Assessment of the Potential Flood Hazard of the Larbaâ Wadi, Rural Center of Sebt Boukellal, Taza, Morocco

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Abstract. Flood risk management often requires the use of geomorphological features to identify flood zones, and the use of hydraulic models to predict inundation dynamics and related impacts on the surrounding area. In this study, we used a hydraulic river simulation model to identify potential flood-prone zones on a small scale. It concentrated on a 2.5-kilometer section of the Larbaâ Wadi, which crosses the rural center of Sebt Boukellal. For estimating the peak discharge that occurs in the return periods of 10, 20, 50, and 100 years of the drainage area, we used the Rational method. Standard tables to estimate Manning's coefficient and direct field measurements to feed the model. Model simulation has shown stability of the steady state, which witnesses the accuracy of the estimated and measured characteristics of the river system. During the calibration phase, we compared the model outputs to the observed floods and made adjustments to align the simulation with the field observations. Indeed, the 50-year flood remarkably matched the extent of the flood that occurred on September 27, 2000. The obtained results have shown that even for a 10-year return period, the overflow affects properties within the floodplain. The 100-year flood exceeded the river's capacity, causing water to spill onto the rural center's streets and cultivated fields. The water level reached an elevation of 552.14 meters at Sebt Boukellal's marketplace. These results were consistent with recent floods and confirm previous observations, indicating that the model precisely predicted the river's behavior. The findings have shown that floods spanned large regions and suggested urgent intervention to protect lives and properties.

1 Introduction

Floods have impacted Morocco for tens of years, continuing to threaten lives and property. Some incidents escalated to catastrophic levels, claiming hundreds of lives and having a negative impact on the local economy. Powerful floods have also affected the Sebt Boukellal

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rural center. The flood that occurred on September 27, 2000, was the largest and most significant in over a century, according to the Hydraulic Basin Agency of Sebou [1]. Witnesses stated that the combination of properties in flood zones and severe rainfall were responsible for the flood amplitudes. The flood strongly impacted the nearby Wadi community. Along National Road 29, floods wrecked the weekly open market and caused major damage to residences.

These days, the use of flood forecasting techniques has become essential, especially with the remarkable growing frequency of abrupt and catastrophic floods primarily linked to climate change [2, 3, 4, 5, 6, 7]. Creating a prediction system is a difficult task that calls for cooperation among scientists in many domains. Despite the development and improvement of multiple methods over decades, the flood issues still require further research. Scientists are working tirelessly to improve flood comprehension and develop more effective mitigation techniques. According to various research studies, the one-dimensional hydrodynamic approach is a popular technique for simulating rivers [8, 9, 10, 11, 12, 13, 14, 15, 16, 17] and allows for estimating river dynamics under various flow frequencies.

In this paper, we suggest utilizing the HEC-RAS model to simulate the one-dimensional hydrodynamic river flow. The assessment of water flow in both natural and artificial channels is possible with this model, which is widely used to mimic river behavior [18]. Researchers from several countries have confirmed its effectiveness and capacity for river modeling [19, 20, 21]. Also, the hydraulic basin agencies in Morocco use the model extensively to determine flood-prone areas. Thus, we used this model to simulate the fluvial dynamics of the Larbaâ Wadi. The study evaluated the model's ability to predict the spatial extent of flooding at various return periods. We used the model to assess overflowing events in populated areas and identify flood impacts. Using this method, we will be able to investigate particular matters, like how closely the model simulates Larbaâ Wadi's behavior? And how well can it predict potential floods and locate areas that are vulnerable to flooding?

2 Study area

Sebt Boukellal Rural County, situated approximately 17 kilometers northeast of Taza City, administers the study area. The community's properties fully occupy the floodplain of the Larbaâ Wadi along Road 29, the national route that links neighboring towns and villages. Such human activities impair the water's ability to flow naturally during floods. Regrettably, the decision-making process neglected the hydrological features.

The study area's watershed is entirely within the eastern pre-Rif mountains, located between latitudes (34° 15' 405 and 34° 30' N) and longitudes (3° 55' 622 and 4° 00' 645 E). The drainage basin is 247 km2 in size, with an outlet at Maknassa el Charkiya village. We used two 1:50,000 topographic maps, Ain Boukellal and Bab el Mrouj, to define the watershed boundaries. The region has a semi-arid climate, with extremely intermittent and unexpected rainfall in the form of brief storms with heavy precipitation. Overgrazing and excessive forest use have significantly degraded the vegetation cover and contributed to intensifying flood events. Impermeable lithologies, such as marls and marl-limestones, prevent water from soaking in, causing more water to run off the surface. The mountain summits to the north are characterized by conglomerate rocks and resistant sandstone. Topographically, the watershed shows a predominance of hilly landforms, resulting from severe erosion over vulnerable lithology and unprotected soil. The Larbaâ Wadi has a torrential hydrological regime characterized by sudden and abrupt floods in the fall and winter, as well as low flows extending for several months.

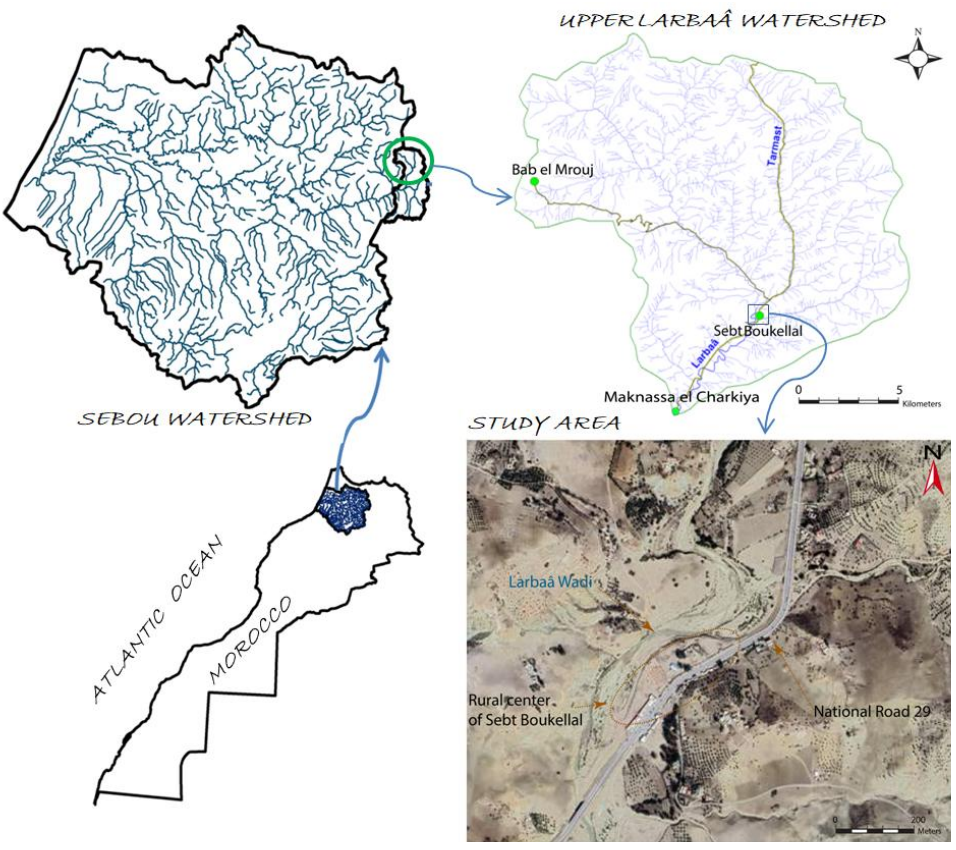

Fig. 1. Study area.

3 Method and material

We followed several steps in order to evaluate flood risk, starting by collecting inputs from the field and estimating some parameters based on charts and standard tables, such as the Manning coefficient. Peak discharges for different return periods were obtained using the well-known Rational method. We then built the numerical model and fed it with the collected and estimated parameters of the river system.

3.1 Hydraulic simulation of the river system

We developed a numerical model based on topographical data to represent numerically the landforms of the Wadi. This data consisted of cross-sections that spanned a distance of 2.5 kilometers (Figure 2). We measured the transversal sections in the field with a GPS and a rolling meter. Their measurements began on the left and progressed to the right, encompassing the entire width of the riverbeds. We carefully selected these profiles and oriented them vertically in the flow direction. We determined the spacing sections to accurately reflect the true shape of the floodplain. Additionally, we delineated the longitudinal profile perfectly aligned with the main channel on a satellite image from 2015 and provided a detailed depiction of Larbaâ Wadi.

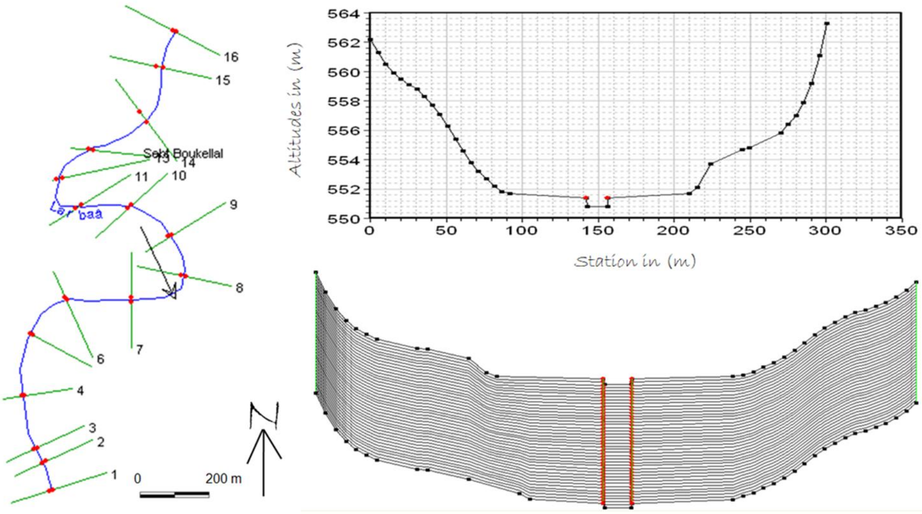

Fig. 2. HEC-RAS simulated topographical surface profile.

3.2 Peak discharge of different return period

Assessing floods necessitates careful consideration of the peak discharge data. We used the Gradex method to identify floods at various frequencies (Table 1), then incorporated them into the model to mimic the wadi's behavior. We specifically input flow rates into the upper section of the channel, and we considered them valid throughout the entire simulated portion. Although the peak discharges themselves remain constant, the hydraulic model has the capability to adjust them in specific situations, especially when certain variables impact the flood dynamics.

Table 1. Runoff, flood volumes, peak discharge and runoff coefficients for different frequencies.

Return period	Runoff (mm)	Volume (Mm^3)	Peak discharge (m^3/s)	Runoff coefficient (%)
10	9.63	2.38	158	26
20	14.65	3.62	240	35
50	21.14	5.22	347	43
100	26.02	6.43	427	47

3.3 The Manning coefficient

Previous research has not thoroughly analyzed the roughness coefficient (Manning coefficient). Only some studies have addressed it, focusing on understanding the spatial and temporal distribution of this variable [22]. In addition, Manning [23] and Colebrook [24] attempted to develop a concise and definitive formula for summarizing this coefficient. However, none of these formulas were highly convincing to researchers [11, 8]. This physical parameter varies based on the terrain's characteristics. It considers a variety of factors, including vegetation density, river bed irregularity, water surface width, and soil composition. These factors have a different impact on the flow resistance coefficient [25].

In this study, we selected roughness coefficients using field evidence. We also relied on reference tables provided by Ven and Chow [26], as well as the experience of practitioners and engineers at hydraulic basin agencies in Morocco. Along the Wadi, we noted the predominance of fine gravel, leading us to classify the roughness coefficients between 0.035 and 0.05. We believe that values between 0.03 and 0.05 accurately represent the possible range of coefficients applicable to the area. Additionally, according to the Hydraulic Basin Agency of Sebou [27], values between 0.04 and 0.05 are more suitable for the upper part of the Sebou watershed.

4 Results and discussion

4.1 Model calibration: steady state

Calibrating the model in a steady state was a challenging step to process. We have calibrated the model using the marks left by the flood that occurred on September 27, 2000 (Figure 3). To achieve the level of these observed marks, we conducted sensitivity tests by carefully adjusting some variables. This allowed us to find the formulation that enabled model stability and strengthened its effectiveness in simulating potential floods. Therefore, this calibration stage was essential to verifying the model's ability to represent hydraulic conditions during the reference flood, enhancing confidence in its results.

Fig. 3. Flood event of the 09/27/2000.

4.2 Simulating potential floods of different return periods

According to the findings, it is clear that the ten-year flood, which has a discharge of 182 m3/s, poses a constant threat to Sebt Boukellal rural center. The water height reaches the coast of NGM at 550.88 meters, causing an overflow of 1.38 meters into the weekly open market and commercial shops along National Road 29 (Figure 4). Moreover, figure 5 illustrates how the water line varies in height over the simulated section, falling between 1.6 and 2.5 meters. These water heights are sufficient to endanger the local residents living on the left bank of the valley (Figure 4). Beyond this particular section, this flood does not threaten the population, as there are no inhabited areas within the floodable zones of the decennial frequency. Likewise, the fifty-year flow rate (443 m3/s) spreads across moderate flood areas, affecting populated sections and agricultural fields. This flood causes the water level to reach the coast at 551.84 NGM, resulting in an overflow of 2.34 meters in the open market (Figure 4). Moving further, the centennial flow rate (551 m3/s) shows exceptional overflow events, with the water levels reaching 552.14 of the coast NGM. This creates a significant overflow of 2.64 meters on properties. The flood extends over the entire floodplain, with submerged sections exceeding 200 meters in width (Figure 4). This flood affects inhabited zones and cultivated fields. The outcomes of the study clearly indicate that the public and their goods are in vulnerable positions, underscoring the urgency for immediate action.

On the other hand, the numerical simulation shows that the 50-year flood matches the one that occurred on September 27–2000 (Figure 3, 4), while the Sebou Hydraulic Basin Agency has considered the event a centennial. Therefore, the local residents witnessed that the flood of 1970 was the strongest event, which is still vivid in people's memories. According to them, this flood surpassed the recorded major floods (2000, 2002, and 2010). Thus, this new information makes this overflowing the most powerful ever experienced in Larbaâ Wadi. Official records did not document this flood, but experts estimate it to be an exceptional event with a return period exceeding 100 years. This data should be considered in future studies to precisely assess the possible upcoming flood events and take the necessary measures to protect populated areas and infrastructure from their impacts.

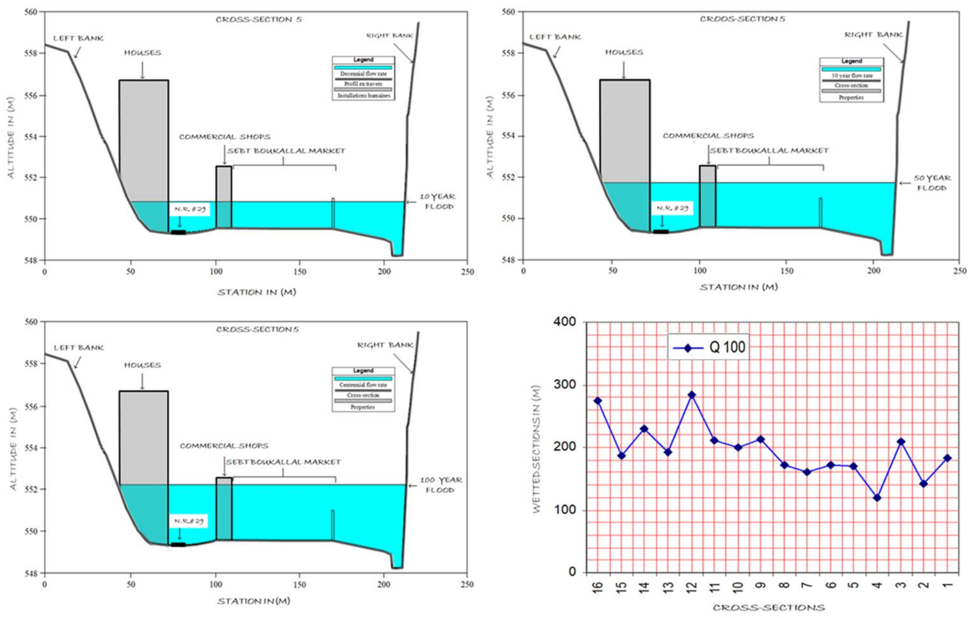

Fig. 4. Water level and its spread for various return periods.

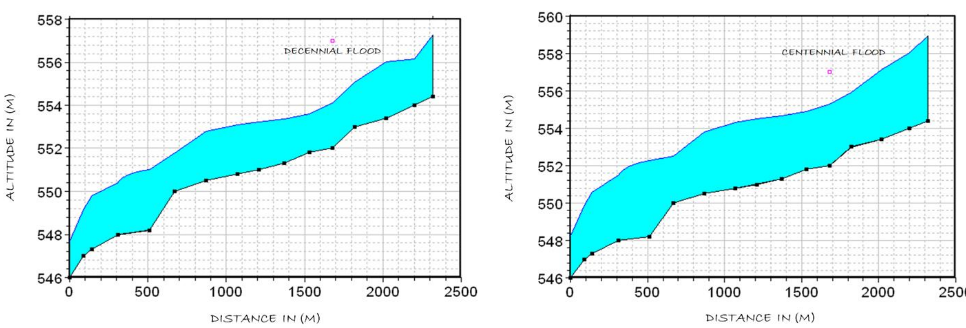

Fig. 5. Water surface profile for 10 years (left) and 100 years return period (right).

4.3 Results and discussion

Overall, there isn't much research on the modeling issues that exist today. Throughout many simulation tests, it has become evident that the model has weaknesses. There are some simulation variables that still need more explanation. We also encountered a model calibration issue, which is common among flood designers. In the literature, there are few studies on calibrating stages. In this case, we tried to digitally replicate the observed floods in order to calibrate our model. To acquire the observed water markings, we carefully made the appropriate changes. Although this calibration technique appears suitable, it nevertheless has certain drawbacks. The inability to identify the physical parameters that caused the recorded flood is one of the major obstacles. These elements were occasionally enigmatic and unknown to us. Therefore, we presume that we may have overvalued or undervalued certain factors, potentially influencing the model's outputs. Even so, the lack of data was another challenge during the model's development. This issue compelled us to estimate the inputs on our own. It was difficult to ascertain those characteristics in certain places, especially where the floodplain is inaccessible or occupied by hydrophilic vegetation. Furthermore, unidentified influences may alter even the determined roughness coefficients across time and space.

Despite these limitations, our model retains a tremendous ability to detect flood-prone areas, making it a powerful tool for explaining the dynamics of floods in the studied area. The developed model has estimated the height and width of flowing water, even in areas with buildings placed within the floodplain. This indicates that the model is extremely efficient in constructed areas, while other methods, such as hydrogeomorphology and integrated geomorphology, are limited. During the simulation process, the model takes into account the volumes of properties, making the results approach real-life scenarios. Likewise, the model's findings provided valuable information for decision-makers and urban planners, which may contribute to implementing preventive measures such as the readaptation of Wadi's wetted sections for possible floods. Similarly, it has become necessary to relocate the weekly open market to a safer location. Thus, through effective interventions, we can reduce or avoid the current flood problems. In the same manner, we encourage future studies to feed this model with additional information sources, such as instantaneous rainfall. These important inputs will enhance the accuracy of predicting floods a few hours before they occur. This will enable authorities to anticipate potential scenarios and coordinate crisis intervention plans, such as emergency response and rescue operations.

5 Conclusion

The empoyed hydraulic river simulation model has proven its effectiveness in detecting flood-prone zones in the Larbaâ Wadi along the rural center of Sebt Boukellal. It predicted the Wadi's behavior at different return periods, demonstrating its reliability for specific sections and a detailed flood risk assessment. This modeling tool is considered powerful for understanding and addressing the challenges posed by flood events. Further research in this area is essential for improving the existing model for more effective prediction and mitigation strategies. The findings highlighted the urgent need for concrete techniques to protect lives and property along National Road 29. They also provided valuable information for local authorities and communities to take decisive action, such as people's evacuations to safer zones and building protections to reinforce vulnerable areas.

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