annual total Floodwaters	**709,009,868.45**

Sizes and Strategic Locations Rainwater Tanks

Tables 8 and 9 show the volume of water collected each month and the possible size of the detention tank required to store two days' worth of rain. For reference, the street width was used as the basis for an 8-meter-wide x 5-meter-deep detention tank. The monthly detention tank calculations are presented for reference and comparative purposes.

Figures 13 and 14 present the possible locations for the detention tank for Downtown Cebu City and North Reclamation. Sanciangko Street presents an ideal location, considering it is situated in the middle of the rainwater catchments and intercepts the water flow from P del Rosario down to Colon St., and J. De Veyra Street is directly in the middle of the North Reclamation.

Table 8. *Rainwater Volume is based on a monthly basis and 2 days of rain for Downtown Cebu City*

Month	Liters of rain per day/sqm	2 days RWH volume (liters, 43.50%)	2-day -rain flood waters (total area) (liters, 100%)	5m deep x 8m wide x length (meters) (2 days of rain, 43.50%)	5m deep x 8m wide x length (meters) (2 days of rain, 100%)
January	135.1	4,503,828.47	10,354,188.74	112.60	258.85
February	88.9	3,951,545.54	9,084,504.11	98.79	227.11
March	60.9	3,480,382.63	8,001,312.40	87.01	200.03
April	55.6	4,448,489.06	10,226,964.81	111.21	255.67
May	94.4	4,196,016.86	9,646,537.55	104.90	241.16
June	180.7	5,560,611.32	12,783,706.01	139.02	319.59
July	210.6	5,616,617.48	12,912,462.76	140.42	322.81
August	157.9	4,858,995.73	11,170,709.35	121.47	279.27
September	190.4	5,440,598.13	12,507,798.69	136.01	312.69
October	207.6	5,536,608.68	12,728,524.55	138.42	318.21
November	131	4,367,146.78	10,039,960.96	109.18	251.00
December	171.9	4,911,968.58	11,292,492.62	122.80	282.31

Table 9. *Rainwater Volume is based on a monthly basis and 2 days of rain for North Reclamation*

Month	Liters of rain per day/sqm	2 days RWH volume (liters, 22.88%)	2-day -rain flood waters(total area) (liters, 100%)	5m deep x 8m wide x length (meters) (2 days of rain, 22.88%)	5m deep x 8m wide x length (meters) (2 days of rain, 100%)
January	135.1	2,167,325.54	9,474,503.78	54.18	236.86
February	88.9	1,901,556.78	8,312,690.71	47.54	207.82
March	60.9	1,674,824.47	7,321,526.24	41.87	183.04
April	55.6	2,140,695.19	9,358,088.71	53.52	233.95
May	94.4	2,019,200.90	8,826,974.16	50.48	220.67
June	180.7	2,675,868.98	11,697,610.89	66.90	292.44
July	210.6	2,702,820.18	11,815,428.55	67.57	295.39
August	157.9	2,338,238.59	10,221,653.34	58.46	255.54
September	190.4	2,618,116.42	11,445,144.46	65.45	286.13
October	207.6	2,664,318.47	11,647,117.60	66.61	291.18
November	131	2,101,551.78	9,186,972.58	52.54	229.67
December	171.9	2,363,730.10	10,333,089.99	59.09	258.33

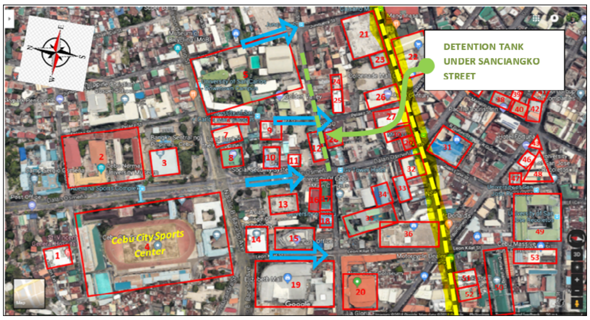

Figure 13. *Probable Location of Tank Downtown Cebu City (Google, n.d.)*

Figure 14. *Locations of Detention Tank in the North Reclamation Area (Google, n.d.)*

DISCUSSION

The urbanization of Cebu City has generated a series of interrelated challenges, most notably traffic congestion, pollution, and recurring floods. During the rainy seasons, surface water runoff accumulates from various elevated and paved sections of the city, often leading to flooding in the City.

Drawing on the photogrammetric assessments of Cebu City's Google Map and the Geohazard map, the flooding conditions, precipitation, and surface water runoff calculations reveal a set of interrelated characteristics that significantly impact stormwater behavior across the study areas. The photogrammetric assessment confirms that both downtown Cebu City and the North Reclamation Area are dominated by paved, impermeable surfaces, with only a few green or absorptive spaces. The Cebu City Sports Center is the sole ample open space in downtown Cebu. In contrast, the North Reclamation is composed of scattered, undeveloped patches, the majority of which have compacted soil with limited infiltration capacity (Figures 7-9).

The area around P. del Rosario Street (Figure 11), extending down to Colon Street, meets the criteria of a rainwater catchment for downtown Cebu City. The area is on the north side of the downtown area and is slightly elevated. The connecting streets have a slight downward gradient to Colon Street, allowing surface water to flow without hindrance. Meanwhile, the assessed portion of the North Reclamation (Figure 12), which is a flat surface and slightly lower in elevation than the bigger part of the North Reclamation, forms a basin. Multiple street networks that run across these areas become the default passageways for surface water, directing surface runoff toward the lowest part. Due to its slightly low level, with limited pathways for water to exit, the area is a consistent flood-receiving corridor. These observations are corroborated by geohazard indicators (Figures 8 and 9).

According to photogrammetric analysis and the Google Maps measuring feature, as shown in Figure 1, Figures 11 and 12 mapped the necessary information for determining the total possible rainwater catchment that floods both locations, as well as the possible total catchment area for RWH. The red and numbered rectangles were identified as the area for RWH, and the whole image surface approximately represents the overall catchment area. These measured data, catchment areas, are tabulated in Tables 4 and 6.

In a typical watershed or drainage basin, the hydrological equation is used to calculate the volume of water storage. In its expanded form to include specific environmental processes:

$$P-(R+E+T+G) = \Delta S$$

A watershed is a considerable area of land used for a large-scale rainwater collection system. Rainfall in a watershed, due to its size, is never consistent; it may rain more in one area and less in another. Thus, a hydrological equation is used to determine actual rainwater storage data accurately. Urban flooding, on the other hand, is a highly localized event that occurs over a short period; it is also referred to as an urban street flash flood. This street flash flood can develop within hours of heavy rain and may recede in several hours to several days. During such an event, evaporation (E) and transpiration (T) are negligible due to the short time frame (from the start of heavy rains to total drainage time) and the relatively small area of consideration. Cebu City experiences flooding in several sections, and this study focuses on analyzing a small section of the flooding event, specifically the downtown area and the North Reclamation area. Urban surface water runoffs do not travel far, nor do temperature changes or winds happen to carry off humidity within the given time frame. These factors mentioned are the mechanisms for evaporation and transpiration. Water seepage (G) into the soil is almost zero, as the urban surface has become largely concretized, and surface water runoff (R) in the highly paved city is not going anywhere. Drainage is the primary means of allowing water to flow out of the city area. Hence, if flooding occurs, it is most likely failing due to poor maintenance or a low elevation towards the destination. The lower the elevation, the slower the water flow, which causes the floodwaters to stay on the streets longer, as drainage systems cannot cope with the heavy rains of today's weather conditions.

Thus, to determine the volume of water, the equation for a localized urban catchment with a short duration of event is a static equation of

$$P = \Delta S$$

$$\text{intensity of rain x number of days of rain x catchment area} = \Delta S$$

In Cebu City, the typical rainy season starts from June to November, with strong typhoon occurrences from August to December (Cebu City News & Information, 2023; Erram, 2024b; Perez, 2022). During a typhoon, continuous rainfall usually lasts for 24 to 72 hours. Although typhoons can remain in the Philippine Area of Responsibility (PAR) for up to six days, the duration of the most intense, continuous rain for a particular area, such as Cebu, is typically significantly shorter. Three days of continuous or nearly continuous wet conditions can be caused by significant rainfall, including pre-landfall showers and post-storm following rain (PAGASA, n.d.).

In engineering, size estimation is a balancing act of performance and costs. "Two days of rain" is an arbitrary number that can be revised at any time based on further studies. However, considering the Philippines is a hotspot for typhoons, each typhoon can last up to six days, and continuous rain can persist for up to three days. Additionally, given that Cebu City is often flooded even during heavy rains, a one-day detention tank will not be sufficient. It can accept normal rain events, but it is likely to fail during heavy typhoon events. A three-day rainwater storage system may appear oversized for a typical rainy day, and extreme weather conditions have a lower probability of occurring. A two-day event storage, at present, will be the best example that can be cited. It can very well accept any rainy-day event, including a regular typhoon, and is likely to overflow during extreme weather conditions.

The following are example calculations for a 2-day rain event with equivalent precipitation for every month.

$$2/14 \text{ days x } 190.4 \text{ liters/m}^2 \text{ x } 200{,}021.99 \text{ m}^2 = 5{,}440{,}598.13 \text{ liters of rainwater in 2 days}$$

Total liters of water that can be collected from roof decks and similar selected structures within the rainwater catchment area of downtown Cebu City in a 2-day rain. Rain during the month of September occurs every other day.

$$14/14 \text{ days x } 190.4 \text{ liters/m}^2 \text{ x } 200{,}021.99 \text{ m}^2 = 38{,}084{,}186.90 \text{ liters of rainwater}$$

and for the whole month of September, the amount of rainwater that can possibly be harvested, or flood downtown Cebu City

$$2/14 \text{ days x } 190.4 \text{ liters/m}^2 \text{ x } 459{,}845.54 \text{ m}^2 = 12{,}507{,}798.69 \text{ liters of flood waters}$$

Liters of water that will fall for 2 days of rain in all the catchment area of downtown Cebu City.

$$190.4 \text{ liters/m}^2 \text{ x } 459{,}845.54 \text{ m}^2 = 87{,}554{,}590.82 \text{ liters of flood waters}$$

Liters of floodwaters for the whole month to fall on the downtown catchment area.

The Catchment area for downtown Cebu City, as measured through photogrammetry, covers 459,845.54 m^2, of which 200,021.99 m^2 (43.50%) consists of rooftops and paved compounds suitable for potential rainwater harvesting. Simulating a two-day rainfall using the 30-year average for September, the catchment generates 12,507,798.69 liters of stormwater, which is enough to produce knee-deep flooding in several areas. Harnessing the available roof area could capture an estimated 5,440,598.13 liters; this could reduce runoff by nearly 50% (Tables 4 and 5).

The North Reclamation Area shows a catchment size of 420,777.37 m^2, with structures covering 96,254.28 m^2 (22.87%). For the same rainfall scenario, the district accumulates 11,445,144.46 liters of water. Its structural footprint has a rainwater-harvesting potential of 2,618,116.42 liters, corresponding to a 22.87% reduction in floodwater volume (Tables 6 and 7).

To manage these volumes, whether water harvesting is employed or a flood control intervention is implemented, a substantial storage capacity is required. While drainage systems remain the conventional flood-management approach, global case reviews and local experience indicate that drainage alone is insufficient in low-lying or highly urbanized environments. These systems generally perform effectively only when supplemented by additional measures such as detention tanks. Constraints such as low city elevation, extensive drainage lengths, maintenance issues, and under-designed systems all contribute to reduced drainage performance.

Based on September rainfall data, estimated detention tank volumes needed to store floodwater are approximately 8 m × 5 m × 312.69 m for downtown Cebu and 8 m × 5 m × 286.13 m for the North Reclamation. If sized only for potential harvested rainwater, the required capacities decrease to 8 m × 5 m × 136.01 m and 8 m × 5 m × 65.45 m, respectively. These values represent two-day storm events; the choice of a larger or smaller design should be determined through further technical feasibility assessments and policy considerations (Tables 8 and 9).

Due to the limited availability of land, the suggested locations for Rainwater Harvesting (RWH) or flood-control storage structures are beneath existing streets. According to the analysis, the suggested locations are Sanciangko Street (downtown) and J. de Veyra Street (North Reclamation), as they are promising central locations adjacent to major contributing structures. However, these recommendations require validation through comprehensive feasibility studies (Figures 13 and 14).

Tank Design and Technical Considerations

For the Downtown Cebu City, utilizing a box-type detention tank to hold a volume of 12,507,798.69 liters, will have a size of 8m x 7m x 312.69 m, and for the North Reclamation area to accommodate a volume of 11,445,144.46 liters, a box-type detention tank beneath a street with approximate dimensions of 8m x 7m x 286.13 m. Figure 15 shows the cross-section of the detention tanks. Volume compensations can be adjusted through the length of the tank. The 7m height should give enough headroom for facilities inside. Access and ventilation should also be provided for safety operations. It is, however, worth noting that this design presentation is arbitrary and should be cited as an example. The design and calculations were made as factual as possible, with assumptions to provide the most accurate reference possible. The design is also made scalable to allow volume extensions by increasing the length of the tunnel.

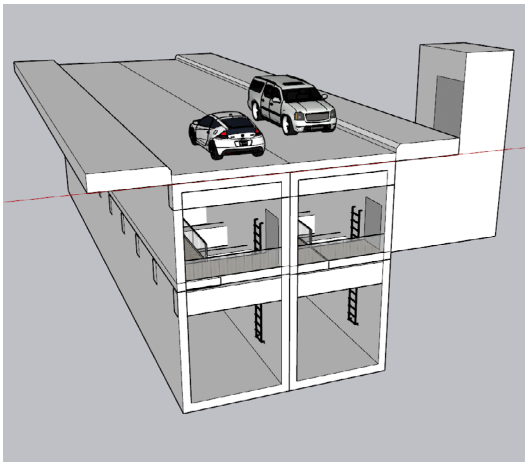

Figure 15. *Detention tanks Cross-Section*

Cost and Viability of the Design

Based on a review of similar projects in the Visayas and Mindanao regions, the approximate cost range per linear meter for this type of project is between PHP 1 million and PHP 1.7 million per linear meter of tunnel. A tabulated review of the results is presented in Table 10 of Appendix A. A separate costing provided by an expert on this type of infrastructure yielded the following estimates: PHP 1.34 million per linear meter, along with the proper assumptions. Rectangular tanks with lengths of 312.69 meters and 286.13 meters will cost PHP 419.00 million and PHP 383.41 million, respectively. The details of the works and budgetary assumptions are presented in Appendix B. The readers are highly cautioned that, although these calculations are made as realistically as possible, they are intended as a reference for discussion, not as a final design calculation. An engineering design and feasibility study must be conducted based on updated real site conditions.

The cost of clean water on the market, based on the Metro Cebu Water District selling price, is PHP 16 per cubic meter. Assuming a half-price valuation for raw water, capturing 1.45 million cubic meters (Sum of Annual total Floodwaters, Tables 5 and 7) of rain annually would generate a PHP11.6 million annual revenue. However, these values are arbitrary and highly dependent on actual seasons, global climate, and numerous other factors that can significantly alter weather conditions. Based on rough estimates, the expenditure of both projects may take more than 60 years to recover, considering only the revenue from raw water. These assumptions did not include the economic benefits that may be derived from totally removing or preventing floods on the streets of Cebu City.

CONCLUSION

This study examined the feasibility of sustainable urban RWH as a strategy for mitigating flooding and enhancing water resource management in Cebu City, using photogrammetric analysis and precipitation–catchment modeling. The recurring floods in downtown Cebu City and the North Reclamation Area are primarily driven by dense urban development, limited permeable surfaces, site and elevation conditions of the region under investigation, and the unusually high volume of stormwater generated by today's rainfall events. The analysis indicates that existing drainage systems alone are insufficient to manage these conditions. A large-scale intervention, particularly the integration of rainwater harvesting and urban stormwater detention facilities, is needed for the City's flooded sections. Drawing on the successful international precedents, a comprehensive flood management approach will be most effective. These will require substantial investment; however, the reduction in flood-related damage and economic losses will eventually justify these investments. Overall, sustainable rainwater harvesting, combined with strategically designed detention systems, offers a viable and forward-looking solution for improving flood resilience and water management in Cebu City.

Author Contributions

R. K. Salazar: Conceptualization, Methodology, Formal Analysis, Writing-Reviewing and Editing; **E. K. H. Ruiz:** Data curation, Writing- Original draft preparation; **Y. J. Secican:** Structural Design Validation, Structural Works Detail, Budgetary Assumptions, and Cost Estimates

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Ethical Approval

Not applicable.

Competing interest

The authors declare no conflicts of interest.

Data Availability

Data will be available upon request.

Declaration of Artificial Intelligence Use

Artificial Intelligence (AI) was utilized strictly for language editing and grammatical refinement. AI tools were not employed for data generation, idea formation, or content creation. All information, concepts, and analyses presented in this work are original contributions from the authors. AI-assisted modifications were limited to improving clarity, coherence, and readability without altering the substantive content of the research.

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