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MODELING THE BEHAVIOR OF THE SEWERAGE NETWORK IN RAINY WEATHER AND CLASSIFICATION OF OVERFLOWS ACCORDING TO THE FLOOD HAZARD CASE OF THE ALGIERS CITY

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ABSTRACT

To reduce losses induced per urban flood risks, it is necessary to study them through numerical modeling and obtain beforehand accurate and reliable information. In this manuscript, the sewer rainwater network (in the central part of the city of Algiers) has been modeled, and its behavior has been simulated for different return periods using the one-dimensional model of Mike Urban with unidirectional coupling between the hydrological and hydraulic models. The simulation focuses on two known flow processes: hydrological simulation (single and double linear reservoir) and hydraulic simulation (solving the Saint Venant equations). Model calibration is carried out on rainfall-flow measurements conducted during rainy periods. The simulation allowed to identify the overflow points in the network. These points will be classified according to the flood hazard defined by the overflow height and flow velocity, which will be estimated from the slope map. To combine these two factors (height and velocity), the concept of specific energy is used to quantify the flood hazard. The hazard scores obtained were classified into four classes using the jenks natural breaks method, where 58% of overflow points present a significant hazard.

Keywords: Modeling, Urban Floods, Simulation, Sewer Network, Hazard.

INTRODUCTION

Urban flooding poses a significant global challenge and stands as one of the most devastating recurring natural disasters (Benkhaled et al., 2013; Eldho and al., 2018; Hafnaoui et al., 2022; Remini, 2022; Remini, 2023; Hafnaoui et al., 2023). It not only results in substantial socio-economic repercussions but also leads to adverse environmental and ecological consequences (Yin and al., 2016). Urban flooding comes in three forms: pluvial, fluvial, and coastal (Sebastian and al., 2022). This study specifically focuses on pluvial flooding.

Pluvial flooding transpires when heavy or prolonged rainfall saturates and overwhelms an insufficient or failing stormwater drainage system, causing it to overflow. Historically, pluvial flooding has often been underestimated, perceived as manageable, and deemed less destructive. Nevertheless, mounting evidence suggests that pluvial flooding is a significant contributor to cumulative damage over time (Sebastian and al., 2022; Abd Rahman et al., 2023).

Urbanization, anarchic occupation of space, and the lithological nature of watersheds, emerge as a potential driver of pluvial floods (Nezzal et al., 2015; Derdour et al., 2017; Kouadio et al., 2018; Aroua, 2023; Ben Said et al., 2024). The process of urbanization entails the removal of vegetation and the waterproofing of surfaces, resulting in increased peak hydrograph levels, greater runoff volumes, and reduced infiltration capacity, thereby diminishing groundwater recharge. Furthermore, the majority of existing drainage systems are inadequately equipped to handle these changes. Rapid urbanization has far outpaced the development of urban infrastructure, rendering cities more susceptible to pluvial flooding (Yang and al., 2020).

Furthermore, climate variability and change have a direct impact on overall flood risk (Benslimane et al., 2020; Aroua, 2020; Nassa et al., 2021; Nakou et al., 2023). Global warming, in particular, is accelerating the Earth's water cycle, resulting in increased flood frequency and intensity in various regions. Climate change introduces greater uncertainty into weather patterns, making rainfall less predictable and heavy rainstorms more likely (Chagas and al., 2022; Li and al., 2022).

As a consequence, the implementation of urban flood forecasts and early warning systems is crucial for mitigating flood-related damages (Hountondji et al., 2019; Cherki, 2019; Remini, 2020; Gassi and Saoudi, 2023; Zegait and Pizzo, 2023; Bentalha, 2023; Shaikh et al., 2024). Urban flood modeling is therefore an essential component of flood risk management (Bekhira et al., 2019; Addison-Atkinson and al., 2022). The field of urban flood modeling is a relatively recent area of research. Until the early 21st century, there was limited research dedicated to understanding and modeling urban flooding. However, the past two decades have witnessed a significant increase in both experimental and computational studies in this field.

For instance, Yang and al. (2020) introduced an innovative approach to model urban pluvial flooding by combining the 1D stormwater management model (SWMM) and the 2D flood model (ECNU Flood-Urban). The study by Baudhanwala et al. (2023) aimed to simulate the existing stormwater drainage system and to identify any overflowing manholes in Surat City (West Zone of India) by employing the Storm Water Management Model (SWMM). The SWMM modeling results, specifically the manhole overflows, are utilized as an input boundary condition for the ECNU Flood-Urban model to replicate rain-runoff processes in an urban setting. This approach was implemented within the central business district of East Nanjing Road in downtown Shanghai, China. The results of the coupled model demonstrate its reliability, suggesting that it can effectively simulate urban surface water flooding using this methodology. Similarly, Huang and al. (2021) introduced an integrated hydrological and hydrodynamic model that establishes horizontal and vertical connections. This model is based on the stormwater management model (SWMM) and a self-developed two-dimensional model, and it was applied in the Donghaochong basin in Guangzhou, China. Their study affirmed the reliability and significant practicality of this integrated hydrological and hydrodynamic model. Some studies employed the one-dimensional (1D) SWMM and the two-dimensional (2D) MIKE URBAN model to design an efficient drainage system for a small urbanized area in West Bengal, India. They also designed a retention pond to address groundwater recharge and mitigate peak flow during high-intensity precipitation events downstream. This study underscored the importance of the 2D model in addressing location-specific flooding issues. Other studies are also available in the literature, such as those by Su and al. (2019), Hasan and al. (2019), Rabori and Ghazavi (2018), Qureshi et al. (2024), Mah et al. (2024).

The fundamental science of urban flood modeling draws upon urban hydrology, hydrodynamic mechanisms, and their interplay (Salvadore and al., 2015). Typically, an urban flood model encompasses modules for runoff generation, confluence, and flood analysis. Nonetheless, it is challenging to model urban flooding due to the complex flow phenomena that rapidly change in space due to the multiple flow paths typical of urban areas (Mignot and al., 2022). When water flows through the streets, local pressure losses occur due to the presence of obstacles, such as vehicles or street furniture, as well as interactions between the drainage system and surface flow. Flow characteristics become particularly intricate at intersections and in various configurations, such as when water enters open spaces like courtyards and parks, infiltrates buildings and large underground areas such as metro stations, or follows unconventional flow paths created by the arrangement of obstacles in urbanized areas. Moreover, rapid urban flooding, such as flash floods, leads to complex transient effects and the transport of debris and objects (Martínez-Gomariz and al., 2018).

Furthermore, there's the additional challenge of a scarcity of observational data to verify urban flooding calculations. These data, for the most part, are limited to watermarks on building facades, typically recorded through visual inspections shortly after a flooding incident. This approach leads to a lack of appropriate calibration and validation data, especially in terms of velocity fields and time-dependent hydraulic information. The growing use of smartphones and video recording by citizens introduces a new approach to gathering validation data, and current research is heavily focused on extracting reliable information from amateur videos (Mignot and al., 2022).

The aim of this work is to establish a model of the Algiers sewer network, simulate its performance for various return periods using the 1D model of Mike Urban, featuring unidirectional coupling between the hydrological and hydraulic models. Subsequently, our approach will involve identifying the primary overflow-prone areas within the network and categorizing them based on the level of flood hazard, assessed using the specific energy equation.

RAINFALL-RUNOFF IN URBAN AREAS

Flood modeling requires a good understanding of the important processes that occur in the drainage network, from input (rainfall) to output (Bulti and Abebe, 2020; Jaafar and al., 2015). In most urban areas, precipitation is the main source of runoff (Bulti and Abebe., 2020; Tingsanchali, 2012; Butler and Davies, 2011). Therefore, it is essential to model these input data with the utmost precision.

Numerous models have been developed to replicate rainfall-runoff processes in urban settings. These models include the Storm Water Management Model (SWMM), the Urban model by the DHI group for simulating urban infrastructure (MIKE), the Hydrological Simulation Program Fortran (HSPF), the Storage Treatment Overflow Runoff Model (STORM), and the Integrated Catchment Modeling (InfoWorks-ICM). Most urban runoff models documented in the literature are generally structured around two categories of functions: production functions and transfer functions (Fig. 1) (Rammal and Berthier, 2020; Rossman and Hube, 2015).

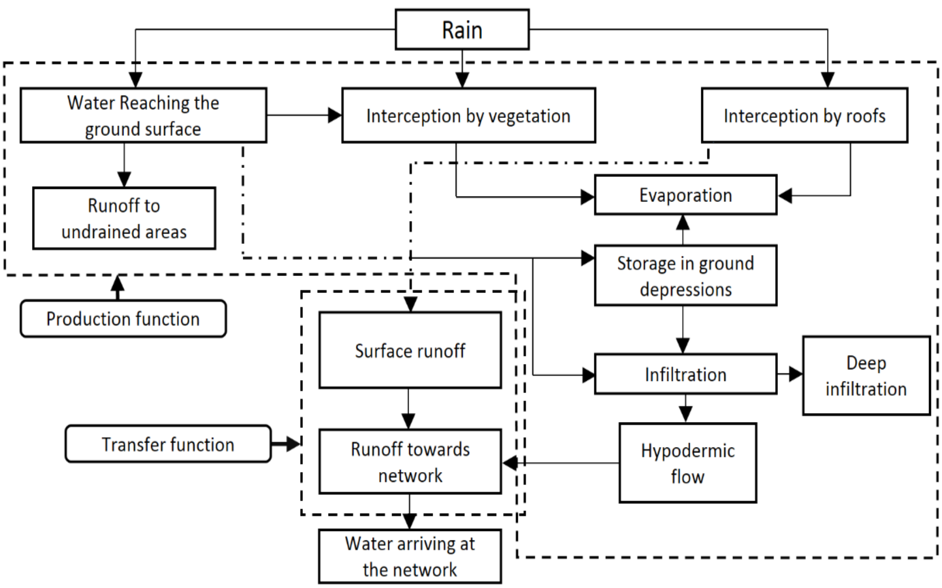

Figure 1 : The details and interactions between the production function and the transfer function

The production function represents the hydrological processes responsible for all the losses incurred by rainwater when it reaches the surface of the catchment before being transported as runoff through the sewerage network to the catchment outlet. Consequently, the volume of runoff arises from a complex interplay of various hydrological processes, which are typically categorized into three processes: retention, evaporation, and infiltration. Retention primarily takes place at the onset of rainfall events and is consequently regarded as initial losses, whereas infiltration and evaporation contribute to runoff losses during and after the rainfall event, thereby considered as continuing losses. The production mechanism, especially on impermeable surfaces, is still regarded as highly intricate and far from complete comprehension (Rammal and Berthier, 2020; Zoppou, 2001). The transfer function models surface flow, subsurface flow, and drainage network flow. Transfer processes can be physically described (Rammal and Berthier, 2020). When the quantity of precipitation surpasses the combined value of initial and continuing losses, the surplus rainfall, referred to as runoff, begins its flow across the surface and enters the drainage system. Nevertheless, if the capacity of the drainage network is met or exceeded, the overflow that occurs as a consequence is termed pluvial flooding (Bulti and Abebe, 2020).

URBAN FLOOD MODELING

In urban flood studies, empirical, hydrodynamic and conceptual models constitute the main categories of flood models (Jeannot, 2018; Tom and al., 2022).

Empirical models

Empirical models, also known as black box models, include parameters that may possess physical characteristics, allowing the modeling of input-output relationships based on empirical data (Tom and al., 2022; Jeannot, 2018, Jun and al., 2016). These models are typically derived from statistical analysis of available input and output data and are represented as equations in the form of: outputs = f (input). They offer several advantages: simplicity, efficient computation, and a minimal number of parameters. Within their domain of validity, empirical models exhibit a high predictive capacity (Jeannot, 2018). However, their lack of insight into the underlying physical processes hinders their generalizability (Ecrepont, 2019).

Hydrodynamic models

These models simulate the movement of water by solving equations grounded in physical laws. Depending on the spatial representation of fluid flow, hydrodynamic models can be categorized as one-dimensional, two-dimensional, or three-dimensional flooding models (Tom and al., 2022; Chibane, 2021; Jeannot, 2018).

One-dimensional models

These represent the simplest hydrodynamic models, known for their computational efficiency, as they assume unidirectional flow, stability, and uniform flow speed within the channels (Tom and al., 2022; Bates and De Roo, 2000) One-dimensional flood models are derived by solving the mass and momentum conservation equations between two cross sections spaced Δx apart, resulting in the one-dimensional Saint-Venant equations (shallow water equation).

Conservation of Mass

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0 \tag{1}$$

Conservation of Momentum

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial(\frac{Q^2}{A})}{\partial x}+g\frac{\partial h}{\partial x}-g\left(S_0-S_f\right)=0 \tag{2}$$

Where Q is the flow discharge, A is the flow cross-section area, t is the time, h represents water depth, g is the gravitational acceleration, S_f is the friction slope and S_0 is the channel bed slope.

While one-dimensional hydrodynamic models require minimal input data, uncertainties exist in model outputs due to a lack of knowledge about crucial hydrological and hydraulic characteristics that characterize urban flooding. To address this, these characteristics need to be parameterized in model simulations and predictions to facilitate effective decision-making. Ongoing efforts persist to enhance the performance of these models (Tom and al., 2022).

Two-dimensional models

In general, 2D models depict the flow of water in floodplains through two-dimensional representations, assuming that the third dimension, often associated with water depth, remains negligible. Two-dimensional flood models such as TUTFLOW, SOBEK, and MIKE 21 employ numerical schemes to solve two-dimensional shallow water flow equations (Nkwunonwo and al., 2020; Dottori and Todini, 2013; Soares-Frazão and al., 2008). These models address the 2D shallow water equation, which considers the conservation of mass and momentum in a horizontal plane while incorporating depth averaging of the Navier-Stokes equation.

Conservation of Mass

$$\frac{\partial h}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hv)}{\partial y}=0 \tag{3}$$

Conservation of Momentum

$$\frac{\partial(hu)}{\partial t}+\frac{\partial}{\partial x}(hu^2+\frac{1}{2}gh^2)+\frac{\partial(huv)}{\partial y}=0 \tag{4}$$

$$\frac{\partial(hv)}{\partial t}+\frac{\partial}{\partial y}(hv^2+\frac{1}{2}gh^2)+\frac{\partial(huv)}{\partial x}=0 \tag{5}$$

Where x and y represent the two spatial dimensions, the (u, v) are 2D vectors representing the horizontal average velocity of the flow, t is the time and h represents water depth, g is the gravitational acceleration.

Advancements in remote sensing technology, particularly the availability of high-resolution and high-precision input data such as airborne Light Detection And Ranging (LiDAR) and synthetic aperture radar data (SAR), along with enhanced computing capacity, have notably boosted the popularity of two-dimensional models (Nkwunonwo and al., 2020).

One of the major advantages of two-dimensional flood models lies in their ability to comprehensively represent flow hydrodynamics, as well as the inclusion of small-scale topographic features that significantly influence urban flooding. Consequently, these models are increasingly employed in predicting flooding from various sources, contributing to their optimal performance in flood modeling (Nkwunonwo and al., 2020).

This model necessitates high-resolution topographic data and access to high-end computing facilities, which presents a significant limitation for its application in developing cities. Furthermore, the absence of rigorous model calibration further restricts the utility of these models in such urban environments (Tom and al., 2022).

Three-dimensional models

Three-dimensional flood models solve the Navier-Stokes equations and fully account for the three-dimensional nature of floodwater flow (Nkwunonwo and al., 2020; Ne'elz and Pender, 2009).

Conservation of momentum

$$\frac{\partial u}{\partial t}+u.\nabla u+\frac{1}{\rho}\nabla p=g+\mu\nabla.\nabla u \tag{6}$$

Incompressibility condition

$$\nabla.u = 0 \tag{7}$$

Where u is the flow velocity, ρ is the fluid density, p is the fluid pressure, g is the gravitational acceleration and μ is the kinematic, t is the time.

Some authors contend that utilizing a three-dimensional model might introduce unnecessary complexity, as a two-dimensional representation could be sufficient for simulating and predicting flow dynamics at various scales (Tom and al., 2022).

The use of 3D modeling in flood prediction is relatively recent, resulting in limited available literature. The challenges associated with implementing 3D models in developing cities align with those encountered when using 2D models (Tom and al., 2022; Nkwunonwo and al., 2020).

Conceptual Models

These consist of a series of interconnected reservoirs subject to processes such as precipitation, infiltration, percolation, evaporation, runoff, and more (Jeannot, 2018; Devia and al., 2015). Semi-empirical equations are employed in this approach. Model parameters are inferred from field data and undergo a calibration phase, notably concerning the parameters of the semi-empirical equations. Each reservoir is governed by three equations: the continuity equation (mass conservation), the storage equation (addressing volume changes), and the exchange equation(s) between reservoirs

(Ecrepont, 2019; Hingray and al., 2009). In a broader context, conceptual models require less computationally intensive demands, making them valuable tools for large-scale applications where flood extent and depth are the only required outcomes. This is because dynamic effects are assumed to be insignificant and have no influence on the results (Tom and al., 2022).

MODEL OF THE STUDY AREA

Presentation of the sewerage system of the study area

The city of Algiers features a predominantly unitary type sewerage system, characterized by a branched structure in which both wastewater and rainwater flow through the same collector. Thanks to favorable topography, the collection network, excluding the wastewater transfer infrastructure to treatment plants, primarily relies on gravity for flow. The system incorporates 60 main storm overflows and includes 3 sewerage treatment plants (STP), as illustrated in Figure 2.

The sewerage system spans approximately 3,050 kilometers and is categorized as follows:

- Primary network: 550Km ovoid or tunnels, with a height (h) > 2 m;
- Secondary network: 550 km of various sections with 1.2 < h < 2 m;
- Tertiary network: 1,950 km of non-visitable collectors of various sections with 0.2 < h < 1.2 m.

In rainy weather, the city frequently experiences significant flooding due to the overflow of the sewerage system. This is primarily attributed to the under-sizing of the network. In fact, several parts of the network were designed with return periods of 2 years or even 6 months, in accordance with the directives of the sewerage master plans from 1975 and 1994. These design criteria appear to be highly unreliable when compared to the standards applied in other similar large cities around the world.

In many countries, it is considered a minimum standard to factor in return periods of 10 years, with the possibility of increasing this for specific sectors where network overflows would have a significant impact. For example, the European standard EN 752, endorsed by the European Committee for Standardization (Schmitt and al., 2004), recommends that urban drainage systems be designed to withstand floods with return periods ranging from 10 to 50 years.

Additionally, the network faces issues with clogging caused by the accumulation of various waste and sediment due to insufficient maintenance, exacerbating its capacity limitations. In certain areas, the slope of the network promotes the occurrence of overflows. In reality, the sewer network in the city of Algiers largely follows the natural topography, which features both high and low zones. In the lower areas, the collectors have very gentle slopes, typically ranging from 0.1% to 0.2%. These minimal slopes hinder self-cleaning processes, leading to the deposition of solid materials and silt, consequently reducing the network's capacity. These challenges are compounded by poorly controlled urban development, including construction in bowl-shaped areas, and greater basin waterproofing than initially anticipated.

Fig. 2 provides a simplified overview of the sewerage system in the city of Algiers. In this study, our focus will be on the performance and behavior of the sewerage system in the central area of the city, as depicted in Fig. 3.

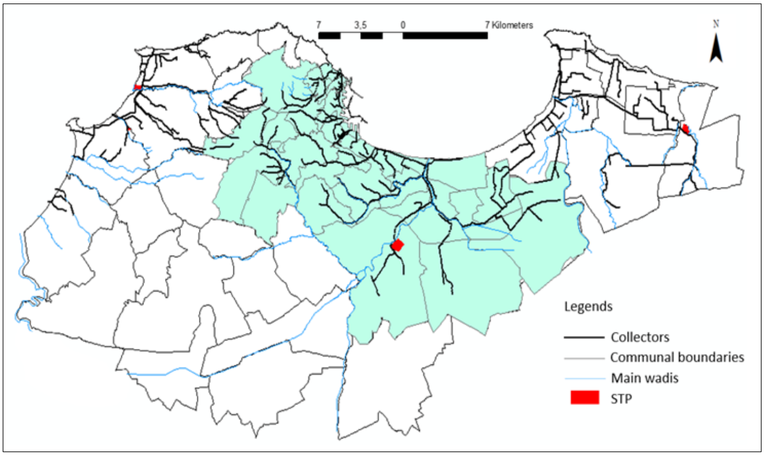

Figure 2 : Sewerage network of the city of Algiers

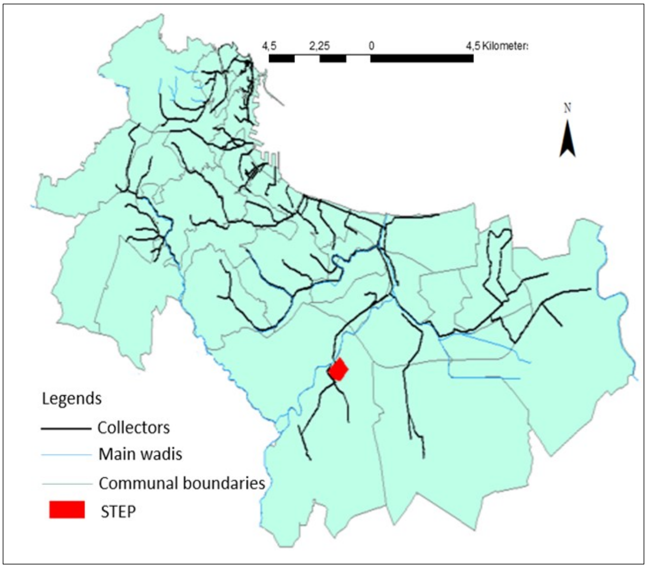

Figure 3: Targeted Modeling Area (Central Algiers)

Mike Urban

MIKE URBAN is professional software that offers advanced modeling for drinking water distribution networks as well as wastewater and/or rainwater collection networks, all integrated into a GIS (Geographic Information System) interface. This interface, called "Model Manager", is mainly based on ArcGIS components. Model data is stored in a standard georeferenced database. With MIKE URBAN, it is possible to carry out hydrological and hydraulic simulations for collection networks. This includes the calculation of runoff, free surface flows, network loading, as well as taking into account water quality and sediment transport both on catchment areas and in networks (ESRI, 2023).

Modeling process

Structural network modeling

The construction of the structural model (Fig. 4) first involves dividing the overall catchment into sub-catchment, defining the nodes and pipe segments, as well as the ancillary works of the network. Once the model was constructed, the results from the measurement campaign were used to calibrate the model. The model was calibrated at numerous points based on rainfall and hydraulic measurements (water levels and flow rates) taken during rainy weather throughout the winter campaign. This calibration relies on these data to adjust certain hydraulic and hydrological parameters to align the simulations with real flow conditions. The parameters adjusted during calibration are of two types: hydrological parameters, including the imperviousness coefficients, reduction coefficient, initial losses to runoff, and catchment response time, as well as hydraulic parameters such as the Manning-Strickler roughness coefficients and singular losses.

The imperviousness coefficient, is a key parameter for characterizing catchments. It is an intrinsic property of each catchment, expressed as a percentage, indicating the rate of imperviousness, i.e., the proportion of built surfaces. Before constructing the model, we created a land use map to estimate this coefficient. Eight types of land use were identified in Algiers, and imperviousness coefficients were assigned to them. These coefficients were then visually adjusted using aerial photographs of each sector during calibration. The reduction coefficient, denoted C_r, characterizes the rate of collection of surface runoff by the catchment's surface infrastructures (drainage grates, gutters, etc.). In cities where the network is well-developed, C_r is typically set at 0.90, meaning that 90% of runoff water is collected by the network. In our case, a $C_r = 0.70$ was initially adopted before calibration, consistent with our field observations. The adjustment of this coefficient, like that of imperviousness, directly impacts the maximum runoff volumes and flow rates.

The catchment response time (Lagtime) was calculated for the Algerian model using Chocat's formula. The Manning-Strickler roughness coefficient, characterizes the nature of the materials constituting the networks or the occupancy rate of the bed in open wadis. In Algiers, we distinguished three categories for the examined surfaces and assigned roughness coefficients based on these categories before calibration. Adjusting this parameter affects the transit time of water in the networks, with significant impacts, particularly in long networks like those in Algiers.

The Mousse algorithm within the Mike Urban software relies on three primary categories of input data for hydrological and hydraulic simulations: network data, catchments data, and boundary conditions.

Network inputs mainly consist of nodes and pipes. The nodes most often represent the inspection points (manhole). Nodes are defined by the natural ground, raft ratings, the diameter and the type of node (normal, sealed, overflow). The “normal” type node allows the water which overflows, when the network is loaded, to be fictitiously maintained over a large surface area and reinjected into the model when the flood recedes. For the 'sealed' node type, water does not overflow, and the inherent loading is translated in terms of pressure. The water volumes from the 'overflow' node type are lost when the network overflows. Specific nodes with geometric descriptions can also be introduced into the model to characterize features such as pump chambers or detention basins. The outlets are also considered as specific nodes, because they make it possible to model the flow conditions upon arrival of the networks (downstream boundary conditions) at the receiving environment, whether in dewatered or flooded regime. These nodes are connected by pipes.

The main inputs for pipes include upstream and downstream nodes, the section (standardized or specific), pipe material type, slope, and optionally, an inlet or outlet elevation (to model falls). Catchment input data mainly includes the drained area, the average slope, the length of the longest hydraulic path, and the injection node to which the watershed drains. The catchment should flow to a predefined node from the defined nodes. Intrinsic 'hydrological' data related to the sub-catchment is also introduced into the model. There are two types of boundary conditions: upstream and downstream.

The upstream boundary conditions represent the results generated by the hydrological simulation (flow) that will enter the network through the injection nodes defined for each catchment (hydraulic simulation). The downstream boundary conditions consist of determining the outlets.

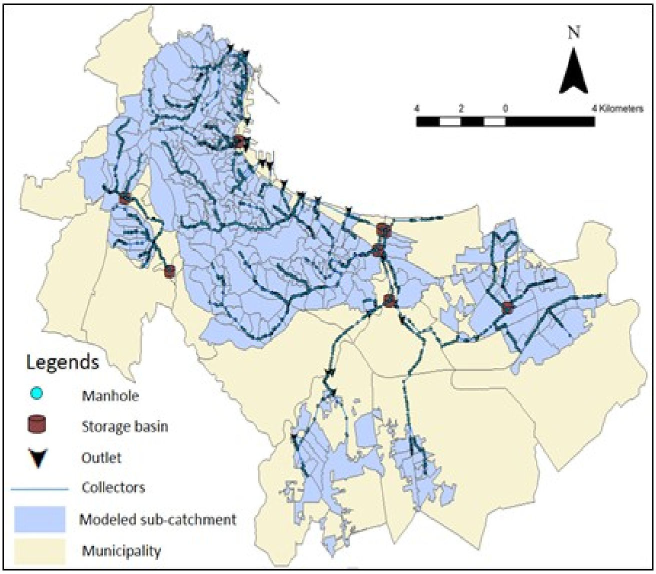

Figure 4: Structural model of the Algerian network

Rainfall Modeling

The input rains used are centered double triangle type project rains, with a total duration of 4 hours and an intense duration of 30 minutes. The choice of intense duration was guided by the average concentration time of the different modeled catchments. The objective being to choose the most unfavorable duration with regard to the risk of overflow. The precipitation amounts of these theoretical rains were defined using the IDF (Intensity Duration Frequency) curves from the Bir Mourad Raïs pluviograph, updated by the ANRH.

The project rainfall used are presented in Table 1 in terms of precipitated heights

Table 1: Project rainfall used for modeling network operation in wet weather

Return period (years)	Precipitation depth (30 mn)	Precipitation depth (4 hours)
2	28,7 mm	46.4 mm
5	38.7 mm	62.4 mm
10	45.3 mm	73.0 mm
20	51.6 mm	83.2 mm
50	59.8 mm	96.4 mm
100	65.9 mm	106.3 mm

Hydrological Modeling - Linear Reservoir Model

The linear reservoir is utilized to model surface runoff. In this method, each catchment is treated as a reservoir, which delays the arrival of rains to restore flow while maintaining volume. In addition, this time delay is carried out in a linear manner. These two notions, linear timing and conservation, are translated by the following equations (HYDRA, 2023).

Linear Delay

$$V(t) = K \ x \ Q_s(t) \tag{8}$$

Volume Conservation

$$\frac{dV(t)}{dt} = Q_e(t) - Q_s(t) \tag{9}$$

Where V(t) is storage volume, $Q_e(t)$ is inflow discharge deduced from net rainfall, $Q_s(t)$ is Outlet Flow, K is Linearity coefficient of time delay. It is commonly referred to as the catchment response time (Lag Time) in minutes. It is defined as the duration between the center of gravity of the input hyetograph and that of the output hydrograph.

There are two types of linear reservoirs: single and double, differentiated by the waterproofing coefficient. In regions with low waterproofing coefficients, the double linear reservoir method is commonly applied. This method involves the application of the simple linear reservoir approach twice, with each having a reaction time equal to half of the overall reaction time. This approach assumes that storage occurs in two stages, considering that depressions and the slow propagation of rainwater increase the effect of storage and response time (SAFAGE, 2015).

Hydraulic Modeling -Dynamic Wave

The hydraulic modeling of flows in the networks is established through the comprehensive resolution of the Saint-Venant equations (Eqs. (1) and (2)). The dynamic wave model is derived by assuming the complete non-linear form of the Saint-Venant equations (Venutelli, 2011). In addition to the complete St. Venant model (dynamic wave), MIKE URBAN also provides the option to use simplified forms of the St. Venant equations, namely, the diffusive wave model and the kinematic wave. According to the diffusive wave approximation, the spatial and temporal variations of the local momentum are neglected, and Eq. (2) simplifies to:

$$\frac{\partial h}{\partial x} = (S_0 - S_f) \tag{10}$$

The kinematic wave approximation considers only the effects of friction and the loss of potential energy. It is expressed as follows:

$$g(S_0 - S_f) = 0 \tag{11}$$

Either

$$S_0 = S_f \tag{12}$$

This approximation allows overcoming numerical difficulties associated with the use of Saint Venant's dynamic equations in certain cases. It is particularly suitable for modeling steep and very rough slopes with relatively low lateral water inputs (Weill, 2007).

The Saint-Venant equations, along with its two classical approximations, are non-linear partial differential equations. Only the kinematic wave approximation offers an analytical solution in a straightforward one-dimensional scenario. For more complex cases, numerical techniques are required for an approximate solution. The numerical resolution method for the Saint-Venant system employed by MIKE URBAN is of the fine-implicit difference type.

RESULTS AND DISCUSSION

The simulation of the Algiers sewerage system during rainy weather enabled the identification of network overflow points, as shown in Fig. 5. These points have been classified according to flood hazard.

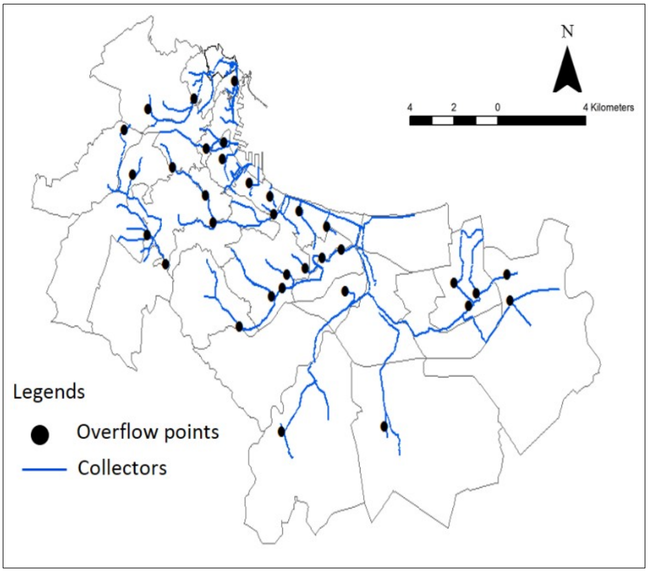

Figure 5: Location of the overflow points in the sewerage network of the central area of the city of Algiers

In the context of hazard, a flood is characterized by its magnitude (water height) and violence (flow speed). High water levels can result in drowning and property damage due to flooding, while fast flow speeds can carry away people, vehicles, and erode structures. People often underestimate the speed of flows, which can be perilous even with low water levels. To quantify this hazard using these two independent variables, we employ the concept of specific energy (E), as defined in Eq. (13) (Ayari and al., 2016).

$$H_i = E_i = h_i + \frac{v_i^2}{2g} \tag{13}$$

Where H_i is hazard at overflow point i, E_i is specific energy at overflow point i, h_i is overflow height at point i; v_i is flow velocity at overflow point i, g is the gravitational acceleration.

The heights are derived from simulation results, where for each point, we retain the water height corresponding to the return period of the first overflow occurrence. Since velocity data is not available, it will be estimated using the slope map (Fig. 6). The slopes are grouped into four classes using the natural breaks method. Each class is assigned a score from 1 to 4. It is assumed that velocity increases with the steepness of the slope. The velocity will be equal to the slope score.

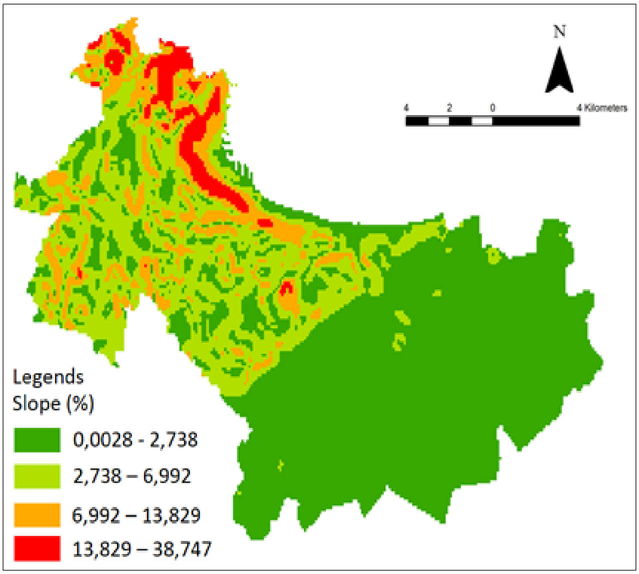

Figure 6*:* Slope classes

The natural breaks method optimizes the grouping of similar values and maximizes the differences between classes (categories). Entities are divided into classes, and the boundaries are defined where significant differences in data values occur (Arcgis Pro).

The hazard values obtained are transformed and rescaled to a scale of 10 using Eq. (14) and are then categorized into four classes using the natural breaks method (Fig. 7).

$$s_{H_i} = \frac{H_i * 10}{H_{max}} \tag{14}$$

Where s_{H_i} is hazard score out of 10 at point i, H_i is hazard at point i, H_{max} is maximum value of the hazard.

According to Figure 7, it can be observed that among the 33 overflow points, 19 of them, or 58%, are classified in the category of significant hazards (categories 3 and 4), while the remaining 42% fall into less significant hazard categories (categories 1 and 2).

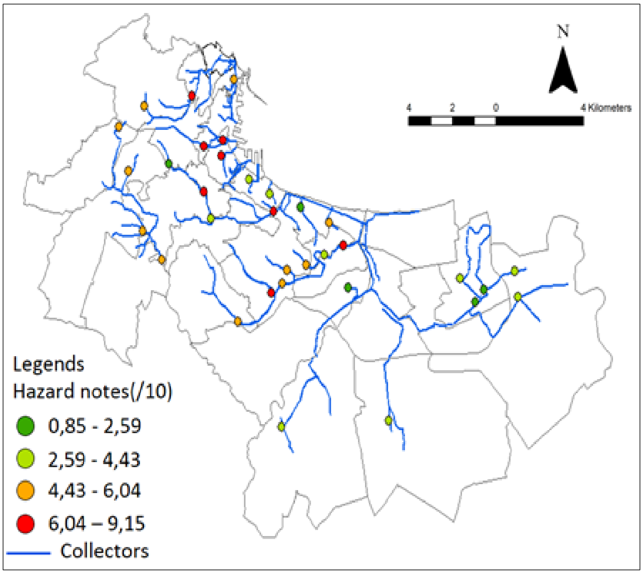

Figure 7: Classification of overflow points according to the hazard concept

The scores obtained for each point, are summarized in Figure 8.

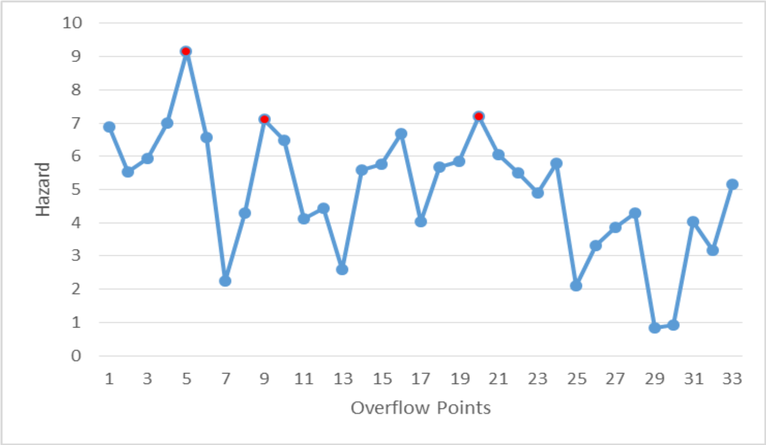

Figure 8: Hazard results according to overflow points

According to Figure 8, it appears that points 5, 9, and 20 have the highest hazard scores, particularly point 5, where the score exceeds 9 out of 10. This point is located in a very densely urbanized area, where overflows occur during rainfall with a return period of 2 years. Point 9 concerns a collector resulting from the covering of an oued, with works carried out between the 1930s and 1950s. This collector drains a catchment area of nearly 1,300 hectares, which is heavily urbanized, and it is one of the main collectors in Algiers. Regarding point 20, it is a collector built parallel to the oueds. During rain events, excess flows that the collector cannot handle are discharged into the oueds, either through storm overflow structures or by manhole overflow. However, frequent overflows occur due to insufficient hydraulic capacity, caused by undersizing and clogging issues.

The sanitation managers in the city of Algiers have proposed solutions to address these overflows, particularly at points 5 and 9. Given the importance of these collectors and the potential impact of overflows on the urban areas they cross, the proposed solutions are mainly conventional: the construction of storage basins and the duplication of collectors to increase their capacity. While these solutions may be effective, in an arid country like Algeria, which faces increasing water stress, it would be wise to explore alternatives for utilizing rainwater. The adoption of non-conventional techniques, such as collecting and reusing rainwater for irrigation or other purposes, could offer a more sustainable response to the overflow issues while helping to address the challenges of water resource management.

CONCLUSION

Through this study, we have been able to construct a model of the sewerage system in the central part of the city of Algiers. The objective was to identify critical points in the network with respect to rainfall overflow and classify them based on their hazards, thereby prioritizing interventions on the network. To quantify the hazard in a nuanced manner, we combined both water height and velocity using the specific energy formula. The ideal approach was to use a 2D model to not only identify the affected areas but also determine flow velocities, thus creating a flood hazard map for the city. This map will be a critical tool in flood management.

However, as mentioned above, the 2D model has the drawback of being costly and requires high-resolution topographic data and high-end computing facilities. Nevertheless, there are alternative methods that can utilize 1D simulation results as an initial condition and an elevation map to determine the affected areas. This can be achieved through meshing the elevation map and, for example, using cellular automata methods.

Urban flood modeling has become an important tool for flood management planning and drainage system design. It also provides valuable tools for crisis management and reducing potential damage caused by flooding, assessing the impacts of climate change on flood risks, and proposing adaptation solutions.

Declaration of competing interest

The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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