Rainfall Duration-Drainage Capacity Model for Urban Flooding

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ABSTRACT

The Philippines often experiences strong typhoons and heavy rainfall due to its location within the Pacific Typhoon Belt, making flooding a common problem in many urban areas. This study develops a Rainfall Duration–Drainage Capacity Model to assess if local drainage systems can handle different rainfall events. Conducted in Magtoto Compound, Sindalan, City of San Fernando, Pampanga, the research used manual measurements and satellite mapping to gather data on canal dimensions and nearby surfaces. The model focuses on rainfall intensity, duration, and drainage capacity to simulate potential flooding scenarios. Although factors like ground elevation and debris were not included, the model offers a simple way to estimate flood risks. Its main goal is to provide a simulation tool that communities can use to understand drainage performance and support better flood management.

Keywords

Rainfall Duration–Drainage Capacity Model, urban flooding, drainage system capacity, rainfall intensity, flood risk assessment, surface runoff, simulation model, hydrological modeling, hydrologic, hydraulic, climate change

1. INTRODUCTION AND BACKGROUND

The Philippines experiences numerous typhoons mainly because it lies within the Pacific Typhoon Belt—an area in the Pacific Ocean where almost a third of the world's tropical cyclones develop [1]. The Philippine Area of Responsibility (PAR) experiences more tropical cyclones than any other region in the world, with an average of around 20 forming or entering the area each year, and approximately eight to nine making landfall in the Philippines [2].

The Philippines' high typhoon vulnerability is largely due to alternating monsoon winds and warm Pacific sea temperatures, as the southwest monsoon (Habagat) brings warm, moist air that intensifies storms, while the northeast monsoon (Amihan) can interact with tropical disturbances, creating favorable conditions for typhoon development [3].

Climate change has also intensified the Philippines' exposure to stronger and more destructive typhoons, as rising global temperatures warm Pacific sea surfaces, providing extra heat energy that fuels storm formation and intensification [3]. Each year, these powerful weather events cause widespread destruction, displace communities, and lead to significant loss of life. The flooding problem in the Philippines has become harsher and more relentless as typhoons grow increasingly severe.

Urban flooding is a common issue affecting nearly all cities, posing risks to residents as natural surfaces like farmland and vegetation are replaced with buildings and pavement [4]. Urban flooding occurs when excessive surface runoff from impermeable urban surfaces overwhelms drainage systems, leading to localized flooding, especially during heavy or prolonged rainfall [4]. With the intensification of typhoons driven by climate change, the likelihood of urban flooding is expected to increase even further [5].

This study aims to develop a Rainfall Duration–Drainage Capacity Model to assess how varying rainfall intensity and duration interact with local drainage systems in urban areas, specifically applied to Magtoto Compound, Sindalan, City of San Fernando, Pampanga. The model evaluates the existing drainage system's capacity to handle different rainfall events and predicts potential flood risks, aiming to identify thresholds beyond which the system fails. By simulating various rainfall conditions, the study provides a decision-support tool for communities and planners to better assess urban flood risks and enhance drainage management. The findings of this study can contribute to local disaster risk reduction efforts, promote sustainable urban planning, and provide baseline data that can guide future infrastructure improvements.

While the model focuses on drainage capacity and rainfall characteristics, it does not account for factors like topography, sewer pipe conditions, blockages, or tidal backflow due to data and resource limitations. Despite these constraints, the model offers valuable insights into drainage system performance and underscores the need for data-driven approaches in mitigating urban flooding.

2. REVIEW OF RELATED LITERATURE

2.1 Tropical Cyclone Trends in the Philippines

The Philippines is one of the most cyclone-prone countries in the world because of its position in the Western North Pacific, with about 20 storms entering or developing within its area of responsibility each year [6].

Intensified by rising ocean temperatures linked to climate change, these storms typically produce heavy rainfall and powerful winds, which can damage infrastructure, disrupt economic activities, displace populations, and cause significant loss of life [6]. The economic damages from storms have consistently increased because of both the growing strength of extreme typhoons and to socio-economic factors such as urbanization, settlement in coastal zones, and inadequate disaster preparedness [7].
These findings highlight the need to integrate cyclone data into climate change adaptation and disaster risk reduction and management frameworks, ensuring that planning accounts for the rising destructiveness of future storms.

2.2 Urbanization and Drainage System

Urban development creates impervious surfaces like concrete, asphalt, and buildings, which reduce the ground's ability to absorb water, leading to rapid surface runoff that can overwhelm drainage systems and cause flooding [8].

As urban areas expand, more land is used for housing, businesses, and infrastructure, leading to a surge in buildings and impervious surfaces. The swift rise in urbanization can result in inadequate drainage capacity, often stemming from ineffective urban planning. This growth increases the volume of water runoff, placing greater pressure on drainage systems. In many cases, these systems are not designed to handle the rising demand, making them insufficient for managing the excess water [8].

Drainage systems are an important part of any infrastructure, as they help protect farmland, buildings, and roads from being damaged or eroded by flooding or excess water [9]. To mitigate urban flooding risks, effective drainage systems are essential for managing and directing stormwater efficiently.

2.3 Rainfall Extremes

Short-duration extreme rainfall events are projected to increase in both frequency and magnitude due to ongoing climate change [10]. Atmospheric warming increases the atmosphere's moisture capacity, resulting in rainfall bursts that can exceed historical patterns. This indicates that rainfall assumptions used in traditional infrastructure planning may no longer be reliable, particularly in urbanized and flood-prone areas [10].

Climate change is already impacting the performance of urban drainage systems. Many designs still rely on outdated intensity-duration-frequency (IDF) curves, which may underestimate future rainfall peaks [11]. Consequently, drainage systems that previously met safe capacity standards may now be insufficient during more intense storms, resulting in localized flooding, infrastructure damage, and heightened vulnerability for communities.

The accuracy of flood models is significantly influenced by how precisely drainage infrastructure is represented; simplified models may underestimate conveyance capacity, leading to less reliable predictions [12]. Identifying the point at which rainfall duration and volume exceed infrastructure limits is therefore essential for reliable flood risk assessment.

2.2. Flood Risk Assessment

Disastrous floods often occur when a significant volume of water from heavy rainfall or overflow from waterways temporarily submerges areas that are typically dry, adversely affecting the communities residing there [13].

A flood risk assessment method has been developed for data-poor river basins, using the Pampanga River Basin as a case study. The method integrates a Rainfall Runoff Inundation (RRI) model, satellite-based information, and socio-economic surveys to estimate flood damages [14]. It emphasizes capturing both hazard characteristics, such as flood depth and duration, and exposure factors to quantify risk more accurately in areas lacking sufficient baseline data. This simulates how rainfall turns into runoff and then leads to flooding across landscapes, which in turn allows assessment of the flood's impacts.

2.4 Hydrologic and Hydraulic Modeling Approaches

The Philippines' growing urban flooding issue is a result of both rapid urbanization and intensifying climate change. Previous studies have emphasized the importance of understanding how urbanization and climate change impact urban hydrological processes such as peak runoff, flooding volume, and drainage system efficiency to effectively mitigate anticipated flooding risks.

To properly assess localized flood risk, reliable yet useful modeling tools are required. The Rainfall Duration-Drainage Capacity Model is based on existing literature in hydrological modeling and infrastructure assessment, particularly in highly urbanized, limited-information regions such as the Philippines.

The Rainfall Duration-Drainage Capacity Model relies on standard data collection techniques and the application of well-established physical formulas. Rainfall intensity (I) and storm duration inputs to the model are calculated from the Intensity-Duration-Frequency (IDF) curve principles, which are important sources of information and functional connections for this study [15]. In this study, the real challenge is precisely specifying the design rainfall intensity (I) for engineering purposes, that includes determining the necessary drainage system size and capacity. Relying on historical data may overlook the frequency of climate change incidents that occur today, according to regional studies [16].

Simultaneously, the model implements the physical formula for Manning's Equation to simulate drainage capacity. Findings support both the practical approach to structure assessment and the methodology for evaluating drainage capacity using Manning's Equation. They established protocols for gathering crucial, localized data specifically regarding the dimensions, condition, and base surface materials of informal drainage networks, demonstrating how low-cost, real-world data can be systematically acquired to inform the model's physical inputs and evaluate flood risk [17].

3. MODEL AND METHODS

Field measurements using measuring tape and satellite mapping through Google Earth were first carried out to gather spatial and dimensional data on the canal and the surrounding drainage area. These data provided the basis for evaluating the stormwater runoff and drainage capacity of Magototo Compound, Sindalan, City of San Fernando, Pampanga.

The study also applied hydrologic and hydraulic analysis methods, where hydrologic analysis estimates how much water flows out of a watershed over time, and hydraulic analysis examines how that water behaves, such as its depth, velocity, and the forces it exerts on surfaces or hydraulic structures [18].

3.1 Total Area

The canal dimensions (length, width, depth, and slope) were manually measured on-site using standard measuring tools. The drainage area contributing to runoff was determined using Google Earth, measuring the extent of roofs, concrete/asphalt surfaces, and open land. These measurements were used to estimate the total area (A) and assign appropriate runoff coefficients (C) for each land type.

3.2 Runoff coefficient (C)

The runoff coefficient (C) is a unitless measure that describes the proportion of precipitation that becomes runoff. Areas such as paved surfaces or land with a steep slope—have a higher value for C. They have high runoff and low infiltration. Well-vegetated areas on the other hand have lower permeability where more water can infiltrate such as forests and flat land [19].

Knowing the runoff coefficient is crucial for flood control planning, including the design of drainage channels and identifying potential flood hazard zones. A high C value can signal a risk for flooding during rain events because it indicates that water rapidly moves across the land's surface to reach a river or valley floor.

Table 1. Runoff Coefficient Values

Land Use Classification	Asphalt and Concrete	Roof of Houses	Heavy Soil (Average)
Runoff Coefficient	0.95	0.95	0.22

It is calculated using the formula: $C = \frac{A_1C_1 + A_2C_2 + A_3C_3}{A_T}$

3.3. Rainfall Intensity (I)

Rainfall Intensity (I) is a measurement of how much rain falls over a specific period. It effectively gauges the strength of a storm by measuring the cumulative depth of the water layer deposited on the ground.

The rainfall intensity is based on the formula: $I = \frac{d_{max}}{Tc}$

where d_{max} is the rainfall depth in a given time duration. While Tc is the time of concentration

3.3.1 *Time of Concentration (Tc)*

The time of concentration (Tc) is the duration it takes for a raindrop to travel from the farthest point in a watershed or subcatchment to the outlet or point of collection [20].

The Kiripich formula is used to determine the time of concentration:

$$T_C = 0.01947L^{0.77}s^{-0.385}$$

Where L is the travel water length in meters, while s is the slope of the drainage.

3.5. Manning's Equation

Manning's Equation is a commonly applied formula in open channel hydraulics that calculates the flow velocity of water by considering the channel's physical properties and flow conditions [21].

The formula is as follows: $Q = A(\frac{1}{n})(R^{\frac{2}{3}})\sqrt{S}$

Where A is the canal cross-sectional area, n is the Manning's Roughness Coefficient, while R is the hydraulic radius obtained by dividing the area by the wetted perimeter (A/P). The term **S** represents the slope of the canal bed, and P, or the wetted perimeter, is the total length of the canal boundary that is in contact with water. For a rectangular canal, the wetted perimeter is simply the canal's width plus twice the depth.

3.6. Triangular Hyetograph

A hyetograph is a chart that depicts how rainfall intensity varies over time, commonly used for analyzing stormwater runoff, designing drainage infrastructure, and evaluating flood management strategies.

Triangular hyetographs represent rainfall by rising to a maximum intensity and then declining, offering a closer approximation of typical storm patterns. They are commonly used in hydrological modeling to simulate the timing and distribution of rainfall, aiding in the evaluation of river flow responses and flood risk. The formula is expressed as:

Before Peak:

$$i(t) = \frac{2P}{D} \times \frac{t}{t_p}$$

After Peak:

$$i(t) = \frac{2P}{D} \times \frac{D-t}{D-t_p}$$

where P is the total precipitation depth, D is the total storm duration, tp is the time to peak, and t is the time elapsed.

All the above parameters were combined to simulate the runoff and drainage performance of the study area. Rainfall intensity distributed over time by the triangular hyetograph was multiplied by the total area and the runoff coefficient to estimate inflow at each time step. The canal's outflow capacity was calculated using Manning's equation. By comparing inflow and outflow, the model determined water depth, potential overflow, and flooding risk.

4. DATA AND RESULTS

Before carrying out the hydrologic analysis, several key inputs were collected. The measured dimensions of the study area and canal are summarized below.

Image 1. Satellite view of Magtoto Compound

The total area of the study area (Magtoto Compound, Sindalan, City of San Fernando, Pampanga) is 19,275.25m squared.

Table 2. Canal Dimensions

Structure	Length	Width	Depth	Slope
Canal	176.16 m	0.3045 m	0.33 m	0.0128 m/m

Because the study area contains multiple land-use types, the runoff coefficient was determined by first identifying and quantifying each category of land cover. Three primary classifications were considered: asphalt and concrete surfaces, building roofs, and heavy soil lawns. The areas of each classification were manually measured using Google Earth.

Table 3. Runoff Coefficient Values

Land Use Classification	Asphalt and Concrete	Roof of Houses	Heavy Soil Lawns	Total Area
Area (m²)	1091.44	9195.08	8,987.73	19,274.25

C = 1091.44 x 0.95 + 9195.08 x 0.95 + 8987.73 x 0.22 / 19274.25

C = 11749.4186/ 19274.25

C = 0.61

For the rainfall intensity, the rainfall depth and time duration are both user inputs. This is used to compute for the dmax. The following computation shows the time of concentration of the study area:

$$Tc = 0.01947(176.16)^{0.77}(0.01047)^{-0.385}$$

$$Tc = 0.01947 \times 53.62 \times 5.79$$

Tc = 6.05 minutes

Tc is then converted to hours.

The Manning's Roughness Coefficients for concrete is 0.015 [22]. Using the Manning Equation gives us:

$$n = 0.015$$
$$A = 0.3045 \times 0.33 = 0.100485 m^2$$
$$P = 0.3045 + 2(0.33) = 0.9645 m$$
$$R = 0.100845/0.9645 = 0.1046 m$$
$$S = 0.01047$$

$$Q = 0.100485\left(\frac{1}{0.015}\right)\left(0.1046^{\frac{2}{3}}\right)\sqrt{0.01047}$$
$$Q = (6.699)\,(0.00365)\,(0.10232)$$
$$Q = 0.15217 m^3/s$$

To explore the response of the drainage system under varying conditions, randomized generation of input rainfall depths was conducted. For example, inputting a small rainfall depth, such as 25 mm, resulted in no flooding, whereas inputting a large rainfall depth, such as 200 mm, resulted in severe flooding. These tests helped demonstrate the sensitivity of the system to different rainfall scenarios.

The main simulation was conducted with a total rainfall depth of 50 mm over a storm duration of 5 hours, divided into 10 timesteps, using a runoff coefficient (C) of 0.61 and a time of concentration (Tc) of 0.1 hours. The results indicate that the water depth gradually increased throughout the storm, starting at 24.98 mm at 0.5 hours and reaching a peak of 112.75 mm at 4.5 hours. Notably, even as rainfall intensity decreased toward the end of the storm, the water depth remained relatively high because inflow continued to exceed outflow, demonstrating the cumulative effect of the storm on urban flooding.

For the data cleaning, all collected measurements were reviewed for completeness and accuracy. Outliers and inconsistencies were cross-verified with satellite imagery, and corrections were made where possible. Units and labels were standardized to ensure compatibility with the simulation model. This step ensured that the input data were reliable for the subsequent hydrologic simulation.

Based on PAGASA's classification, the rainfall in this simulation can be considered heavy rain, as the rainfall rate exceeded 7.5 mm per hour [23]. However, for the study area, Magtoto Compound, the simulation shows only minor flooding throughout the storm duration. This suggests that the area has a relatively good capacity to manage heavy rainfall events, with water accumulation remaining limited and not reaching severe flooding levels.

5. CONCLUSIONS

This study developed a Rainfall Duration–Drainage Capacity Model to assess the ability of local drainage systems to handle varying rainfall events in urban areas. Data from Magtoto Compound in Sindalan, City of San Fernando, Pampanga, were analyzed to simulate how rainfall intensity and duration interact with drainage capacity. The results indicate that areas with higher surface runoff are more prone to flooding during prolonged or intense rainfall. Despite the canal dimensions in Magtoto Compound being relatively small, the model shows that the canal can adequately handle light to moderate rainfall events without significant flooding.

It is important to note that all data and model results are estimations. Gauging actual rainfall and predicting real-world flooding is complex, as many factors—such as ground elevation, debris, sewer conditions, and soil saturation—affect outcomes. This simulation provides a practical approximation, allowing us to assess whether the canal dimensions and study area are likely to experience flooding, but it is not fully accurate or exhaustive.

Overall, the study demonstrates that simple, data-driven models can help visualize and understand local drainage performance, providing a useful tool for preliminary flood assessment and supporting better decision-making in flood prevention and urban planning.

6. RECOMMENDATIONS

Future studies should expand the model by including additional factors such as ground elevation, land slope, debris buildup, and sewer condition to improve accuracy. Installing rainfall and water level sensors in the study area would also allow for real-time data collection and model validation. The model could be integrated into a user-friendly simulation tool or application that communities and local government units can use to evaluate drainage performance under different rainfall scenarios. Conducting similar studies in other flood-prone urban areas would further test the model's effectiveness and adaptability. Lastly, regular maintenance of drainage systems, proper waste disposal, and sustainable urban design should be prioritized to reduce surface runoff and enhance flood resilience.

Future research can expand upon this work by integrating additional hydrological, geological, and infrastructural data to create a more comprehensive flood prediction framework.

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