ijems | scientific article

Flood Hazard Assessment and Risk Management in Dar Belamri: A Hydrological and Hydraulic Approach for Effective Urban Development and Slum Reduction

Rachid Dahmani
University of Ibn Tofail, Morocco
rachid.dahmani1@uit.ac.ma

Fatehi Altalqi
University of Ibn Tofail, Morocco
abdullahhussien.altalqifatehi@uit.ac.ma

Amine Belmzoukia
University of Ibn Tofail, Morocco
amine.belmzoukia@uit.ac.ma

Adil Echchelh
University of Ibn Tofail, Morocco
echchelh.adil@uit.ac.ma

Saïd Chakiri
University of Ibn Tofail, Morocco
said.chakiri@uit.ac.ma

Mohammed Benammi
University of Ibn Tofail, Morocco
mohammed.benammi@uit.ac.ma

Aït Fora Abderrahmane
University of Ibn Tofail, Morocco
abderrahman.aitfora@uit.ac.ma

Dar Belamri is considered one of the emerging centers in the Sidi Slimane region, but it suffers from the spread of slums in the center, especially in the Ouled Abdel Sadek area, part of which is located on the edge of a cliff near scattered quarries, in addition to the Fajr area, which is located near the Beht River. What distinguishes these areas is that they are located in a natural flood zone, which requires proactive management of these risks by local planners and decision-makers. This study provides a flood risk assessment tool that is adapted to the conditions of these specific areas. The methodology combines flood frequency and flood impacts using a hydrological and hydraulic approach. This approach uses a hydrological model to analyze the spatio-temporal evolution of hydraulic properties (such as flow rate, velocity, water height, and inundated areas) during design flood events, while assessing the effects of hydraulic developments on flow dynamics. The study focuses on two main watercourses, Wadi Beht and Wadi Oum El Zein. Comprehensive topographic surveys provided detailed morphological data, allowing for accurate hydraulic simulation of floods at different return periods. This helped accurately identify flood zones and contributed decisively to the delineation of areas suitable for urbanization and construction, thus producing a flood risk map. It is a crucial tool for targeted flood risk management and mitigation efforts, ultimately supporting the development of a final urban suitability map and, through it, identifying appropriate solutions for informal housing and avoiding various risks in the center of Dar Belamri, with the potential for application across other high-risk areas.

Key Words: urban planning, flood, slums, topography, land use, remote sensing

https://doi.org/10.70908/2232-6022/18.147-176

INTRODUCTION

Climate change is a major driver of natural disasters worldwide, dramatically increasing their frequency and severity. As for these disasters, floods are among the most widespread and devastating. Since 1980, natural disasters have killed more than 2.5 million people worldwide and inflicted enormous economic losses annually (Bolan et al. 2024).

Floods, caused by extreme hydrological events such as heavy rainfall, are a global threat that affects countries to varying degrees. They cause significant damage to populations, infrastructure, economies and ecosystems, while also causing secondary disasters such as erosion, landslides and pollution – particularly in poorly equipped slums with no sanitation facilities (Berlemann and Wenzel 2018). Over the past two decades, floods have accounted for nearly 35% of natural disasters, affecting nearly 2 billion people. People all over the world and those living in the Mediterranean region in particular, in particular, face a growing threat of severe flooding, with rainfall often exceeding 200 mm in just 24 hours – sometimes in less than six hours. Morocco, for example, has witnessed major flooding events over the past six decades, causing significant economic losses in various regions (Anande and Luhunga 2019; Schilling et al. 2012). This underscores the urgent need for robust flood management and climate adaptation strategies to mitigate these impacts (Chaqdid et al. 2023).

Morocco, like many countries, has faced a series of devastating natural disasters in recent years. From the Al Haouz earthquake in 2023 to the Ourika flood in 1995, these events have left indelible scars on the country's economy, society and environment (Bannari et al. 2016). Among these risks, flooding poses a constant threat, particularly in the eastern region. Heavy rainfall, exacerbated by climate change and semi-arid landscapes, has caused frequent and severe flooding (Bekkali et al. 2024). The losses resulting from these floods are enormous, highlighting the urgent need to take proactive measures to mitigate their impacts. By implementing effective strategies, Morocco can strengthen its resilience to these increasingly frequent and severe natural disasters (Kundzewicz et al. 2014). Their frequency and intensity have increased significantly, especially over the past 20 years (Athmani et al. 2024). These floods are mainly due to the slow rise of waters in low-lying areas and the rapid formation of floods after heavy rains or stormwater runoff in urban or rural areas (Liu et al. 2019). These phenomena are not directly linked to the frequency or magnitude of natural hydrological events; on the contrary, they result from the increasing occupation of flood-prone areas, particularly shantytowns, unregulated constructions, and the failure to use planning tools that identify different risks, such as the Urbanization Suitability Map (USM) (Manandhar et al. 2023). Due to the urbanization of valleys and the increasing pressure on land, these conditions can generate serious risks. To address them, structural protective works are not the most important preventive solution – except in areas that are already heavily urbanized. Priority must be given to the preservation of flood zones, monitoring of urban planning, and consideration of risks associated with different land-use planning approaches, all within a sustainable development framework (Hudson et al. 2022).

In this context, the Ministry of National Land Use Planning, Housing, Urban Planning and Urban Policy has committed, in close cooperation with local stakeholders, to implementing a new generation of land use planning documents. These aim to prevent natural risks, by incorporating flood risk considerations into the urban planning process, particularly during the development of various planning documents. The goal is to enable the sustainable development of regions through a strategy that aims to cover the entire national territory with maps adapted to urbanization (Cea et al. 2022). This document presents, through a cartographic approach within the Geographic Information System, the mapping of flood risk areas in the center of Dar Belamri in the Sidi Slimane province. This planning tool will assist and guide local authorities in their land use planning and development efforts, by promoting the integration of flood risk data into urban planning documents, avoiding the unchecked expansion of informal settlements, and serving as a decision-making tool for policy-makers working toward sustainable development.

[150] This study aims to fill existing gaps by developing a flood risk assessment tool specifically adapted to the Dar Belamri Center (Shawaqfah et al. 2024). By focusing on the interaction between hydrological and topographic features, the study seeks to improve the understanding of flood dynamics in the region (Lombana et al. 2024). The methodology used combines hydrological and hydraulic techniques to analyze flow rates, velocities, water depths, and the extent of flooded areas for different return periods (Akallouch et al. 2024). This approach also assesses the effects of hydraulic developments on flow patterns, providing essential information for flood risk mitigation. Using detailed topographic surveys of Wadi Beht and Wadi Umm Al-Zein, the main tributaries in the region, the study reconstructed the geometry of the watercourses and conducted hydraulic simulations to predict the extent of flooding under various scenarios. These simulations led to the development of a flood risk map, identifying the areas most and least affected by flooding. This study is based on the hypothesis that a hydrological and hydraulic approach, based on accurate topographic data, can provide a reliable tool for identifying flood-prone areas and understanding the impact of hydraulic developments on flow dynamics. Furthermore, it assumes that the resulting risk map can serve as a basic resource for local planners, enabling informed decisions to effectively mitigate flood risks (Aksoy et al. 2016). The results of this study aim to address the knowledge gap in flood risk assessment at the local level in Morocco. By proposing a scientifically sound methodology for identifying flood zones, the study supports planners and decision-makers in integrating flood risk considerations into urban planning and development strategies (Santos 2024). The risk map developed through this research serves as a practical tool for proactive flood risk management, helping to reduce the social, economic and environmental impacts of flooding in Dar Belamri.

METHODOLOGY

To enhance the resilience of the territory, it is crucial to integrate risk components into the development of updated urban planning documents. This study focuses on mapping key factors (referred to as 'layers') and identifying the primary issues that contribute to the terri-

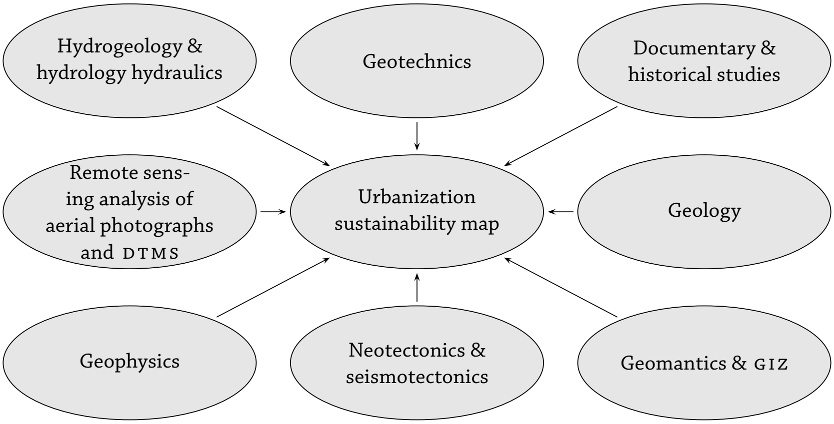


FIGURE 1 Main Components of the Urbanization Suitability Map

tory's vulnerability by adopting a multidisciplinary approach. Among the risks considered are earthquakes and their direct and indirect effects, land movements, floods, and torrential phenomena. The outcome of this comprehensive study will be an 'Urbanization Suitability Map,' which synthesizes the analyzed risks. However, this paper specifically addresses the flood component, which must be integrated with the other identified factors to produce the final suitability map. The process is illustrated in figure 1.

Study Area

The Dar Belamri center is located in a natural flood zone, requiring the consideration of flood risk by local planners and decision-makers, as shown in figure 2. In this context, identifying the areas likely to be affected by flooding is essential for better risk management (Mai et al. 2020). The methodology adopted in this study provides a flood risk assessment tool at the scale of the study area, based on the premise that flood risk Results from the hazard factor (specifically, the frequency and physical intensity of the natural phenomenon) (Mai et al. 2019). The assessment of the hazard factor is based on the combination of two concepts: flood recurrence and the resulting inundation. Hydraulic modeling enables the monitoring of the spatiotemporal evolution of flood characteristics (Amellah et al. 2024). Today, there are several approaches to flood risk assessment, based on recognized methods (such as historical analysis, empirical modeling, and numerical modeling).

The Dar Belamri center is located in a flat area with a low slope

FIGURE 2
Spatial Representation of the Study Area

and natural flooding, dominated by vast agricultural lands and settlements (Athmani et al. 2024). It is crossed by Oued Oum Ezzine and Oued Beht, which have very remarkable beds that generate overflows over the banks due to the reduction of their transit capacity from upstream to downstream (Karmouda et al. 2023). Therefore, considering that a detailed topography of the sections of Oued Beht and Oued Oum Ezzine running through the center was carried out as part of this study, and with the available rainfall data (Talha et al. 2025), the hydrological and hydraulic approach was adopted in order to simulate the flow of Oued Beht and Oued Oum Ezzine (Beven and Kirby 1979). The following paragraphs will describe the stages of the methodology adopted for this work.

Flood Hazard

In the context of hazard analysis, a flood refers to the numerical prediction of the spatiotemporal evolution of a watercourse's hydraulic characteristics during a flood event. This includes parameters such as flow rate, water depth, and the extent of flooded areas, a watercourse's hydraulic characteristics (Hakim et al. 2024).

Determining flood hazard requires a detailed field survey (including field visits) as a preliminary step, along with the collection and analysis of historical and recent flood events, including testimonies from local residents (Al Kuisi et al. 2024). The hydrological and hydraulic approach utilizes a hydrological model to determine the spatiotemporal evolution of a watercourse's hydraulic during a reference flood (e.g., flow rate, flow speed, water height, inundated areas, etc.) (Zhu et al. 2022).

It also enables the assessment of the impacts of developments (such as bridges, dikes, etc.) that influence flow dynamics. However implementing this approach requires data on observed rainfall, measured flow rates, and detailed topography. All of these elements contribute to the creation of a hazard map that highlights the most and least affected areas, allowing for the identification of areas where flooding is likely to occur, with varying degrees of intensity and frequency (Köhne et al. 2011).

Precipitation Assessment The assessment of rainfall in the study area is based on the analysis of data collected from the rainfall station serving the watersheds of the rivers included in this study (Chanyour et al. 2024). This approach also evaluates the effects of hydraulic developments on flow patterns, offering critical insights for flood risk mitigation. For example, at the Al-Kansara Dam, the average annual rainfall recorded during the period 1970–2022 is 342 mm.

Flood Frequency Analysis Estimation of flood flows: Flood flow depends on several factors, including climatological, topographical, pedological and geological conditions, etc. To assess flood flows, a variety of empirical formulas can be applied, each appropriate for specific conditions and subject to certain limitations.

The empirical calculation methods used in this study consider two essential factors: the size of the watershed (the surface area and/or length) (Marchezepe et al. 2023) and the topographic gradient of the watershed (the slope or elevation difference). Flood flow estimates corresponding to different return periods (T = 10 years, T = 20 years, T = 50 years and T = 100 years) for the study area are derived using several empirical formulas, including (Guillot and Duband 1969): Mallet-Gauthier method; Fuller II method; Francou-Rodier method; Rational method; Hazan-Lazarevic method; SCS method.

Topographic Works As part of this study, topographic surveys were carried out for sections of Oued Beht, Oued Om Ezzine and the existing hydraulic structures in the urban center of Dar Belamri. This step is essential for conducting accurate hydraulic simulations. Topographic surveys were designed to capture the maximum morphological detail of the watercourses, their watersheds, and associated hydraulic structures (such as bridges, weirs, etc.).

Hydraulic Modeling Hydraulic modeling aims to numerically predict the spatiotemporal evolution of hydraulic characteristics during a reference flood – including flow rates, velocities, and water depths – and to determine the geographical extent of flood zones. The objective is to build a reliable hydraulic model that takes into account the geometry of the relevant watercourses, including both the minor and major channels, as well as existing and projected infrastructure (Grimaldi et al. 2018).

The model will, among other things, determine the flow capacity of the watercourses and identify critical areas during flood events, specifically, overflow points and flood-prone zones, based on the results obtained in hydrological studies. Hydraulic simulation typically involves modeling reference floods for all watercourses that cross the study area.

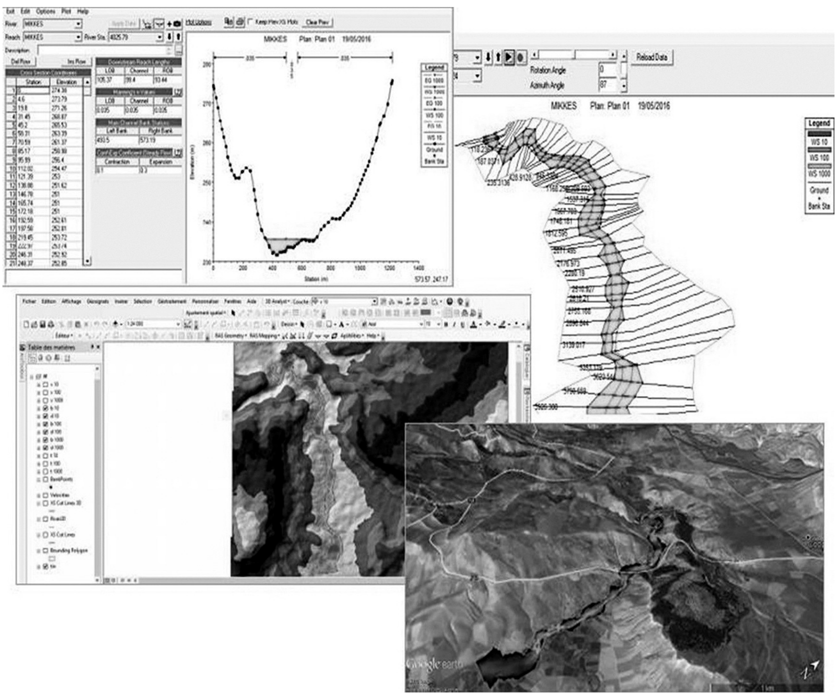


FIGURE 3 Hydraulic Simulation under HEC-RAS

To accomplish this, we used HEC-RAS software developed by the Hydrologic Engineering Center of the US Army Corps of Engineers (HEC, USACE) (Peker et al. 2024). It is the most widely used tool for assessing water flow rates and heights across all sections of a watercourse (river, canal, etc.). The software is based on free-surface hydraulic equations (Saint-Venant 1D, Manning-Strickler, etc.) and incorporates models for weirs, friction, and other hydraulic features. In this study, we used HEC-RAS to simulate flow in streams relevant to the study area.

RESULTS

Rainfall in the study area is determined through the analysis of precipitation data collected at the rainfall stations monitoring the watersheds of the watercourses considered in this study. This section addresses the climatic parameters of the study area based on statistically processed daily precipitation data. The temporal variability of these parameters, particularly annual, monthly and daily rainfall, enabled the characterization of differences between wet years, marked by water surpluses, and dry years, characterized by water deficits. It also allowed for the identification of climate trends over time. All results from the statistical analysis are presented below.

Annual Rainfall El Kensera Dam Station

Figure 4 illustrates the annual rainfall records at the El Kensera Dam station over the period from 1970 to 2022. It highlights the interannual variability in precipitation, showing fluctuations in rainfall amounts, with some years experiencing significantly higher or lower values. This variability is critical for understanding hydrological patterns and for planning effective water resource management in the region.

Over the 52 years of rainfall analysis, 39 years recorded below-average rainfall (representing 54%), while 33 years recorded above-average rainfall (46%). The lowest annual rainfall was observed in 2000, measuring 97 mm, whereas the highest occurred in 2010, with 703 mm exceeding the annual average (342 mm/year) by 360 mm.

Figure 5 illustrates the deviations from the average rainfall (absolute values) recorded at the El Kensera Dam station during the period 1970–2022. This demonstrates a clear pattern of interannual variability, indicating that fluctuations in rainfall from one year to the next are a consistent characteristic of the region's hydrological behavior.

These deviations from the average rainfall at the El Kensera Dam

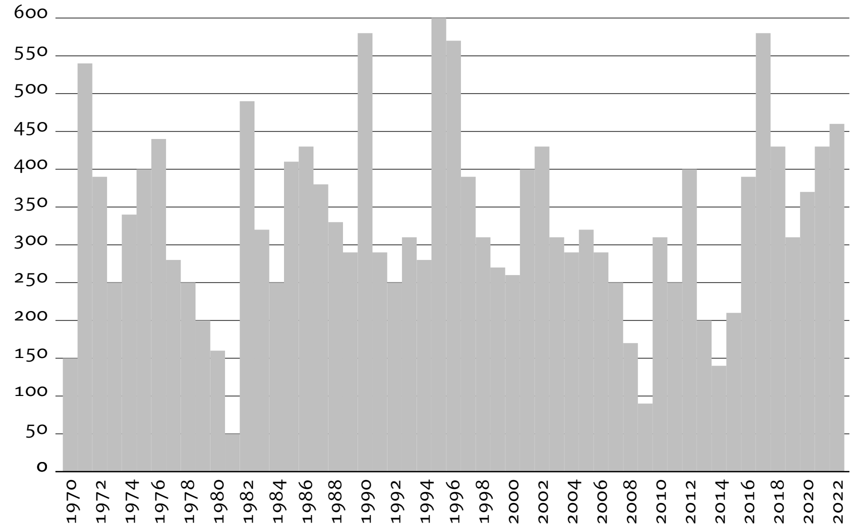


FIGURE 4 Annual Precipitation Trends: El Kensera Dam Station (mm, 1970–2022)

FIGURE 5 Annual Rainfall Deviations from the Mean: El Kensera Dam station (mm, 1970–2022)

station show that the rainfall regime is characterized by alternating wet periods and dry spells. The very significant differences between the recorded annual rainfall and the calculated average (342 mm/year), along with the interannual variations, reflect the high variability and instability of the rainfall regime in this region.

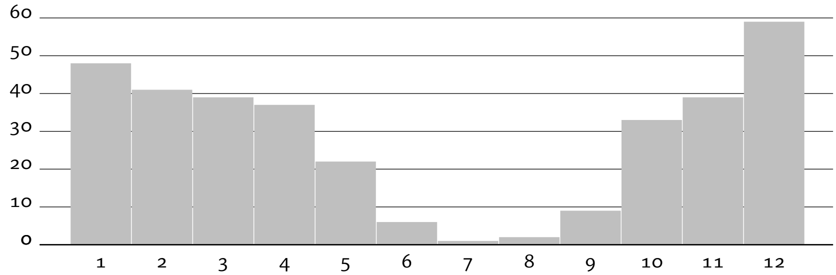


FIGURE 6 Variations in Monthly Average Precipitation at the El Kensera Dam Station (mm, 1970–2022)

Monthly and Seasonal Rainfall Patterns at El Kensera Dam Station

The monthly variation in rainfall at the El Kensera Dam station for the 1970–2022 period is illustrated in figure 6. The analysis of the figure highlights the pronounced monthly variability in rainfall. Two distinct periods can be identified, each showing a strong contrast in terms of precipitation:

- *October to May:* This is the period of highest local rainfall, with an average of 58 mm per month, peaking in December, which is the wettest month during the 1970–2022 period.
- *June to September:* Precipitation is much lower during this period – 9 mm in September (1970–2021) – and can be nearly zero in July and August. Rainfall during this time is mostly due to localized thunderstorms.

The analysis of variations in the number of rainy days at the El Kensera Dam station clearly reveals a strong seasonal contrast. While precipitation occurs throughout the year, winter is the rainiest season. It is also notable that summer occasionally experiences exceptional rainy days, primarily due to storm activity, as shown in figure 7.

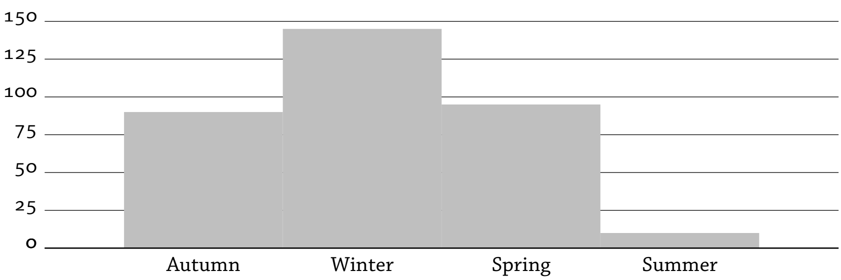


FIGURE 7 Seasonal Distribution of Precipitation at the El Kensera Dam Station (mm, 1970–2022)

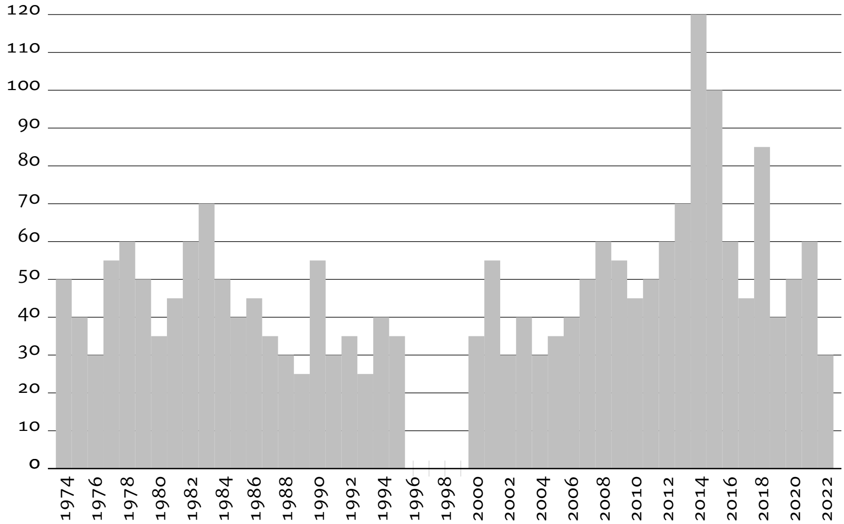


FIGURE 8 Annual Maximum Daily Rainfall Recorded at El Kensera Station (mm, 1970–2022)

Statistical Analysis of Rainfall at El Kensera Station

Figure 8 presents the series of annual maximum daily rainfall recorded at the El Kensera Dam station between 1970 and 2022. The graph illustrates the significant variability in extreme daily rainfall events over the study period. The recorded values range from a minimum of 25 mm in 1989 to a maximum of 120 mm in 2014, highlighting the irregular and sometimes intense nature of precipitation in the region.

Characterization of Flood Risk at the Dar Belamri Center

The area is crossed by two major rivers: Oued Beht and Oued Oum Ezzine, Oued Beht, the main tributary of Oued Sebou, is regulated a few kilometers upstream by the Al Kansera Dam, it flows from south to north in a distinctly concave riverbed, 20 to 40 meters wide and 3 to 4 meters high on the banks, as shown in figure 9. It highlights the drainage basins – labeled WSH1, WSH2, and WSH3 – along with the corresponding watercourses. This spatial representation of hydrological boundaries and flow networks is essential for understanding water management, flood risks, and resource planning in the region.

The subdivision of the watersheds was carried out in such a way that each unit is considered to contain homogeneous hydrological characteristics, which implies that their behavior can be correctly simulated.

To determine the watersheds, we proceeded as follows: we used the following cartographic data:

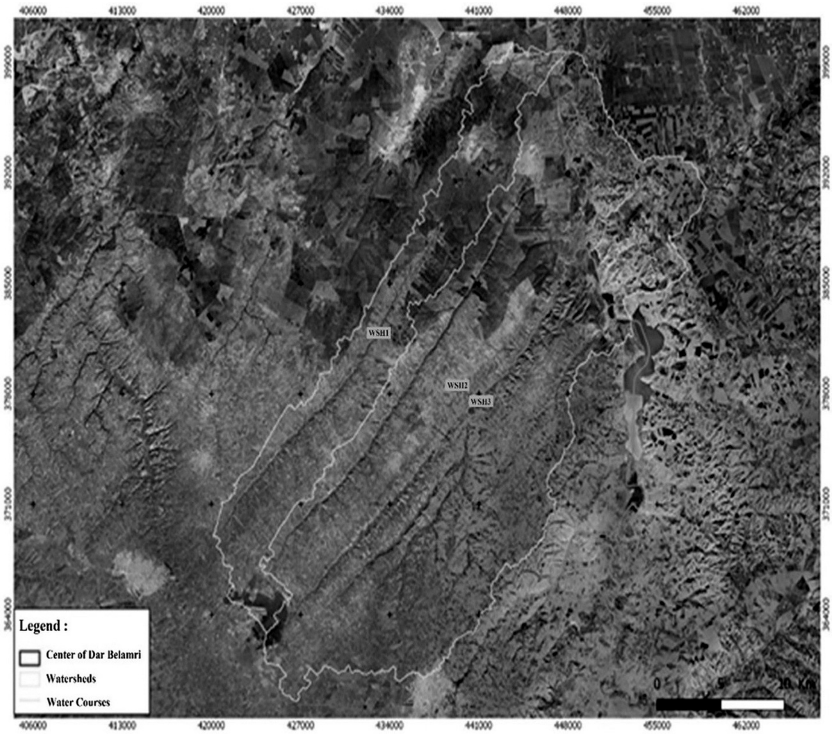


FIGURE 9 Map of the Main Watersheds: Dar Belamri Center

- For the centers equipped with restructuring studies and urban planning documents, we used contour lines from aerial photo restitutions and topographic surveys at scales ranging from 1/500, 1/1000 to 1/5000;
- Remote sensing data (with a spatial resolution of approximately 50cm) and GIS (Geographic Information System) tools;
- A very precise DTM calibrated to include point clouds and highly accurate orography.

Method The watersheds dominating the study area were defined at the confluence points of the main tributaries and at the location points of the urban centers using the contour lines (the equidistance is 10 meters) and the hydrographic network by connecting the highest peaks surrounding the watercourses and their tributaries, respecting the following rules: tracing the watercourses from their source to their outlet, including the tributaries; determining the outlets from which the starting and ending points of the watershed lines, delimiting the water-

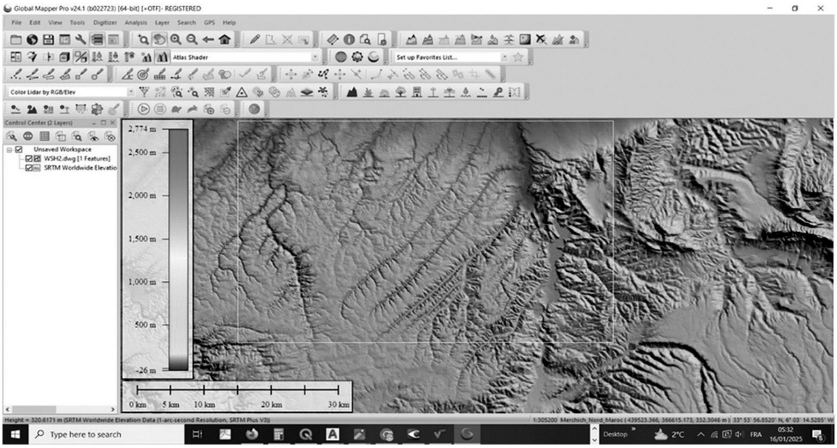


FIGURE 10 Map of the Main Watersheds: Dar Belamri Center

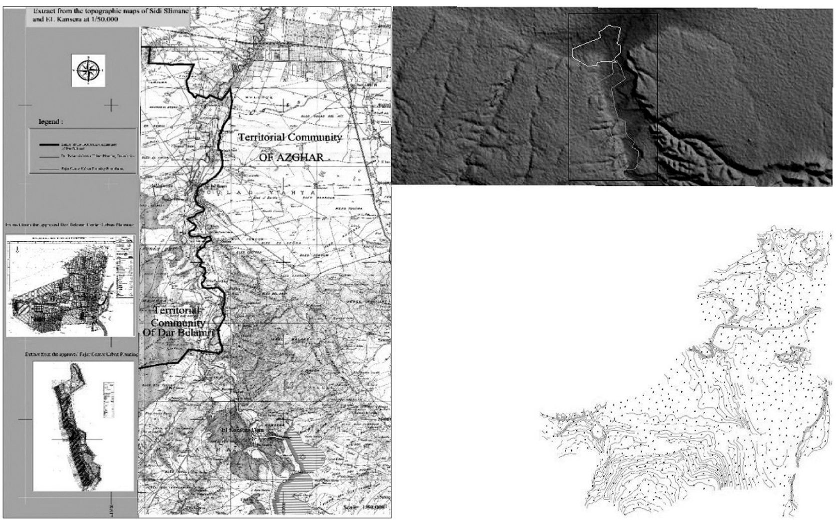


FIGURE 11 Topographic Map and Indication of Urban Planning Documents for the Dar Belamri and Fajar Centers (left), High-resolution Digital Terrain Model (top right), Orographic Data (bottom right)

sheds, can be traced; the peaks are then connected connected by passing through the highest points, ensuring the boundary of the basin crosses the contour lines perpendicularly; the location of the rivers, lakes, streams, swamps or other bodies of water is identified without crossing them. We also note that, from a hydrological perspective, the area is crossed by a large river, the Oued Beht, the main tributary of the

TABLE 1 Physiographic Parameters of the Main Watersheds: Center Dar Belamri

WSH	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
WSH1	770.95	167.00	53.00	443	28	415.0	0.79	73.68	10.46	1.697	0.2819
WSH2	589.98	159.95	52.30	443	28	415.0	0.79	72.45	8.14	1.858	0.2157
WSH3	181.06	133.69	49.22	400	28	372.0	0.76	64.56	2.80	2.803	0.0747

NOTES Column headings are as follows: (1) area (km^2), (2) perimeter (km), (3) length (km), (4) maximum altitude, (5) minimum altitude, (6) elevation (m), (7) slope (%), (8) equivalent length (km), (9) equivalent width (km), (10) IC Gravelius, (11) IC Horton.

Oued Sebou. The Oued Beht is regulated a few kilometers upstream by the Al Kansera Dam. It flows from south to north, through a very remarkable concave-shaped bed, with a width ranging from 20 m to 40 m and a height of 3 m to 4 m from the banks. The river crosses regional road 409 via a bridge located at point (*x*: 447663/*y*: 398964) and then continues its course north through the agricultural land. Qued Oum Ezzine forms the boundary between the Dar Belamri center and the Douar Oulad Abdessadek, a tributary located on the left bank of the Oued Beht. This chaâba flows from west to east and occupies an area called Bled Faida, a daya area that, due to consecutive droughts has dried up, reducing runoff. A factor amplifying the flooding phenomenon is the presence of old quarries along the edge of the bed of the chaâba. The depressions in these quarries receive runoff water which helps mitigate the flooding in the chaâba, thereby reducing the impact of the floods and exacerbating the occupation of the flood zones. The evaluation of physiographic parameters (surface area, perimeter, length of the main watercourse, slope, height difference, average altitude, compactness index, etc.) allows for the determination of the geometric configuration and shape of the delimited watersheds.

The geometric configuration of the WSH, coupled with the relief data, conditions the surface runoff, which in turn influences the flood flows carried by the wadis concerned. The physiographic parameters of the main watersheds considered in this study are presented in table 1.

Estimation of Flood Flows

The calculation of the peak flood flow for a basin was based on an empirical method (the Mallet-Gauthier formula), commonly used in hydrology. The formula takes into account factors such as watershed size, topographic gradient, and rainfall characteristics. The key equation is shown below. The peak flows retained for return periods of 10 years, 20 years, 50 years and 100 years are presented in table 2.

TABLE 2 Summary of the Calculation of Peak Flows for the Different Watersheds: Dar Belamri Center WSH Area

WSH	Area (km)	Flow rates retained (m^3/s)			
		Q10	Q20	Q50	Q100
WSH1	770.95	346.77	442.61	570.96	688.50
WSH2	589.98	292.80	370.37	474.18	568.8
WSH3	181.06	142.42	172.46	210.63	244.12

$$Q = C \times A \times I^{\frac{1}{2}},$$

where Q is the peak discharge (m^3/s), C is the runoff coefficient (dimensionless), A is the watershed area (km^2) and I is the rainfall intensity (mm/h).

Hydraulic Modeling: Oued Beht

The hydraulic model of the Oued Beht section crossing the Dar Belamri center allows for the simulation of flow during floods of various return periods along the wadi defines the extent of flood zones during these flood events.

Topographic Survey The watercourses crossing the center were the subject of a topographic survey campaign designed to capture the maximum morphological detail of the watercourses. Topographic profiles were created both longitudinally and transversely along the watercourses and at the locations of hydraulic structures.

These topographic data were analyzed, filtered and processed to prepare the geometry of the watercourses for the hydraulic simulation. The section of Oued Beht included in this study is defined in table 3.

Preparation of the Geometry of the Watercourses The geometry of the watercourse was developed in WMS over a 2 km section of the Beht Wadi running through the center. This geometry is defined by a series of cross-sections perpendicular to the direction of flow, taking into ac-

TABLE 3 Section of Oued Beht, Included in the Topographical Study

Oued	Length (km)	Coordinates			
		Upstream		Downstream	
		x	y	x	y
Oued Beht	2.53	447418	398272	448142	399870

count the geomorphological modifications of these tributaries. Each cross-section is characterized by a length describing the distance between the current section and the next section downstream. Regarding the crossing structures spanning the tributaries of the Beht Wadi section, the profiles located upstream and immediately downstream of each structure allow for the most accurate modeling of the water surface behavior in their vicinity

Boundary Conditions The model is framed by two boundary conditions:

- The upstream condition: it consists of introducing a slope that determines the nature of the flow – either fluvial or torrential – with a value of 0.034;
- The downstream condition: the slope calculated at the downstream end has a value of 0.00036.

Manning Coefficient These values are based on land use data, allowing for realistic modeling by taking into account the velocity of the water along the channel bed and the banks.

Simulated Flows For the steady-state simulation, the flow is constant and is specified at the upstream end of the watercourse. The applied flows represent the average values of the flows calculated using empirical formulas for different return periods, as shown in table 4.

Hydraulic Simulation of the Modeled Section of the Beht Wadi under HEC-RAS Figure 12 illustrates the flood waterlines, the longitudinal profile for the different return periods, and summary tables of the simulation results for the 100-year return period.

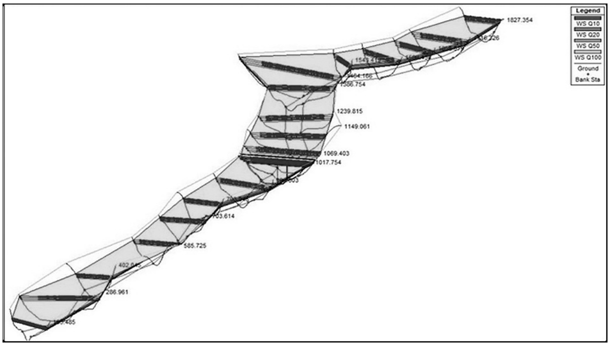
From the longitudinal profile, we can see a convergence of the four simulated flows: Q10, Q20, Q50 and Q100, as shown in figure 13. Therefore, the difference in the water surface elevation is minimal.

The summary tables of the hydraulic simulation results for the 100-year return period on the Oued Beht section are presented below. The

TABLE 4 Flow Rates for Return Periods: Oued Beht Watercourse

Watercourse	Retained flow rates (m^3/s)			
	Q10	Q20	Q50	Q100
Upstream Oued Beht	292.8	370.37	474.18	568.8
Downstream Oued Beht	346.77	442.61	570.96	688.5

FIGURE 12 Perspective View of the Modeled Section of Oued Beht



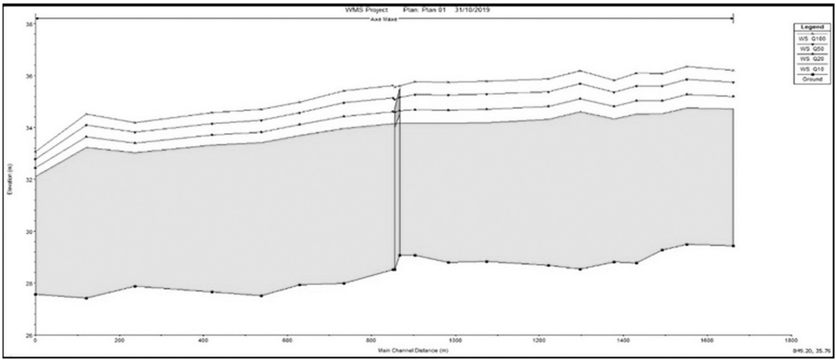


FIGURE 13 Longitudinal Profile of the Simulated Section of Oued Beht

flow velocities in the simulated watercourses vary significantly, influenced by channel slope and geomorphology. For the modeled section of the Beht Wadi, table 5 shows that flow velocities range from a minimum of 1.04 m/s to a maximum of 5.89 m/s, indicating moderate to high velocity conditions. These variations highlight the dynamic hydraulic behavior of the wadi, particularly in sections with steeper slopes.

The calculated widths of the reaches in the modeled section of the Beht Wadi demonstrate significant variability, ranging from a minimum of 48.44 meters to a maximum of 164.60 meters. This wide range

TABLE 5 Summary Table of the Hydraulic Simulation Results for Beht Wadi

Item	Minimum	Maximum
Speed of simulated watercourses (m/s)	1.04	5.89
Widths of the reaches (m)	48.44	164.60
Water blade depths (m)	5.14	7.06

FIGURE 14 Flood Zone Boundary Map of the Section of Oued Beht Running through the Center of Dar Belamri

reflects the heterogeneous nature of the channel's morphology, which impacts the distribution and extent of flow during hydraulic events.

The water blade depths, determined for various cross-sections along the modeled section of the Beht Wadi, show variability influenced by channel geometry and flow characteristics. The depths range from a minimum of 5.14 meters to a maximum of 7.06 meters, reflecting the dynamic distribution of water levels across different sections of the wadi.

Flood Zone Mapping Following the hydraulic modeling developed, figure 14 illustrates the extent of floodwaters for the different periods.

Hydraulic Modeling: Oued Oum Ezzine

Creation and preparation of input data: the hydraulic model of the watercourses crossing the Dar Belamri center makes it possible to simulate the flow for floods of different return periods along the Oum Ezzine Wadi, and to delimit the extent of the flood zones during the passage of these floods.

Topographical Surveys The topographic survey of Oued Oum Ezzine was conducted to gather detailed morphological information about the

TABLE 6 Sections Covered by This Topographic Study

Oued	Length (km)	Contact details			
		Upstream		Downstream	
		x	y	x	y
Oued Oum Ezzine	1.29	446447	399340	447648	399563

watercourse, focusing on sections along its length, cross-sections, and hydraulic structures. The surveyed section spans 1.29 km, extending from upstream coordinates (446447, 399340) to downstream coordinates (447648, 399563). Table 6 presents this precise data, which was analyzed, filtered, and processed to define the geometry of the watercourse, forming the basis for the hydraulic simulation.

Preparation of the Geometry of the Watercourses The preparation of the geometry of the watercourses concerned was developed under WMS on a 1.29 km section of the Oum Ezzine Wadi that crosses the center.

This geometry is described by a set of cross-sections perpendicular to the direction of flow, which take into account the geomorphological modifications of this tributary. Each section is characterized by a length that describes the distance between the current section and the next section downstream.

Profiles characterizing the channel carrying the waters of the chaâba enable the best modeling of the waterline behavior in its vicinity.

Boundary Conditions The model is framed by two boundary conditions. The upstream condition involves applying a slope that determines the nature of the flow – either fluvial or torrential – with a value of 0.0038. The downstream condition is defined by a slope of 0.005.

Manning Coefficient These values are established based on land use data, enabling realistic modeling by accounting for water velocity along the channel bed and riverbanks.

Simulated Flow Rates Table 7 presents the flow rates used for different return periods in the modeled section of Oued Oum Ezzine. These values, derived using empirical formulas, represent the steady-state flow rates applied at the upstream boundary of the watercourse during hydraulic simulations. For the 10-year return period (Q10), the flow rate is 105.65 m^3/s, progressively increasing to 213.63 m^3/s for the 100-year

TABLE 7 Return Period Flow Rates

Watercourse	Debits retained (m^3/s)			
	Q10	Q20	Q50	Q100
Oued Oum Ezzine	105.65	136.26	177.21	213.63

return period (Q100). This steady increase reflects the rising flow intensity associated with rarer, more extreme flood events.

Hydraulic Simulation of the Oum Ezzine Wadi under HEC-RAS Figure 15 illustrates the flood water lines, the longitudinal profile for the different return periods and summary tables of the simulation results concerning the centennial return period. We note that figure 16 shows the

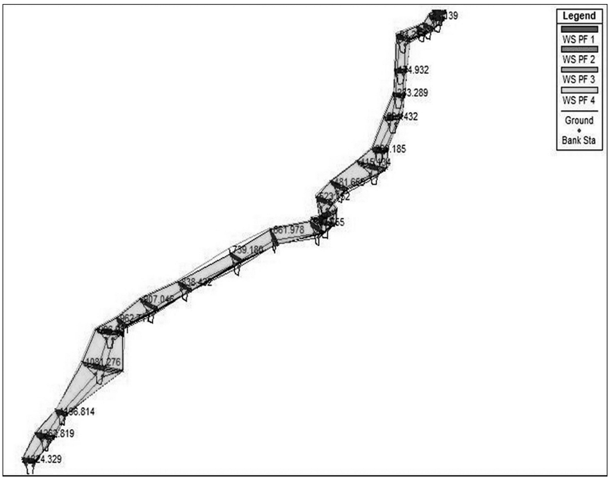


FIGURE 15 Perspective View of the Modeled Section of the Oum Ezzine Wadi

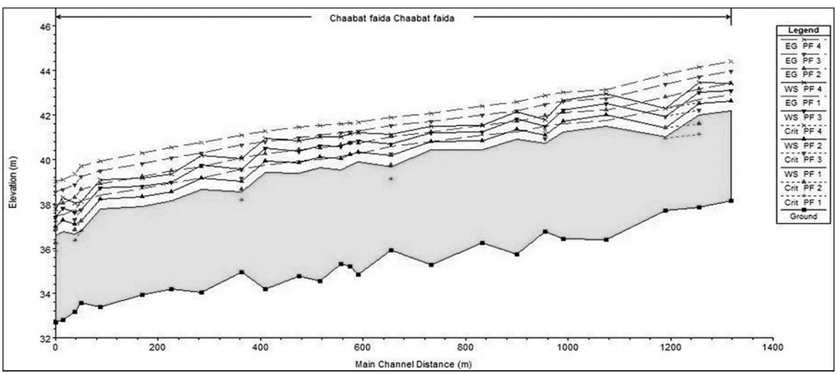


FIGURE 16 Longitudinal Profile of the Simulated Section of Oued Oum Ezzine

TABLE 8 Summary Table of the Hydraulic Simulation Results for Oued Oum Ezzine

Item	Minimum	Maximum
Speed of simulated watercourses (m/s)	5.14	7.06
Widths of the reaches (m)	14.91	55.29
Water blade depths (m)	4.20	6.38

longitudinal profile with a comparison for the four simulated flows: Q10, Q20, Q50 and Q100. Thus, the difference in altitude of the water body is minimal.

Table 8 presents the hydraulic simulation results concerning the centennial return period on the modeled section of Oued Oum Ezzine. The slopes vary from moderate to steep in different sections, and the flow speeds are high. The calculated widths of the reaches along the modeled sections exhibit notable variation. For Oued Oum Ezzine, the width ranges from a minimum of 14.91 meters to a maximum of 55.29 meters, reflecting the heterogeneity in channel morphology and cross-sectional geometry across the modeled stretch. The water blade depths, calculated at various cross-sections along the modeled segments, demonstrate variability between sections. For Oued Oum Ezzine, the water blade depth ranges between a minimum of 4.20 meters and a maximum of 6.38 meters, indicating fluctuations influenced by channel geometry, slope, and flow conditions.

Flood Zone Mapping Figure 14 presents the flood vulnerability of the Oum Zine Wadi, based on the developed hydraulic modeling and shows the extent of floodwaters for the different return periods. This vulnerability is becoming increasingly evident with the rampant urbanization that has continued to grow throughout the local authority, particularly in the center of Dar Belamri, which has adopted an urban planning document whose resulting developments have significantly contributed to an increase in the stakes. While hazard is not a quantifiable concept, exposure and stakes are. Regarding Oued Beht, located to the east of the center of Dar Belamri, it constitutes an obstacle to the expansion of the urban area and poses a permanent threat during flood periods. Figure 17 illustrates the combined flood risks of the Oum Zine and Baht rivers, which must be taken into serious consideration to ensure the success of any future urban planning efforts.

Figure 18 combines the risks to housing and drinking water, highlighting the importance of addressing these issues to ensure the suc-

FIGURE 17 Flood Zone Delimitation Map of Oued Oum Ezzine for Different Return Periods: Dar Belamri

cess of all future urban planning documents. It should also be noted that vigilance, combined with effective monitoring, must remain a priority for future development projects planned near these two valleys. These projects must necessarily minimize soil sealing, as failing to do so could lead to increased volumes of surface runoff downstream. In addition, there must be investment in studies and the implementation of flood protection measures for the Dar Belamri community, taking into account the multiple technical constraints related to the topography of the land. These efforts should focus on protecting existing neighborhoods from flooding and improving rainwater drainage in already urbanized area. It is also necessary to prevent urban development in areas at risk of flooding.

Characterization of Flood Hazard

The assessment of the hazard factor is based on a combination of the hydrological and hydraulic approaches (specifically the recurrence of a flood and the resulting submersion). Figure 19 illustrates the varying degrees of flood hazard (very low, low, medium, high).

Figure 20 shows the flood risk profile of the approved development

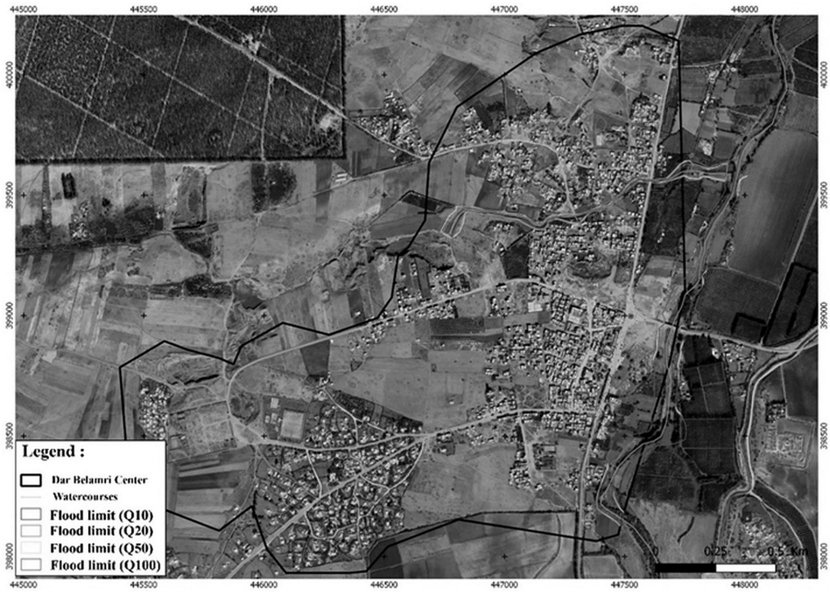


FIGURE 18 Map Showing the Delimitation of Flood Zones of Watercourses Passing through the Center of Dar Belamri

plan for the Dar Belamri center. This risk was clearly not taken into account during the preparation of the plan. As a result, two- and three-story residential areas were planned within flood-prone zones. This adds to the existing older urban fabric that predates the current urban planning document. Moving forward, future urban planning documents must consider these flood-prone areas within the study area.

Given the scarcity of land allocated for multifunctional facilities – particularly those dedicated to education and sports – and as part of strategic efforts to promote youth engagement in athletic development, local playgrounds have been established to fulfil this objective. However, the selection of these sites often overlooks essential planning and assessment protocols, leading to hazardous scenarios – such as the one illustrated in figure 21 – which highlights the significant threat posed by stormwater accumulation and flooding.

CONCLUSION

The Dar Belamri center is located in a natural flood zone, which requires careful consideration of flood risk by local planners and decision-makers. In this context, identifying the areas likely to be affected by

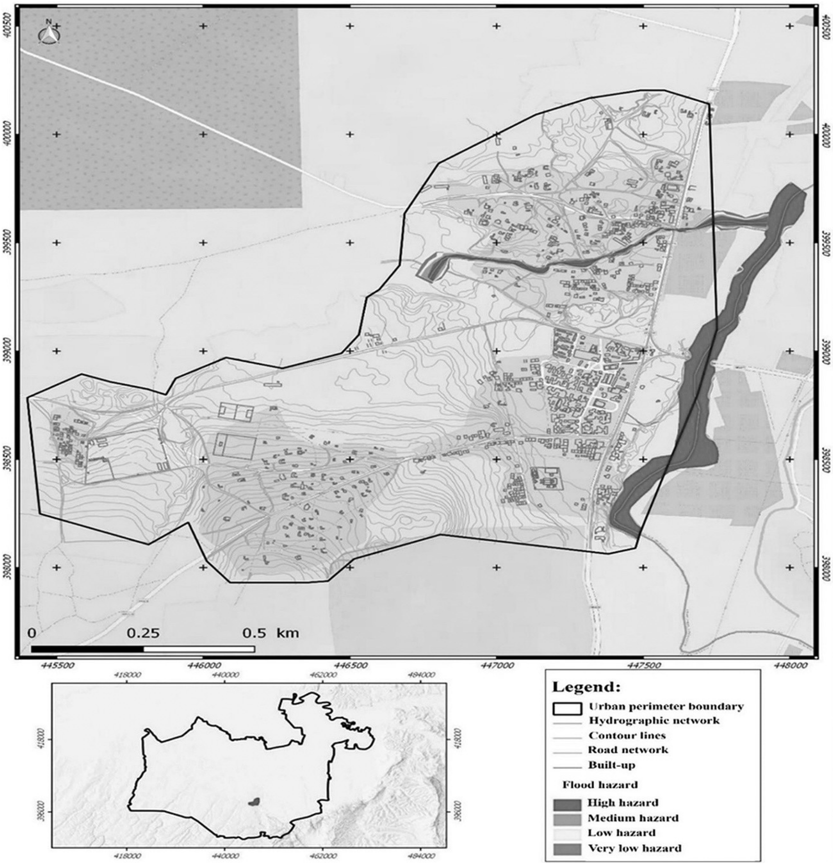


FIGURE 19 Flood Hazard Map: Dar Belamri Center

floods is essential for effective risk management. The methodology adopted in this study provides a flood hazard assessment tool at the scale of the Dar Belamri center. The hazard factor was assessed through a combination of two concepts: flood recurrence and the resulting submersion. In this study, we opted for the hydrological and hydraulic approach – a judicious choice given the specific characteristics of the area. This approach uses a hydrological model to determine the spatiotemporal evolution of the hydraulic characteristics of a watercourse during a reference flood (e.g., flow rate, flow velocity, water height, flooded areas, etc.). It also helps assess the impacts of hydraulic developments that influence flow behavior. The Dar Belamri center is crossed by Oued Beht and Oued Oum Ezzine. Oued Beht, the main

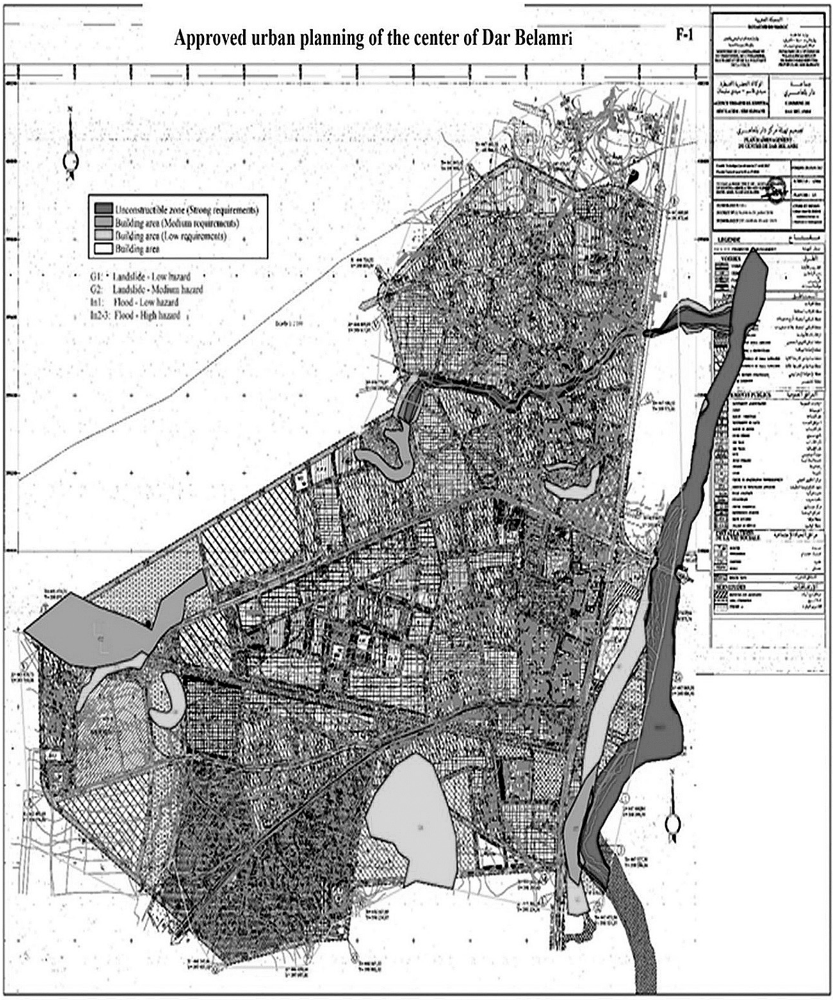


FIGURE 20 Projection of the Flood Risk Map onto the Approved Urban Plan of the Center of Dar Belamri

tributary of Oued Sebou, is regulated a few kilometers upstream by the Al Kansera Dam. It flows from south to north through a well-defined concave riverbed approximately 20 m to 40 m wide and 3m to 4 m deep. As part of this study, the watercourses crossing the center were surveyed through a campaign of topographic data collection, aiming to capture detailed morphological information. Topographic profiles were taken both along and across the watercourses, including at key hydraulic structures. These topographic data were then analyzed, fil-

FIGURE 21 Example of a Stadium in Front of Oued Oum ZINE

tered, and processed to prepare the river geometry required for hydraulic simulation. The simulation modeled flood events with different return periods along Oued Oum Ezzine and the segment of Oued Beht running through the Dar Belamri center. This made it possible to delineate the flood zones and assess their extent. The results allowed for the development of a hazard map that identifies the most and least affected areas, providing critical insight into zones that are more or less prone to frequent and extensive flooding. The study clearly shows that the approved development plan did not take flood risk into account, despite preliminary and multidisciplinary studies carried out by the design office responsible for the urban planning document. On the contrary, we observed that flood-prone areas have been designated for continuous residential development. Under pressure from increasing land demand, these planning decisions pose serious risks. Furthermore, during a site visit, we observed community facilities installed in areas prone to submersion, highlighting a dangerous lack of coordination between planning and flood risk management.

REFERENCES

Akallouch, A., A. A. Mashoudi, M. Ziani, and R. Elhani. 2024. 'GIS Application in Urban Flood Risk Analysis: Midar as a Case Study.' *Open Journal of Ecology* 14 (2): 148–64.

Aksoy, H., V. S. O. Kirca, H. I. Burgan, and D. Kellecioglu. 2016. 'Hydrological and Hydraulic Models for Determination of Flood-Prone and Flood Inundation Areas.' Paper presented at the 7th International Water Resources Management Conference of ICWRS, Bochum, 18–20 May.

Al Kuisi, M., N. Al Azzam, T. Hyarat, and I. Farhan. 2024. 'Flood Hazard and Risk Assessment of Flash Floods for Petra Catchment Area Using Hydrological and Analytical Hierarchy (AHP) Modeling.' *Water* 16 (16): 2283.

Amellah, O., P. Mignosa, F. Prost, and F. Aureli. 2024. 'Assessment of Flood Hazard Mapping Using a DEM-Based Approach and 2D Hydrodynamic Modeling.' *Water* 16 (13): 1844.

Anande, D. M., and P. M. Luhunga. 2019. 'Assessment of Socio-Economic Impacts of the December 2011 Flood Event in Dar Es Salaam, Tanzania.' *Atmospheric and Climate Sciences* 9 (3): 421–37.

Athmani, H., D. B. Kouider, S. Bensefia, and D. S. Ali. 2024. 'Flood Risk Assessment in Arid Regions Based on Hydraulic Modeling with Hec-Ras Case Study of Wadi Tamda in Doucen, Algeria.' *Larhyss Journal* (61): 81–109.

Bannari, A., G. Kadhem, A. El-Battay, N. A. Hameid, and M. Rouai. 2016. 'Assessment of Land Erosion and Sediment Accumulation Caused by Runoff after a Flash-Flooding Storm Using Topographic Profiles and Spectral Indices.' *Advances in Remote Sensing* 5 (4): 315–54.

Bekkali, S., A. O. Touhami, M. Mohamed, M. Benmakhlouf, and O. Arab. 2024. 'Flood Risk Assessment Basing on Flood Flow Modeling in the Oued Martil Region, Western Part of Northern Morocco.' *Ecological Engineering & Environmental Technology* 25 (5): 243–55.

Berlemann, M., and D. Wenzel. 2018. 'Hurricanes, Economic Growth and Transmission Channels: Empirical Evidence for Countries on Differing Levels of Development.' *World Development* 105:231–47.

Beven, K. J., and M. J. Kirkby. 1979. 'A Physically Based, Variable Contributing Area Model of Basin Hydrology.' *Hydrological Sciences Bulletin* 24 (1): 43–69.

Bolan, S., L. P. Padhye, T. Jasemizad, et al. 2024. 'Impacts of Climate Change on the Fate of Contaminants through Extreme Weather Events.' *Science of the Total Environment* 909:168388.

Cea, L., and P. Costabile. 2022. 'Flood Risk in Urban Areas: Modelling, Management and Adaptation to Climate Change: A Review.' *Hydrology* 9 (3): 50.

Chanyour, Y., O. El Achari, M. Hanchane, K. Obda, and R. Kessabi. 2024. 'Monthly and Annual Precipitation in Arid Environment of the Daoura Watershed (South-Eastern Morocco): Homogenization and Trend Analysis.' *Ecological Engineering & Environmental Technology* 25 (4): 125–42.

Chaqdid, A., A. Tuel, A. El Fatimy, and N. El Moçayd. 2023. 'Extreme Rainfall Events in Morocco: Spatial Dependence and Climate Drivers.' *Weather and Climate Extremes* 40:100556.

Grimaldi, S., Y. Li, J. P. Walker, and V. R. N. Pauwels. 2018. 'Effective Representation of River Geometry in Hydraulic Flood Forecast Models.' *Water Resources Research* 54 (2): 1031–57.

Guillot, P., and D. Duband. 1969. 'La méthode du Gradex pour le calcul de la probabilité des crues à partir des pluies.' In *Dixièmes journées de l'hydraulique*. https://www.persee.fr/doc/jhydr_0000-0001_1969_act_10_1_3763.

Hakim, D. K., R. Gernowo, and A. W. Nirwansyah. 2024. 'Flood Prediction with Time Series Data Mining: Systematic Review.' *Natural Hazards Research* 4 (2): 194–220.

Hudson, P., P. Raška, J. Macháč, and L. Slavíková. 2022. 'Balancing the Interaction between Urban Regeneration and Flood Risk Management: A Cost Benefit Approach in Ústí nad Labem.' *Land Use Policy* 120:106276.

Karmouda, N., T. Bouramtane, M. Tahiri, I. Kacimi, M. Leblanc, and N. Kassou. 2023. 'Deep Learning Approach for Runoff Prediction: Evaluating the Long-Short-Term Memory Neural Network Architectures for Capturing Extreme Discharge Events in the Ouergha Basin, Morocco.' *Ecological Engineering & Environmental Technology* 24 (9): 271–90.

Köhne, J. M., T. Wöhling, V. Pot, et al. 2011. 'Coupled Simulation of Surface Runoff and Soil Water Flow Using Multi-Objective Parameter Estimation.' *Journal of Hydrology* 403 (1–2): 141–56.

Kundzewicz, Z. W., S. Kanae, S. I. Seneviratne, et al. 2014. 'Flood Risk and Climate Change: Global and Regional Perspectives.' *Hydrological Sciences Journal* 59 (1): 857411.

Liu, Y., M. You, J. Zhu, F. Wang, and R. Ran. 2019. 'Integrated Risk Assessment for Agricultural Drought and Flood Disasters Based on Entropy Information Diffusion Theory in the Middle and Lower Reaches of the Yangtze River, China.' *International Journal of Disaster Risk Reduction* 38:101194.

Lombana, L., B. Bhattacharya, L. Alfonso, and A. Martínez-Graña. 2024. 'Hydrogeomorphological Approach for Flood Analyses at High-Detailed Scale: Narrow Rivers with Broad Complex Alluvial Plains.' *Catena* 242:108081.

Mai, T., S. Mushtaq, A. Loch, K. Reardon-Smith, and D.-A. An-Vo. 2019. 'A Systems Thinking Approach to Water Trade: Finding Leverage for Sustainable Development.' *Land Use Policy* 82:595–608.

Mai, T., S. Mushtaq, K. Reardon-Smith, et al. 2020. 'Defining Flood Risk Management Strategies: A Systems Approach.' *International Journal of Disaster Risk Reduction* 47:101550.

Manandhar, B., S. Cui, L. Wang, and S. Shrestha. 2023. 'Urban Flood

Hazard Assessment and Management Practices in South Asia: A Review.' *Land* 12 (3): 627.

Marchezepe, B. K., A. Almagro, A. S. Ballarin, and P. T. S. Oliveira. 2023. 'Streamflow Prediction in Ungauged Catchments by Using the Grunsky Method.' *International Soil and Water Conservation Research* 11 (4): 700–712.

Peker, İ. B., S. Gülbaz, V. Demir, O. Orhan, and N. Beden. 2024. 'Integration of HEC-RAS and HEC-HMS with GIS in Flood Modeling and Flood Hazard Mapping.' *Sustainability* 16 (3): 1226.

Santos, P. P. 2024. 'Flood Hazard and Risk in Urban Areas.' *Geosciences* 14 (12): 329.

Schilling, J., K. P. Freier, E. Hertig, and J. Scheffran. 2012. 'Climate Change, Vulnerability and Adaptation in North Africa with Focus on Morocco.' *Agriculture, Ecosystems & Environment* 156:12–26.

Shawaqfah, M., Y. Ababneh, A.-S. Odat, et al. 2024. 'Flash Flood Potential Analysis and Hazard Mapping of Wadi Mujib Using GIS and Hydrological Modelling Approach.' *Water* 16 (13): 1918.

Talha, S., A. Akhssas, A. Aarab, A. Aabi, and B. Berkat. 2025. 'Enhancing Flash Flood Risk Prediction: A Case Study from the Assaka Watershed, Guelmim Region, Southwestern Morocco.' *Ecological Engineering & Environmental Technology* 26 (1): 8–28.

Zhu, Y., Y. Zhang, J. Yang, B. T. Nguyen, and Y. Wang. 2022. 'A Novel Method for Calculating Distributed Water Depth and Flow Velocity of Stormwater Runoff during the Heavy Rainfall Events.' *Journal of Hydrology* 612:128064.