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Scientific essay

Analysis of people's stability during urban floods using numerical modelling

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Abstract

This study tries to review and focus developing a computational model to simulate the behavior of individuals in flood-prone areas, taking into account some factors such as water depth, flow velocity, and building structures. By incorporating these variables into the model, the study seeks to assess the stability of people in different flood scenarios and identify potential risk factors. The findings of this research will provide valuable insights for urban planners and emergency management authorities to improve flood preparedness and response strategies. Additionally, the study aims to contribute to the development of more effective early warning systems and evacuation plans for urban flood events.

Keywords: Urban; Flood; Numerical modelling; Stability.

1. Introduction

Extreme flood events can cause great economic and/or human losses. The severity of the impact of a flood will depend on the conditions of exposure to such a threat. The occurrence of floods in densely populated urban basins means that people who occasionally move within flood zones are exposed to loss of stability and may be swept away by the current. The probability of a pedestrian losing stability depends mainly on the hydrodynamic conditions and the anthropometric characteristics of the person. In general, the characterization of the hydrodynamic conditions of the flood flow is carried out based on two main variables: water depth and flow speed. Meanwhile, the properties of the human body that is exposed to this current are usually represented by its size and weight. The

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linking of these variables with the objective of detecting instability thresholds is carried out using various stability criteria. The objective of this work is to characterize the danger to people, linked to instability, associated with an ordinary extreme event in a densely populated basin.

Children are particularly vulnerable during floods due to their smaller size, limited mobility, and lack of understanding of the dangers associated with flooding (Rosmadi *et al*., 2023). Instability during floods can pose several risks to children, including:

1) Drowning: Floodwaters can rise rapidly and pose a significant risk of drowning for children who may not be able to swim or understand the dangers of moving water.
2) Injury: Children may be at risk of injury from debris, falling objects, or collapsing structures during a flood. They may also be more prone to accidents due to their smaller size and limited ability to navigate through flooded areas.
3) Illness: Floodwaters can contain harmful bacteria, chemicals, and other contaminants that can cause illness if ingested or come into contact with the skin. Children are more susceptible to these health risks due to their developing immune systems.
4) Emotional trauma: The upheaval and disruption caused by flooding can have a significant impact on children's mental health and well-being. They may experience fear, anxiety, and stress as a result of the instability and uncertainty associated with floods.
5) Separation from caregivers: During floods, children may become separated from their parents or caregivers, leading to further distress and potential danger as they try to navigate through unfamiliar and hazardous conditions on their own.

Stability analysis criteria are essential for people in various features of their lives. Whether it's in personal relationships, career decisions, financial planning, or mental comfort, having a set of stability analysis criteria can help individuals make informed and rational choices. By evaluating different aspects such as risk, consistency, and long-lasting impact, people can assess the stability of their decisions and actions. This can ultimately lead to a more secure and fulfilling life. In this introduction, the importance of stability analysis criteria for individuals and how it can positively impact their overall safety will be explored.

2. Main body

2.1. Stability criteria

In recent literature, new formulations of criteria for the stability of people during a flood can be found and obtained with a solid physical basis (Xia *et al*., 2014; Milanesi *et al*., 2015; Arrighi *et al*., 2017). All criteria base their analysis on the modelling of the human body and on the study of the balance equations that involve all the intervening forces. The differences lie mainly in the approach to body modelling (physically or numerically) and in the degree of simplification of the dynamic forces that act on the human body.

Two different mechanisms can cause people to become unstable during a flood: overturning or sliding. Overturning occurs when the mobilizing moment caused by the incident flow exceeds the moment of resistance offered by the resulting weight of the body. Slipping occurs if the drag force of the flow is greater than the frictional resistance between the person's feet and the ground surface.

In this work, the study of the stability of people exposed to a flood is carried out using the following criteria:

- Xia *et al*. (2014) obtained two formulas for the incipient flow velocity in a human body for sliding and overturning instability. The relationships are based on a mechanical analysis, and both take into account the effect of body buoyancy and the influence of a non-uniform current velocity profile acting from upstream on the human body. These relations were validated with human-scale physical models.
- Milanesi *et al*. (2015) presented a vulnerability criterion based on the analysis of a simplified model of the human body and studying the stability against sliding or overturning through the balance of forces and moments. In addition, they consider the possibility of drowning of the person from a maximum depth. This criterion was validated by contrasting a variety of experiments on physical models.
- Arrighi *et al*. (2017) proposed a dimensionless analysis based on the proposal of a mobility parameter that depends on the Froude number of the flow, and which is validated from the three-dimensional simulation of the hydrodynamic forces that act on the human body during flooding.

2.2. Numerical modelling

In the Metropolitan Region of Buenos Aires (MRBA), the occurrence of extreme rainfall produces urban flooding, directly impacting the quality of life of the population. Precipitations that occurred recently in the MRBA, such as those in October 2012, April 2013 or February 2014, with volumes of the order of 100 mm in one day, have not only caused serious social problems but also a deterioration in the existing infrastructure.

The Dupuy stream basin, in the town of Laferrere in La Matanza (Buenos Aires, Argentina) has a population of about 200,000 inhabitants. During the last five years, the inhabitants of the lower basin in Laferrere Sur-the area of greatest impact, have suffered around 40 floods due to the overflowing of the stream (Figure 1). In this region, the high probability of flooding is combined with the high population density. For this reason, it is necessary to study the dangers associated with the instability of the people in the basin during a flood event.

Figure 1. Problems of the stability of people in the Dupuy stream basin, Laferrere (Garcia Merou street, between Saenz and Varela).

To evaluate the flow characteristics in streets during a flood in this basin, a hydrological-hydraulic model (Re *et al*., 2018) was used based on the EPA-SWMM (EPA storm water management model) code that was implemented for the entire Dupuy stream basin from preprocessed data through a Geographic Information System (GIS). This model is a single-event or continuous flood model with the ability to calculate the phenomena of evaporation, snowmelt, seepage, deep infiltration and subsurface flows, which aims to simulate the quantity and quality of urban watershed runoff. Using it, flow trending is possible in three modes; permanent flow, kinematic wave and dynamic wave.

2.3. Results

Numerical modelling of the Dupuy stream basin was carried out for the storm of February 7, 2014. This storm was selected because it was one of the most important of the last 5 years. It rained around 120 mm in about 8 hours.

From the simulation, the series of flow velocity and depth in each street section of the basin were extracted. Then, the average anthropometric characteristics of children and adults were raised, and the curves that represent the stability thresholds of the three aforementioned criteria were obtained as a function of the depth and speed of the flow. It is observed that there are relatively important differences between the criteria, especially for lower speeds. In each street section these curves were linked to the series of water depth and speed (Figure 2). According to the criterion used, for each street section, it was obtained that whether the stability threshold had been exceeded. This analysis allowed mapping to be carried out indicating the areas with danger of instability of people according to the storm studied (Figure 3).

Then, the time of which the stability threshold is exceeded on each street section was calculated, putting different groups of people at risk. The possibility of associating sections of dangerous streets with exposure times, through specific mapping, offers greater precision in the characterization of the threat. As a summary, Figure 4 shows, for the entire basin, the average time of danger for each criterion, differentiating between adults and children.

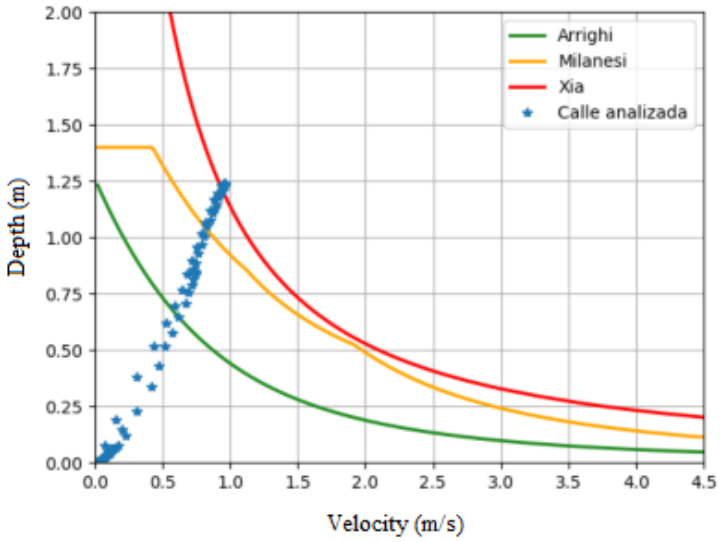

Figure 2. Analysis of the stability criteria considering adults and the simulated hydrodynamics of a particular street.

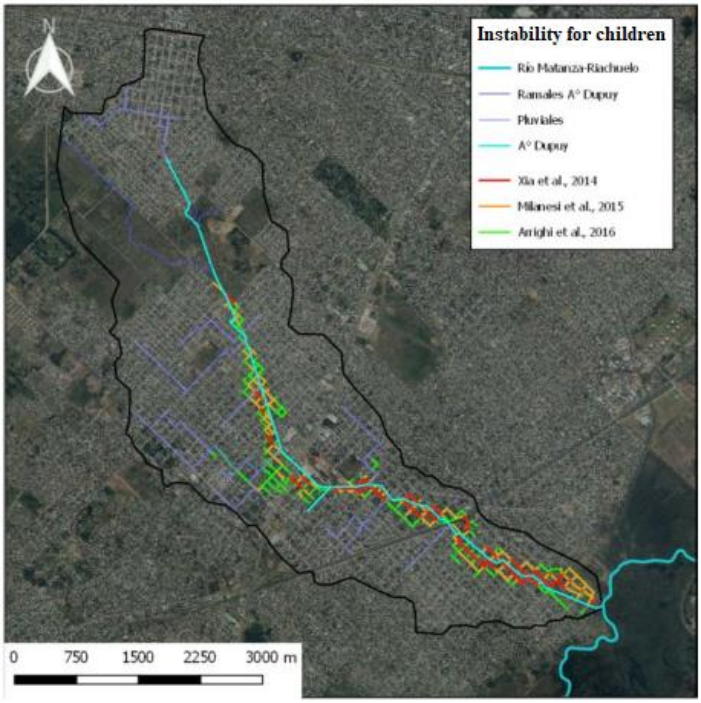

Figure 3. Map of streets with danger of instability for children

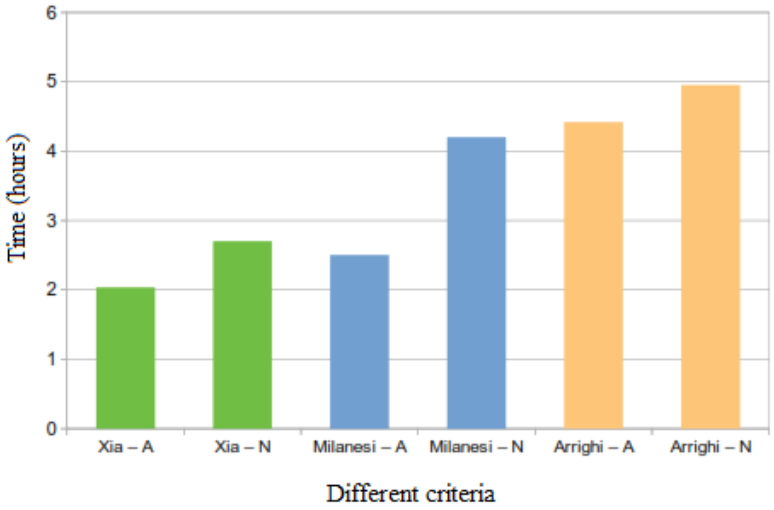

Figure 4. Average duration of hazard for the different criteria for the storm on February 7, 2014.

It is essential for parents, caregivers, and communities to take proactive measures to protect children during floods by ensuring their safety, providing emotional support, and educating them about the risks associated with flooding. Additionally, emergency preparedness plans should include specific provisions for the needs of children in order to minimize the dangers they face during such natural disasters.

Conclusions

The application of stability analysis criteria for people, developed with a solid physical basis, and validated based on different representation strategies of the human body, is an unavoidable task in understanding the danger of flooding in urban basins.

The number of street sections at risk of instability for people during a flood depends on the determination criterion. For the event of February 7, in the Dupuy stream basin, it is observed that the number of dangerous street sections does not result in significant differences, which allows the precise establishment of areas where mitigation measures for possible impacts can be applied (signaling, placement of railings, etc.).

Due to the characteristics of the events that produce important impacts in this basin and the dynamics that occur in the area in terms of flood management, the differences between the criteria regarding the average duration times of the instability situation they are not significant. The result of the average range of 2-5 hours of instability in an area limited by streets in the basin represents a very useful characterization for risk management in the basin and for the implementation of measures to mitigate the impact of floods.

In summary, stability analysis criteria for people are essential for ensuring their physical, mental, and emotional well-being. By considering factors such as balance, coordination, strength, flexibility, and cognitive function, individuals can work towards maintaining stability and reducing the risk of falls and injuries. Additionally, addressing psychological stability through stress management and emotional resilience can contribute to overall

stability and wellness. It is important for individuals to regularly assess their stability and seek professional guidance when necessary to maintain a healthy and stable lifestyle.

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