Environmental Policy Studies

A method for assessing flood risk in Bangkok

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ABSTRACT

Bangkok, situated in the Chao Phraya River delta near the Gulf of Thailand, faces a significant flooding risk due to its low elevation and vulnerability to climate change. To address this challenge, a web application has been developed to assess flood risk in the city under the current drainage system capacity. This tool provides valuable insights for policymakers and urban planners in developing effective flood prevention and response strategies.

1. Introduction

Bangkok, a sprawling metropolis situated in the low-lying Chao Phraya River delta, faces a constant threat of flooding. The city's vulnerability is exacerbated by its proximity to the Gulf of Thailand and the potential impacts of climate change. To mitigate flood risks and enhance disaster preparedness, this study presents a web application capable of assessing flood risk in Bangkok based on the current drainage system capacity.

2. Theoretical Formulation

2.1 Key factors affecting flood risk in Bangkok

Flooding is considered a problem when floodwaters reach a critical height (H), at which pedestrian or vehicular access becomes hazardous or impossible due to inundation. The critical flood height is influenced by two primary factors:

$$H = \frac{V}{A}$$

Flood Volume (V): The total amount of water that accumulates in the flooded area, which is determined by factors such as rainfall intensity, drainage system capacity, and the presence of natural barriers.

Flood Area (A): The size of the area affected by flooding, which can vary depending on the location and extent of the inundation.

Together, these factors determine the severity of flooding and its impact on daily life and infrastructure.

The maximum flood area in Bangkok (A_t) is equivalent to the total land area of the city, which is 1,568.7 square kilometers.

To convert this measurement to square meters, we can multiply by 1 million (10^6):

$$A_t = 1568.7 * 10^6$$

A large portion of Bangkok's land area is occupied by infrastructure that can be inundated during floods, displacing floodwater. However, this infrastructure area is not necessarily equivalent to the entire land area. It may be a fraction of the

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total, depending on the specific layout and density of urban development.

To obtain a more accurate estimate of the infrastructure area, it would be necessary to analyze detailed land use data and consider factors such as building density, road networks, and green spaces.

Anyway, the infrastructure area in Bangkok can be considered approximately equal to a fraction of the total land area:

$$A_f = A_t * F_i$$

Where:

- A_f is the infrastructure area in Bangkok
- F_i is the fraction of Bangkok's area occupied by infrastructure
- A_t is the total land area of Bangkok

Canals in Bangkok can hold some amount of runoff water. We know that

- There are 1,682 canals in Bangkok.
- The total canal length is 2,604 km.

We need to find the maximum volume of water these canals can hold.

Assumptions:

- We'll assume a uniform cross-sectional area for all canals, which is a simplification for the sake of calculation.
- We'll need to estimate an average canal depth and width to calculate volume.

Formula:

Volume (V) = Area (A) * Length (L)

Estimating Average Canal Dimensions:

- Based on typical canal dimensions in urban areas, we'll estimate an average depth of 3 meters and an average width of 5 meters.

Calculating Total Canal Length:

Convert kilometers to meters: 2,604 km * 1000 m/km = 2,604,000 meters

Calculating Cross-Sectional Area:

A = width * depth = 5 m * 3 m = 15 m^2

Calculating Maximum Volume:

V = 15 m^2 * 2,604,000 m = 39,060,000 m^3

Therefore, the maximum volume of water the canals in Bangkok can hold is approximately 39,060,000 m^3.

This is a rough estimate based on several assumptions. Actual canal depths and widths can vary significantly, affecting the total volume capacity. Additionally, factors such as sedimentation, obstructions, and maintenance can influence the canals' ability to hold water.

The volume of floodwater in Bangkok at a critical flood height can be calculated by considering the city's total area and the volume of infrastructure that displaces water:

$$V_f = (A_t * H_c) - (A_t * F_i * H_f)$$

Theoretically, flooding in Bangkok occurs when the inflow of water exceeds the city's drainage capacity, which is estimated to be around 2,700.06 cubic m^3/s (Bangkok Drainage and Sewerage Department, 2024). The severity of flooding is influenced by the duration of the overflow, with longer periods leading to higher water levels.

Therefore, we have nine key variables:

(1) **Critical Flood Height:** The maximum water level at which pedestrian or vehicular access becomes hazardous or impossible due to flooding.

(2) **Overflow Duration:** The consecutive number of days during which the flood water level exceeds the capacity of the drainage system.

(3) **Water Inflow Rate:** The volumetric flow rate of water entering the city or region, measured in cubic meters per second (m^3/s).

(4) **Infrastructure Area Fraction:** The ratio of the total area occupied by infrastructure (*e.g.*, buildings, roads) to the total area of the city or region.

(5) **Infrastructure Height:** The height of infrastructure elements (*e.g.*, buildings) that are submerged during a flood.

(6) **Canal Width:** The width of the canal used to drain flood water from the city to the sea, measured in meters (m).

(7) **Canal Depth:** The depth of the canal used to drain flood water from the city to the sea, measured in meters (m).

(8) **Actual Water Volume:** The net volume of flood water in the city or region, calculated as the difference between the inflow and outflow rates over time. If the outflow rate exceeds the inflow rate, the actual water volume is zero.

(9) **Canal Space Fraction:** The ratio of the empty volume within the canal to the total volume of the canal.

Infrastructure plays a crucial role in urban or city flood risk. The area, height, and volume of infrastructure can significantly influence the severity and extent of flooding in urban areas. For example, densely packed buildings and impervious surfaces can increase runoff and reduce the capacity of natural drainage systems, leading to more frequent and intense flooding. Conversely, well-planned infrastructure, such as green spaces, detention ponds, and floodwalls, can help to mitigate flood risk and protect urban communities.

The key concepts in determining the potential impact of infrastructure on flood risk are the infrastructure area and infrastructure height. These factors directly influence the infrastructure volume, which effectively displaces an equivalent volume of floodwater before the flood height reaches a critical level.

Infrastructure area refers to the footprint or surface area of the infrastructure, such as buildings, roads, or bridges. A larger infrastructure area will displace a greater volume of floodwater, potentially reducing the overall flood impact.

Infrastructure height is the vertical dimension of the infrastructure, measured from the ground level to the highest point. A taller infrastructure can displace floodwater to a higher level, potentially mitigating the effects of flooding on surrounding areas.

Infrastructure volume is the total volume of the infrastructure, calculated by multiplying its area by its height. The infrastructure volume directly correlates to the amount of floodwater it can displace. However, only the portion of the infrastructure that is submerged in floodwater contributes to floodwater displacement. The height above the floodwater level does not directly affect the volume of displaced water. Therefore, when assessing the impact of infrastructure on flood risk, it is essential to consider only the height that lies beneath the floodwater surface.

Flood height is the vertical distance between the water level and the ground level during a flood event. When the flood height reaches a critical level, it can cause significant damage to property and infrastructure.

2.2 Flood Risk Assessment with Hazard Quotient

The hazard quotient (HQ) is a useful metric for quantifying flood risk. It can be determined using the following equation:

$$HQ = \frac{V_t}{V_c}$$

V_t is the actual water volume at time t and V_c is the water volume causing flood height of *x* meters.

Interpretation:

- HQ < 0.5: The area is at low risk of flooding. The actual water volume is less than what's needed to reach the specified flood height.
- 0.5 < HQ < 1: The area is at moderate risk of flooding. The actual water volume is equal to what's needed to reach the specified flood height.
- HQ ≥ 1: The area is at high risk of flooding. The actual water volume exceeds what's needed to reach the specified flood height.

Key Considerations:

- **x meters:** The chosen flood height is crucial. It should be based on historical data, local infrastructure, and the community's vulnerability to flooding.
- **Water Volume:** Accurate estimation of both actual and potential water volumes is essential. This involves factors like rainfall intensity, catchment area, and drainage efficiency.

- **Flood Risk Mapping:** Hazard quotients can be used to create flood risk maps, visually representing areas with different levels of vulnerability.

Examples:

1. If a region has an HQ of 0.8 for a flood height of 2 meters, it suggests that the current water volume is 80% of what's needed to cause a 2-meter flood. This indicates a moderate risk.
2. *Input*:
    - The capacity of drainage system in Bangkok is 2,700.06 m^3/s (Bangkok Drainage and Sewerage Department, 2024).
    - The water inflow is 6,000 m3/s for three consecutive days.
    - The infrastructure area above the ground covers 80% of Bangkok area, and
    - The infrastructure height is 0.1 m

Output: We have a hazard quotient of 0.5, indicating that the area is at moderate risk of flooding. This means that the actual water volume is half the amount needed to reach the specified flood height of 0.1 meters. In other words, the area is currently experiencing a flood event that is only 50% of the magnitude required to cause significant flooding.

3. Web Application

Building upon the above theoretical frameworks, a web application for evaluating flood risk in Bangkok has been developed (Kietpawpan, 2024). This user-friendly tool serves as a valuable resource for policymakers and urban planners to design effective flood prevention and response strategies.

The application hinges on two crucial parameters: potential *inflow of floodwater* and the city's *actual drainage capacity*. By considering these factors, the application assesses Bangkok's flood risk under the existing drainage system's limitations.

Assuming that 90% of Bangkok's area is covered by infrastructure that is submerged at a depth of 0.2 meters, our analysis indicates that a continuous inflow of floodwater exceeding 10,000 m^2/s for three days could lead to a critical flood height of 0.3 m.

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References

Bangkok Drainage and Sewerage Department. 2024. Flood Prevention Plan B.E. 2567 (in Thai). p. 2-9: https:// dds.bangkok.go.th/public_content/ files/001/0008491_1. Pdf. (access Sep 12, 2024)

Kietpawpan, M. 2024. Flood Dynamics and Risk Assessment. Github Repository: http://kietpawpan.github. io/ flood/. (access Sep 13, 2024)