Rainfall Duration-Drainage Capacity Model for Urban Flooding

Euan Roie M. Nicolas
1st author's affiliation
1st line of address
2nd line of address
Telephone number, incl. country code
1st author's E-mail

Ghayzelle Dizon
2nd author's affiliation
1st line of address
2nd line of address
Telephone number, incl. country code
2nd E-mail

Jan Nolasco
3rd author's affiliation
1st line of address
2nd line of address
Telephone number, incl. country code
3rd E-mail

Jared Gabriel Vitero
3rd author's affiliation
1st line of address
2nd line of address
Telephone number, incl. country code
3rd E-mail

Jeremiah Carbungco
3rd author's affiliation
1st line of address
2nd line of address
Telephone number, incl. count*ry code*
3rd E-mail

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. As more land is covered with concrete and buildings, rainwater can no longer soak into the ground, causing surface runoff and drainage overflow. 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, hydrologic analysis, climate change, flood management

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. On average, around 20 tropical cyclones form or enter this area annually, with about eight to nine crossing the Philippines. Typhoon activity peaks between July and October, when nearly 70% of all typhoons develop [2].

Another major factor contributing to the Philippines' vulnerability to typhoons is its exposure to alternating monsoon winds. From June to October, the southwest monsoon (Habagat) carries warm, humid air from the ocean that can intensify storm systems. Between November and February, the northeast monsoon (Amihan) brings cooler, drier air but may also interact with tropical disturbances, creating unstable weather. This continual shift between monsoons keeps atmospheric conditions favorable for storm formation, while the surrounding Pacific Ocean's exceptionally warm sea surface temperatures further fuel typhoon development [3].

Additionally, climate change has played a significant role in increasing the Philippines' exposure to stronger and more destructive typhoons. Rising global temperatures have led to warmer sea surface conditions in the Pacific, supplying additional heat energy that fuels the formation and intensification of storms [3]. Driven by the effects of climate change, the frequency and magnitude of these typhoons are projected to intensify further. Every year, these weather events inflict widespread damage, displacing populations and resulting in significant loss of life

Urban flooding happens often and affects nearly all cities, putting people living in them at risk. As farmland, vegetation, and bare soil are replaced with buildings and paved areas, water can no longer soak into the ground and instead runs off hard surfaces. This process, known as pluvial or urban flooding, becomes more likely as impermeable surfaces and city development grow. Heavy or prolonged rainfall also increases the severity of such floods. With climate change, the chance of urban flooding is expected to rise even further [4]. Urban flooding primarily results from excessive surface runoff in highly developed areas where natural drainage and infiltration are severely limited [5].

To address these challenges, this study aims to develop a Rainfall Duration–Drainage Capacity Model to estimate how rainfall intensity and duration interact with local drainage systems in urban areas. Using manual measurements from Magtoto Compound together with formulas adapted from previous studies, the model determines whether the drainage system can handle specific rainfall events and predicts potential flood depths and severity. This approach aims to offer a straightforward decision-support tool for communities and planners to better assess urban flood risks and improve drainage management.

The model primarily accounts for drainage capacity and the intensity and duration of rainfall. It does not incorporate other important factors such as ground elevation and slope (topography), condition of sewer pipes, the presence of debris or blockages, and tidal backflow, as the necessary time, data, and tools to measure these variables were not available for this study.

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, with an average of 19.4 tropical cyclones entering the Philippine Area of Responsibility (PAR) each year, around nine of which make landfall [6]. Although the overall number of cyclones has slightly decreased over the last decades, the study by Cinco et al. (2016) shows a slight upward trend in extreme typhoons with maximum sustained winds above 150 kph. This indicates that while the frequency of storms may be stable or declining, their intensity and destructiveness are increasing, heightening risks for exposed communities.

Cyclone impacts also vary by region. Northern Luzon is the most frequently affected area, where storms not only occur more often but also contribute significantly to rainfall. In fact, tropical cyclones account for nearly 50% of annual precipitation in Northern Luzon, compared to just 4% in Mindanao, where cyclone activity is rare [6]. Such uneven distribution of storm rainfall underscores the geographic disparities in climate hazards, with some regions experiencing more frequent flooding and disaster risks than others.

Despite no clear rise in cyclone frequency, the economic damages from storms have consistently increased. Cinco et al. [6] attribute this to both the growing strength of extreme typhoons and to socio-economic factors such as urbanization, settlement in coastal zones, and inadequate disaster preparedness. The devastation caused by Typhoon Haiyan (Yolanda) in 2013 exemplifies this trend, where losses reached record levels despite the long-term decline in landfalling cyclones. These findings highlight the need to integrate historical cyclone data into climate change adaptation (CCA) and disaster risk reduction and management (DRRM) frameworks, ensuring that planning accounts for the rising destructiveness of future storms.

2.2. Flood Risk Assessment in Data-Poor River Basins

Flood disasters are among the most damaging hazards in the Philippines, particularly in river basins where population density and agricultural activity are high. Shrestha et al. [7] developed a flood risk assessment method for data-poor river basins using the Pampanga River Basin as a case study. Their method integrates a Rainfall Runoff Inundation (RRI) model, satellite-based information, and socio-economic surveys to estimate flood damages. The study emphasized the importance of capturing both hazard characteristics (flood depth and duration) and exposure factors (agriculture and households) to quantify risk more accurately in areas lacking sufficient baseline data.

In their analysis, agricultural damages were estimated using damage functions that accounted for rice crop stages, flood depth, and flood duration. For instance, damages were observed to increase significantly when floodwaters exceeded 0.2 m during the vegetative stage or 0.5 m during reproductive and maturity stages. The results from the 2011 Typhoon Pedring flood event showed that rice crops covering around 45,900 hectares were affected, with losses valued at ₱1.46 million. This highlights how flood risk assessment in agricultural zones must consider crop sensitivity to water depth and timing, as both variables critically shape the extent of losses [7].

The study also examined household vulnerabilities, showing that building type, elevation, and floor level were significant factors in determining damage severity. Elevated houses with concrete stilts in Candaba municipality, for example, showed greater resilience compared to one-story wooden structures. Household damages from the 2011 flood were estimated at ₱7.27 million for buildings and ₱2.24 million for assets, figures consistent with field survey reports [7]. Shrestha et al. conclude that this integrated approach provides a reliable framework for flood risk assessment in data-poor regions, offering valuable insights for local governments, planners, and communities in designing more resilient urban drainage and flood management systems.

2.3 Model Basis and Main Formulas

The Philippines' growing urban flooding issue is a result of both rapid, frequently unforeseen population growth and intensifying climate change.

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 [8]. 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 like the IDF analysis conducted by Shrestha in Bangkok [9].

Simultaneously, the model implements the physical formula for Manning's Equation to simulate drainage capacity. The findings of See 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 [10].

2.4 Rainfall Extremes, Climate Change, and Drainage System Capacity

Short duration extreme rainfall events are projected to intensify in both frequency and magnitude due to ongoing climate change [11]. Atmospheric warming increases the ability of air to hold moisture, which leads to rainfall bursts that exceed historical patterns. This suggests that long-standing rainfall assumptions used in infrastructure planning may no longer be reliable, especially in urbanized and flood prone areas [11].

Climate driven changes in rainfall extremes are already affecting the performance of urban drainage systems [12]. Many drainage designs still rely on outdated intensity duration frequency (IDF) curves that fail to represent future rainfall behavior. Because of this, systems that once met safe capacity standards may now be insufficient during more intense storms [12].

The capacity of drainage infrastructure is affected not only by rainfall intensity but also by how well the system is represented in flood models [13]. Flood models often overlook the true conveyance capacity of drainage channels, leading to inaccurate flood predictions. This highlights the importance of identifying the point where rainfall duration and volume exceed the limits of existing infrastructure [13].

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 [#].

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 [#].

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 dmax 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 (#).

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 [#].

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	Height	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 (m^2)	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 d_{max}. The following computation shows the time of concentration of the study area:

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

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

$$\mathbf{Tc = 6.05\ minutes}$$

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

$n = 0.015$

$A = 0.3045 \times 0.33 = 0.100485 m^2$

$P = 0.3045 + 2(0.33) = 0.9645 m$

$R = 0.100845/0.9645 = 0.1046 m$

$S = 0.01047$

$Q = 0.100485(\frac{1}{0.015})\ (0.1046^{\frac{2}{3}})\sqrt{0.01047}$

$Q = (6.699)\ (0.00365)\ (0.10232)$

$Q = 0.15217 m^3/s$

The simulation results show that the triangular hyetograph distributed a total rainfall of 200 mm over a 5-hour storm event, divided into ten timesteps of 0.5 hours each. Using a time of concentration of 0.1 hours (6.05/60), rainfall intensity rapidly increased to its peak at the start of the storm and then gradually declined toward the end. The assigned rainfall depths ranged from 38.78 mm in the first timestep down to 2.04 mm in the last, with intermediate values reflecting the triangular distribution pattern. This temporal distribution of rainfall served as the inflow input for the runoff model. When compared against the canal's calculated outflow capacity using Manning's Equation, the results allowed for an assessment of whether the existing drainage system could accommodate peak flows or if potential flooding was likely to occur.

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. Using manual field measurements and satellite mapping, 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 show that areas with higher surface runoff, caused by extensive concrete coverage, are more prone to flooding during prolonged or intense rainfall. The model successfully identifies the point at which the canal's drainage capacity becomes insufficient, helping predict potential overflow and flood risks. Although certain factors such as ground elevation, debris, and sewer condition were not included, the model still provides a practical and accessible tool for basic flood assessment. Overall, the study demonstrates that simple, data-driven models can help visualize and understand local drainage performance, 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.

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