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MODELING APPROACH TO URBAN VULNERABILITY TO FLOODING IN THE METROPOLITAN AREA OF ANNABA

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ABSTRACT

Historically, natural hazards have been a constant presence in Mediterranean regions. Earthquakes, eruptions, and floods frequently impact various territories, underscoring this reality. Consequently, governments have prioritized the establishment of prevention, management, and alert systems, making fundamental applied research essential for the ongoing development of these nations. Algeria has experienced numerous natural disasters in the past, particularly those associated with major earthquakes, such as the El Asnam earthquake on October 10, 1980, the Boumerdes earthquake on May 21, 2003, the Bab El Oued floods on November 10, 2001, and more recently, the Ghardaia floods on October 1, 2008.
The general living conditions in Algeria, especially in urban areas, are characterized by insufficient management of various issues, largely due to rapid growth. This has at times led to unregulated and uncontrolled urban expansion, with developments on riverbeds, unstable slopes, and other high-risk areas. Such urbanization fails to consider the persistent presence of natural hazards, which are further intensified by climate change.
Our objective is to identify the primary causes of natural risks and disasters in urban areas. This study includes an illustrative case in the intermunicipal area of Annaba, located in northeastern Algeria, where flood risk remains significant. The study aims to assess the impact of climate change and the support provided for crisis prevention and management within a sustainable framework.

KEYWORDS

Modeling, Natural Hazard, Vulnerability, Crisis Management, Prevention, Floods, The Greater Annaba Metropolitan Area

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Introduction.

Modeling involves the conceptual representation, known as a model, of a real-world system or phenomenon. There is now a wide range of applications, approaches, tools, and model types, each with its own vocabulary. In particular, advancements in computing have led to an expansion of models, raising methodological questions regarding model construction and evaluation, which are sometimes detached from practical applications. This is especially true for models dealing with complex phenomena or systems (ROADS', 2005).

Therefore, we will first address the challenges of mathematical and dynamic modeling, specifically "outside optimization contexts," from a general perspective based on the state of the art in hydrology, as well as in other life and earth sciences. This general overview will provide a conceptual and semantic foundation for exploring the modeling of rainfall-to-runoff transformation.

Research Methodology.

This document serves to develop a model based on these concepts, the modeler must follow several steps:

- Define the model's purpose and quality objectives, particularly its accuracy. This allows for establishing a modeling strategy that aligns with the research problem and guides all subsequent decisions.
- Identification should enable the definition and characterization of the system, its boundaries, structure, and the perception of it through an observational network. This includes defining the event, analyzing relevant laws, and determining variables and parameters. This phase also involves formulating hypotheses, sometimes simplified, and choosing characteristic time and spatial scales, which influence the processes to be considered.

This is the conceptualization phase in the strict sense, resulting in a set of analytical equations and parameterization.

Two methods, as well as their combination, are available for model identification: the inductive method, which relies on the observation of reality followed by its physical (M.E.D.D', 2004) interpretation to develop the model; and the deductive method, which starts with a theoretical model a priori and then verifies it through experimental observation.

This identification stage is sensitive to the data set available for representing reality and thus requires careful preparation of the data set (PETIT, 1997).

- ***Potential Programming:*** This step, resulting in the procedural model, must be followed by verification of the software itself.
- ***Calibration or Tuning:*** This is the phase of estimating unmeasurable parameters by statistically analyzing a set of real data observed over a reference period, the choice of which is crucial. Several goodness-of-fit criteria, or objective functions, can be used to calibrate models, generally using least squares or maximum likelihood methods. Calibration may be done manually, automatically, or statistically. Critical thinking is essential during data sample analysis to account for experimental errors and model sensitivity to parameter variations.

Non-linearity and Underdetermination: The non-linearity of the model and nderdetermination of the system make calibration challenging, often resulting in multiple parameter sets.

- ***Purpose of Calibration***: Calibration does not provide insights into the processes involved; rather, it serves to estimate parameters and, less explicitly, to adjust for errors inherent in the model and data.
- ***Validation or Evaluation***: Validation checks the quality of the model, typically by comparing the model's simulated response to an experimental stimulus against the actual response, using a different data set from that used for calibration. Validation, however, may extend beyond numerical comparison and include conceptual analysis.

Discussion and Interpretation.

A Digital Terrain Model (DTM) is a digital representation of terrain elevations (BALAYN, 2001). Such a model consists of a set of three-dimensional points and includes information that enables the reconstruction of the terrain's relief from these points.

There are several methods for creating a DTM (El-Sheimy, 2005):

- Direct surveying;
- Digitization and interpolation of contour lines from existing maps;
- Photogrammetric restitution;
- Laser or radar altimetry;
- Radar techniques.

Regardless of the method used, Digital Terrain Model (DTM) creation can generally be described as a two-phase process:

- ***Restitution:*** This phase involves generating a set of points that either calculate the elevation of each terrain point independently of neighboring points or derive elevations by integrating the slope pixel-by-pixel across the terrain.
- ***Resampling:*** This step creates a grid with cells of a specific shape (triangular or rectangular) and size. Sampling can be regular, semi-regular, or irregular, resulting in a mesh of points. These elevations are then interpolated based on observational points, creating a structured or unstructured grid of elevation data.

Through this process, a structured or unstructured point grid is obtained, with elevations derived from interpolation of the observed points (Kennie, 1990).

Context Analysis.

In the context of increasing urbanization and climate change, the need to understand and mitigate the impacts of natural hazards in urban environments has become crucial. Modeling plays a vital role in this endeavor, providing valuable insights into the sensitivity of urban areas to various natural risks.

The city of Annaba, located in northeastern Algeria, serves as a pertinent case study for examining these dynamics. By employing modeling techniques, researchers can analyze the complex interactions between urban infrastructure, population density, and environmental factors that contribute to vulnerability (BG, 2005).

Modeling allows for the simulation of different hazard scenarios, such as flooding, earthquakes, and landslides, enabling urban planners and decision-makers to assess the potential impacts of these events. This is particularly important in Annaba, where the combination of geographical features and rapid urban development increases the risk of such disasters.

Furthermore, modeling helps identify critical areas that are most susceptible to hazards, facilitating targeted risk assessment and resource allocation. It also aids in the evaluation of mitigation strategies and emergency response plans, ultimately enhancing the resilience of urban communities.

The use of modeling in studying the sensitivity of natural hazards in urban settings is indispensable for effective urban management and disaster risk reduction. The Annaba metropolis exemplifies the relevance of this approach, reflecting the broader realities faced by cities across Algeria and the Mediterranean region. Through these studies, stakeholders can better understand the risks and develop proactive measures to safeguard urban populations and infrastructure against the inevitable challenges posed by natural hazards.

Study Area.

The Wilaya of Annaba is located in the extreme northeast of the country, sharing borders with its neighbor El-Tarf and opening onto the Mediterranean coast for 80 km. It covers an area of 1,412 km², accounting for 0.06% of the national territory (BG, 2007).

It is bounded as follows:

- To the North: by the Mediterranean Sea,
- To the South: by the Wilaya of Guelma,
- To the East: by the Wilaya of El-Tarf,
- To the West: by the Wilaya of Skikda.

Annaba's geographical position on a regional scale reflects the role it could play in the future. It is administratively organized into 12 municipalities and 6 daïras: Annaba, Seraïdi, El Bouni, El Hadjar, Sidi Amar, Ain Berda, Cheurfa, El Eulma, Berrahal, Oued El-Aneb, Tréat, and Chétaïbi. It has a population of approximately 588,693 residents (PDAU, 2008), which 90 percent are concentrated in the four municipalities of Annaba, El Hadjar, El Bouni, and Sidi Amar. These make up the Greater Annaba agglomeration (the inter-communal area) (see Figure 1).

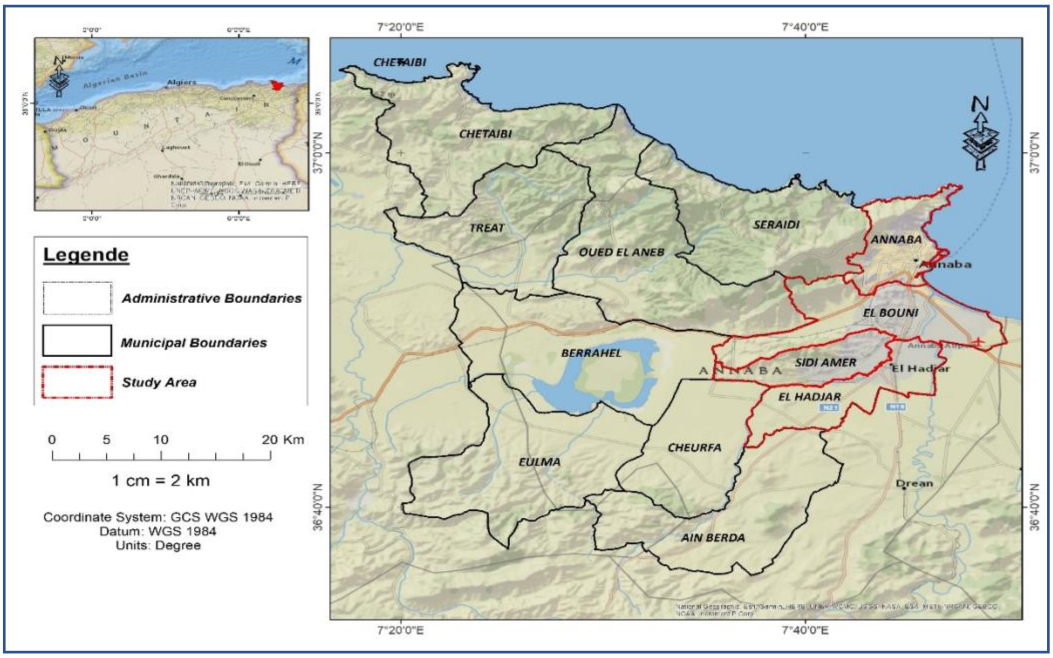

Fig.1. Wilaya of Annaba : Study Area of the Greater Annaba Agglomeration

Characteristics of the Physical Environment

Topography

The topographical features are crucial parameters that can influence urbanization in any development project. The topography of the Annaba El Hadjar and Bouni municipalities is described as follows (PDAU, 2008):

Relief

Three main units can be identified within the crystallophyllian structure of the Edough massif. This massif is bordered to the southwest by Lake Fetzara, to the east by the Annaba plain, and to the north by the Mediterranean Sea (DPAT, 2012). The highest point within this massif reaches an elevation of 1,008 meters at Kef Sbaa, with its main slopes characterized as follows:

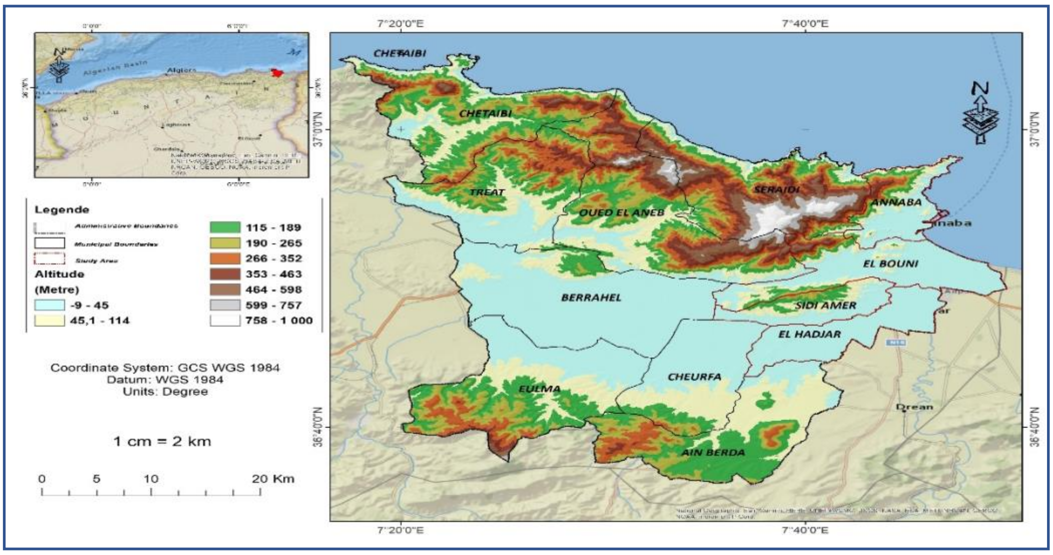

Fig. .2 Wilaya of Annaba : Characteristics of Topography

- The southwestern slope gradually descends toward the El Anneb wadi.
- The southern slope exhibits a steep gradient over a distance of 3.5 km, with an elevation change of 800 meters.
- Two prominent ridges border the Kherraza plain and converge with the Edough massif at Djebel:
- The Bougentas massif, reaching an elevation of 586 meters, extends from Kef Nssour to the Israeli cemetery.
- Djebel Bélélieta, at 288 meters, runs parallel to the Bouhamra massif up to the Basilica of St. Augustine.
- Beyond the Carob Tree massif, the relief rises in a northeastern direction. The landscape includes:
- The small plain of Annaba, situated between the hills of Annaba and the foothills of Edough.
- The Kherraza plain, formed by the confluence of the Bouguentas and Bouhamra rivers.
- The expansive plain of Annaba, which borders the Seybouse and Mafragh wadis.

Coastal Dune Barrier

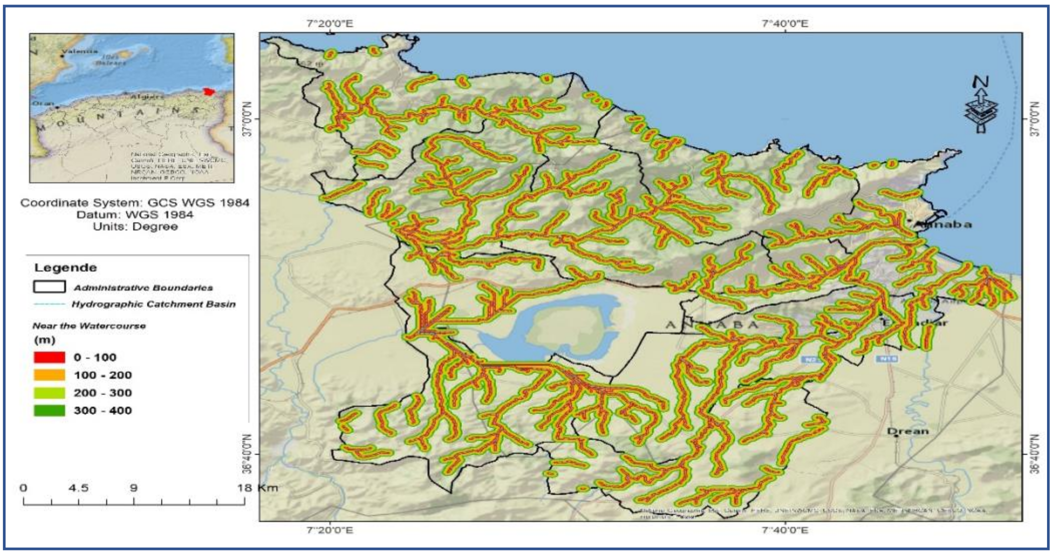

Fig. 3 Annaba Region: Characteristics of Hydrography

A series of sandy dunes stretches along the coastline from Seybouse in the west to El Kala in the east. These dunes separate the vast plain of Annaba from the Mediterranean Sea, increasing in both height and width from west to east.

- The Plains of Annaba

The small plain of Annaba lies between the hills of Annaba and the base of Jebel Edough, while the Kherraza plain is shaped by the estuaries of the Bouguentas and Bouhamra rivers. The great plain of Annaba extends to the east of the Seybouse wadi. Historically, this plain was almost entirely covered by 'garaâ' (wetland) sediments and is now only partially drained by the two wadis that traverse it: the Seybouse and Mafragh (see Figure 3).

These plains, characterized by their low and relatively flat topography, are susceptible to overflow from the wadis, resulting in significant inundation of large areas during flooding events.

Climatic Data

The city of Annaba and its region are covered by a sufficient number of measurement stations. The main ones are : Seraïdi .Edough .Pont Bouchet .Les salines .Chetaibi .Ain Berda .Berahal (ANARH, 2020) .

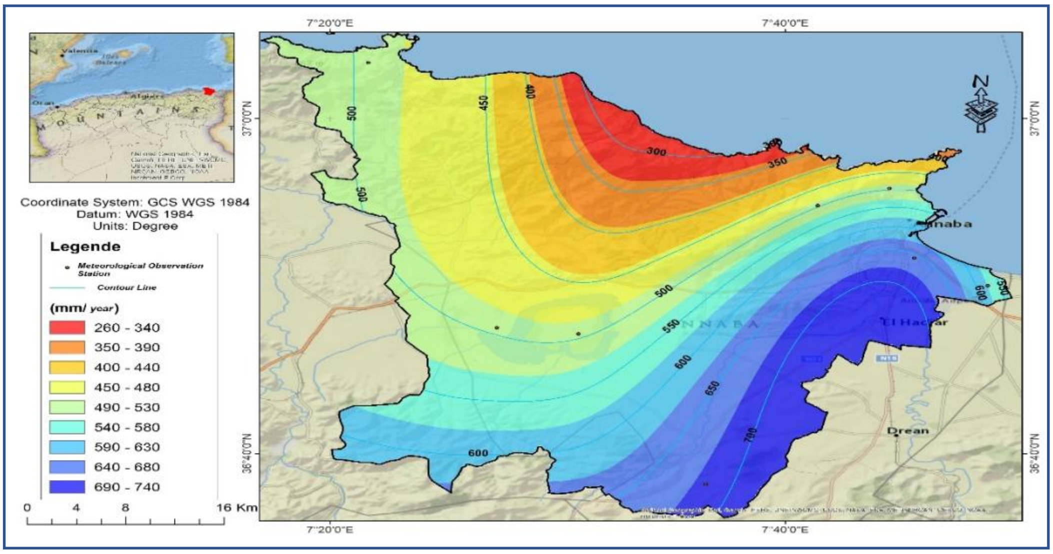

Fig. 4. Wilaya of Annaba : Distribution of Rainfall Zones

Given the spatial significance of the study area, we utilized meteorological data from the Annaba, Cap de Garde, and Séraïdi stations for the observation period of 1913–1938 (SELTZER), along with data from the Annaba airport station (Les Salines) for the period of 1975–1990.

These bioclimatic levels are characterized by two distinct seasons

- A mild and humid season from October to April, accounting for 86.4 percent
- A hot and dry season from May to September، comprising 13.6 percent of the annual rainfall, with an average temperature of 22.5°C.

Orientations And Urbanization Areas.

Urbanization Corridors.

The geographical structure of the inter-municipal region distinguishes three main urbanization corridors, each leading to distinct urbanization zones (see Figure 5):

The RN16-RN21 Corridor: Encompassing the towns of El Bouni and El Hadjar.

The RN44 East Corridor: Leading to Sidi Salem and extending to the Bounamoussa area.

The RN44 West Corridor: Connecting the localities of Kherraza, Chabbia, and Zied Wadi.

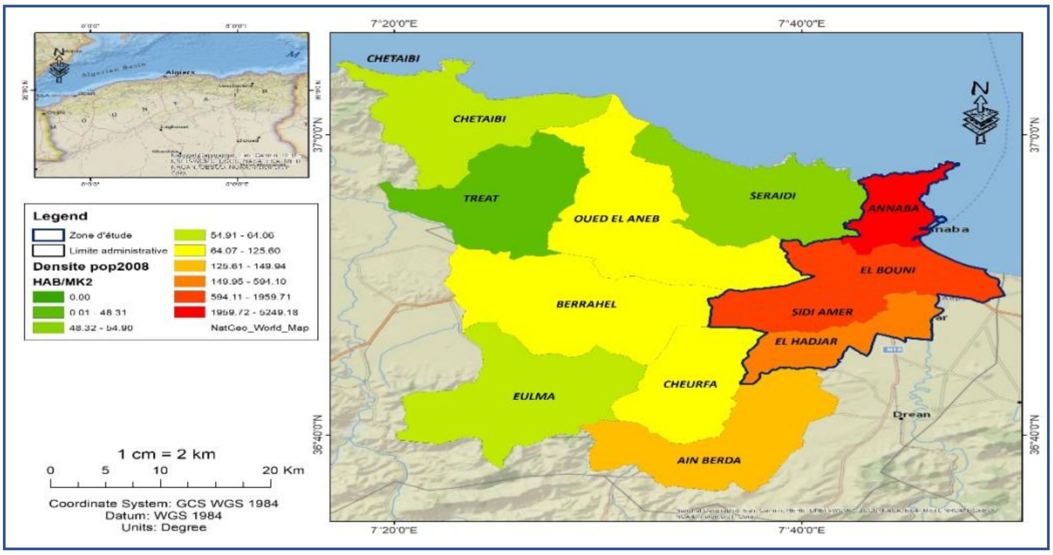

Fig. 5 Wilaya of Annaba: Population Density and Concentration

Additionally, a secondary corridor (CW129-CW56) integrates industrial zones with the localities of Hadjar Eddiss and El Gantera.

Urbanization Areas

Between these corridors, several potential urban expansion areas are emerging:

The area situated between RN16 and RN44 East.

The space between RN16 and RN44 West, including the localities of El Bouni and Sidi Amar.

The flanks of the Edough massif, currently serving as extensions to existing localities.

The coastal space located between the sea and RN44 East.

Results And Discussion.

Flood Risk Zoning

Through an in-depth analysis of the physical environment and its link to flood risk, we examined hydroclimatic and hydromorphological factors, focusing on rainfall patterns within the basin, their frequencies (return periods), and those that are most impactful.

The morphology of the Seybouse watershed and the Edough massif, with processes of erosion and sedimentation, results in heightened risk vulnerability in three primary zones:

The recurring instances of flood risk following heavy rainfall events highlight significant deficiencies in the flood control projects that have been implemented. This necessitates a comprehensive analysis to identify these shortcomings and develop effective solutions to mitigate flood risks. In the Greater Annaba conurbation (refer to Figure 4), the city of Annaba and El Hadjar are categorized as high vulnerability areas (Zone 1), while the areas of Sidi Amar and El Bouni are identified as medium vulnerability zones (Zone 2). Conversely, the communes of Berehal, Oued El Aneb, Treat, and Chetaibi fall into the low vulnerability category (Zone 3).

The delineation of risk zones is informed by the severity of potential flood risks, with very high risk zones marked in red and high risk zones in yellow. This classification is based on an analysis of various assessments conducted by the Hydraulics and Civil Protection Department, which evaluated interventions in flood-prone areas from 2006 to 2010. Notably, several neighborhoods have been successfully removed from high-risk classifications The flood risk can be conceptualized as a wave, with its intensity diminishing as the land's slope becomes less steep, resulting in diffuse flow patterns, particularly to the south of National Road RN16 and near RN44 (see Figure 6).

High Vulnerability Areas (Red): This category encompasses districts situated to the south of the city center, including Pont Blanc, Safsaf, and Tabacop. These areas are particularly susceptible to flooding due to their geographical and hydrological characteristics.

By addressing these vulnerabilities through targeted interventions and improved flood management strategies, the overall resilience of the Greater Annaba region can be significantly enhanced.

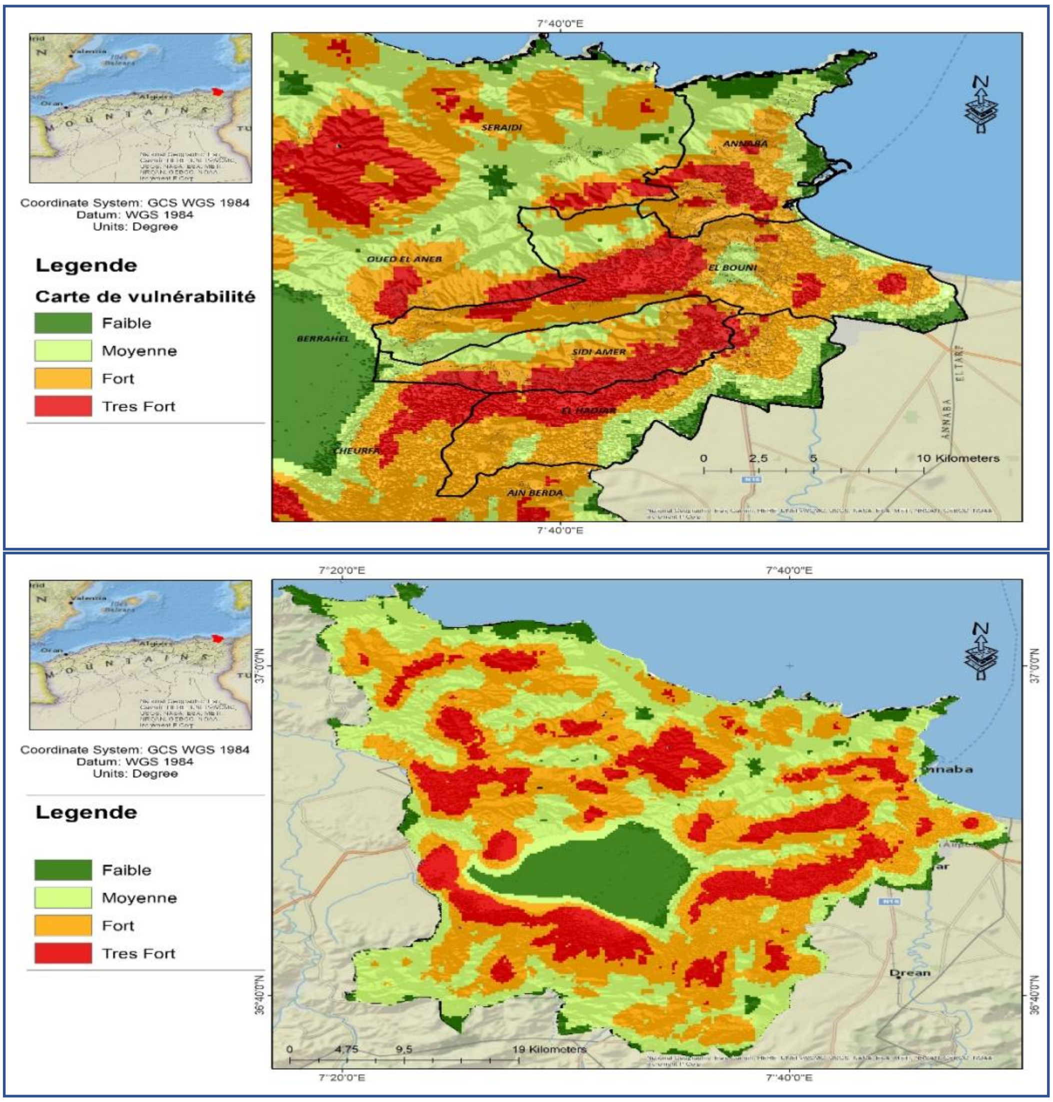

Fig. 6. Greater Annaba Agglomeration : Flood Risk Sensitivity Map

Interpretation of Flood Vulnerability Zones.

High Vulnerability Areas : The areas of highest vulnerability include those situated along the banks of various wadis and ravines, such as Wadi Kouba, Wadi Fourcha, Boukhadra, and Seybouse. These locations are particularly susceptible to flooding due to their proximity to water bodies and the topographical features that can exacerbate flood impacts.

Medium Vulnerability Areas : Medium vulnerability zones are found in the southwest and northeast regions of the conurbation, encompassing neighborhoods such as Beni M'hafer, 19 Mai, Plaine-Ouest, Sidi Achour, Gassiot, and Cité de Caroubiers. These areas may experience flooding under certain conditions but are less prone to prolonged inundation compared to high vulnerability zones.

Low Vulnerability Areas : In contrast, the neighborhoods located in the northwestern part of the city, including Sidi Aissa, Zaafrania, and Kouba City, fall into the low vulnerability category. While these areas can still be affected by heavy rainfall, they are generally less impacted than the more vulnerable zones.

Historically, significant floods in the Greater Annaba area have occurred predominantly between October and April, often resulting in submergence durations exceeding two days. A notable example is the flood event of January 24–25, 2019 (refer to Figure 6), which illustrates the severity of flooding during this period.

The adverse weather conditions recorded in February 2022 further exemplified the flood risk in the region, as over 83 mm of rain fell within just 15 hours—far surpassing the meteorological forecasts for Annaba. This intense rainfall led to widespread concern and challenged the existing flood management strategies, underscoring the need for improved preparedness and response measures in the face of extreme weather events.

Operational Recommendations to Reduce Vulnerability to Natural Risks and Floods in the Intercommunal Area of Annaba.

Risk Assessment and Mapping:

- Conduct comprehensive studies to identify and map high-risk flood zones, integrating historical data on climatic events and drainage patterns.
- Improvement of Drainage Infrastructure:

- Modernize and regularly maintain existing drainage systems to ensure effective rainwater runoff.
- Construct retention basins and infiltration areas to manage floods by temporarily storing rainwater.

Urban Planning Regulations:

- Implement strict standards for construction in vulnerable areas, including requirements for flood-resilient infrastructure.
- Encourage the use of suitable construction techniques, such as elevating buildings above known flood levels.

Restoration of Natural Ecosystems:

- Promote the restoration of wetlands and riparian zones that can serve as buffers against floods and improve rainwater management.
- Integrate watershed management practices to maintain the health of ecosystems and their capacity to regulate water flow.

Community Awareness and Training:

- Organize awareness campaigns to inform citizens about flood risks and the preventive measures to adopt.
- Train local communities in sustainable land and water resource management practices.

Emergency and Response Planning:

- Establish a clear emergency plan for flood events, including evacuation protocols and designated refuge areas.
- Create rapid response teams to manage emergency situations and coordinate relief efforts.

Strengthening Partnerships:

- Collaborate with governmental, non-governmental organizations, and academic institutions to share resources, knowledge, and best practices in risk management.
- Establish partnerships with the private sector to fund sustainable infrastructure projects.

Monitoring and Evaluation of Measures:

- Set up a monitoring system to assess the effectiveness of risk reduction measures and adapt strategies based on results.
- Regularly analyze climatic and hydrological data to adjust forecasts and flood management strategies.

By integrating these recommendations into a comprehensive action plan, the intercommunal area of Annaba will be better equipped to face natural risks and reduce vulnerability to floods, thereby protecting local communities and infrastructure.

The analysis of flood risk in Annaba underscores the importance of using modeling techniques to study urban sensitivity to natural hazards. By providing a clearer understanding of flood dynamics and identifying vulnerable areas, these models serve as valuable tools for enhancing flood risk management. Effective planning and implementation of mitigation strategies can significantly reduce the adverse effects of flooding in urban environments, ensuring safer and more resilient communities in Annaba.

Conclusions.

Flood risk in urban areas, particularly in Annaba, Algeria, poses significant challenges due to the city's geographical features and proximity to water bodies. Recurrent flooding has led to extensive damage to infrastructure and property, especially in areas with inadequate drainage systems, disrupting daily life and economic activities. The social and economic consequences include population displacement, loss of livelihoods, and increased health risks, further straining local resources. Additionally, flooding harms local ecosystems, particularly wetlands, which are vital for natural flood mitigation. The use of modeling techniques has improved flood risk assessment by integrating hydrological and meteorological data, allowing for the identification of vulnerable zones and informing targeted interventions. These insights assist urban planners and policymakers in developing effective mitigation strategies, such as upgrading drainage systems and restoring ecosystems. Moreover, modeling outcomes enhance public awareness of flood risks, encouraging community preparedness to reduce flooding impacts.

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