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GIS Application in Urban Flood Risk Analysis: Midar as a Case Study

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Abstract

The significance of this study lies in its exploration of the advanced applications of Geographic Information Systems (GIS) in assessing urban flood risks, with a specific focus on Midar, Morocco. This research is pivotal as it showcases that GIS technology is not just a tool for mapping, but a critical component in urban planning and emergency management strategies. By meticulously identifying and mapping flood-prone areas in Midar, the study provides invaluable insights into the potential vulnerabilities of urban landscapes to flooding. Moreover, this research demonstrates the practical utility of GIS in mitigating material losses, a significant concern in flood-prone urban areas. The proactive approach proposed in this study, centered around the use of GIS, aims to safeguard Midar's population and infrastructure from the devastating impacts of floods. This approach serves as a model for other urban areas facing similar challenges, highlighting the indispensable role of GIS in disaster preparedness and response. Overall, the study underscores the transformative potential of GIS in enhancing urban resilience, making it a crucial tool in the fight against natural disasters like floods.

Keywords

Geographic Information Systems, Risk Assessment Models, Hydrological Modeling, Urban Planning, Decision-Making Methods, Urban Centers

1. Introduction

Floods, a natural hydrological phenomenon, result from various factors, such as intense precipitation and landscape characteristics [1] [2]. These natural disasters, including floods and droughts, significantly threaten lives and properties. Floods occur in diverse environments like rivers, wadis, and coastal areas, causing severe damage and loss of life when rivers overflow. Addressing flood risk estimation and mitigation is thus crucial in the current era.

Floods are often linked to extreme climate events [3] [4]. Defined as the probability and potential consequences of flooding [5], several factors contribute to their occurrence, including intense short-duration rainfall, topographical features, and human-induced factors such as urbanization and settlement expansion in flood-prone areas [6] [7].

Globally, floods are among the most common weather-related hazards, causing property loss, fatalities, and farmland destruction [8]. For instance, the 2008 floods in Morocco resulted in losses exceeding 22 million.

In Morocco, the frequency and impact of floods, including flash floods, are rising, leading to significant losses of life and property damage, such as the 1995 Ourika valley incident with over 200 deaths [9] [10]. Floods are Morocco's most perilous natural disasters, with the highest number of affected individuals and fatalities over the last three decades [11].

Urban flooding studies in Morocco remain scarce. The limited number of studies on this topic (9) hinders a comprehensive understanding of the phenomenon, primarily due to the lack of extensive climate event data. Like in many developing countries, detailed records of rainfall and runoff data are seldom available in North Africa [12]. In our study area, such research is virtually non-existent, with only a few studies in nearby areas like Nador [13], Saidia [14] [15], and Zaio [16].

Recent advancements in flood risk assessment techniques, classified by [17] into three categories, have significantly improved our understanding. This study investigates using GIS to identify flood-prone areas in the "Midar" Center, Driouch Province. GIS integrates spatial data and analytical tools to examine factors like land elevation and proximity to water bodies. Through comprehensive analyses, we aim to pinpoint areas within "Midar" vulnerable to flooding, assisting in devising effective flood risk management strategies, including urban planning and infrastructure improvements, for future mitigation efforts.

2. Data and Methods

2.1. Study Area

The study is centered around the town of "Midar", located in the province of "Driouch" in northern Morocco (as shown **Figure 1**). "Midar" is naturally situated in the "Beni Touzine" mountains within the "Kart" basin, which extends from the Aknol region to the shores of the Mediterranean Sea. The "Kart Valley" river flows longitudinally through the center of "Midar" from the northwest side.

Similar to Tangier in the northwest of the country, which experienced exceptional floods in 2008 [18], Wed Fes [19], and Ourika [20], "Midar" was also flooded in 2008 as a result of the increased levels of water in "Kart Valley" (as shown in **Figure 2**). This flood resulted in significant material damages, prompting the authorities at the time to implement a range of measures to prevent similar losses. However, despite these efforts, many neighborhoods in the "Midar" Center remain vulnerable to the risk of flooding. This vulnerability is primarily attributed to a lack of public awareness, the unregulated construction of new buildings in high-risk areas, and the slow implementation of measures to prevent unauthorized expansion into restricted construction zones as stipulated in the development plan.

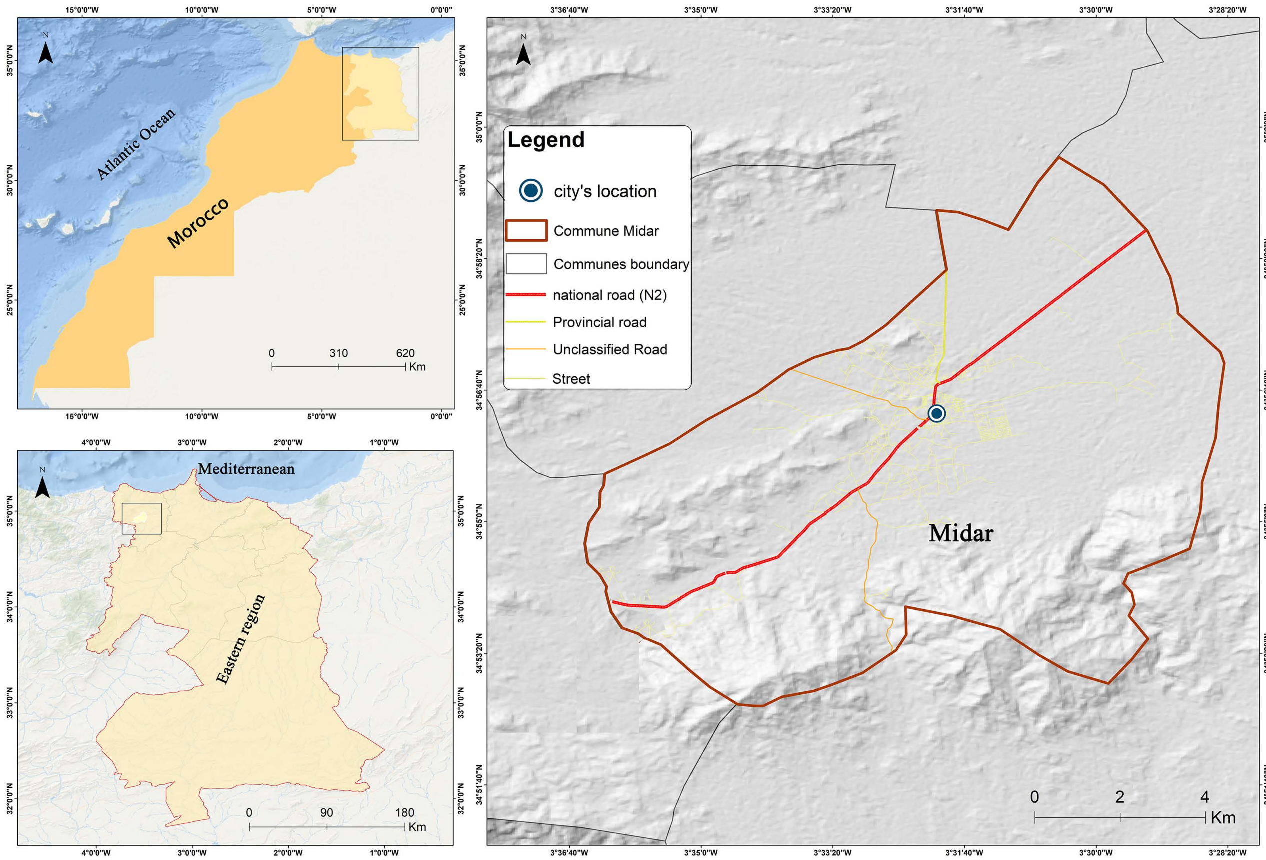

Figure 1. Study area location, "Midar" city.

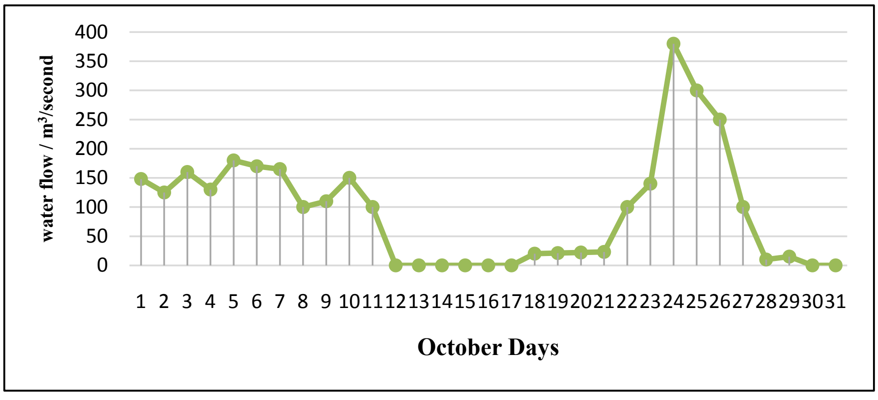

Figure 2. Average Daily Flow of Oued Kart, "Driouch" Station, in October 2008.

2.2. Methodology of the Study

Floods typically occur when the drainage network is overwhelmed by excessive rainfall. In urban environments, the water flow is impacted by several factors. The permeability of the soil is often reduced due to dense construction, limited green areas, and extensive paving of roads. These elements exacerbate the severity of water flow during heavy rains. This issue is particularly acute in cities near mountains, such as the center of "Midar."

Recognizing the detrimental effects of floods in these areas, a detailed study is essential. This research is motivated by the need to understand the hazards of river erosion, especially its threat to the urban area of "Al-Maidar." It focuses on the area around "Wadi Kart," a zone of ongoing urban expansion near the riverbanks. Leveraging the advancements in remote sensing and Geographic Information Systems (GIS), this study aims to enhance flood mapping and risk assessment capabilities [21]. We utilized a statistical method to convert field measurements into GIS maps. Additionally, hydrographic drawings are instrumental in watershed modeling and designing stormwater management infrastructures [22].

2.2.1. GIS Database Collection and Preparation

Geographic Information Systems (GIS) play a crucial role in the use of scientific methods in various fields, facilitating timely and accurate decision-making [23]. In this study, we seek to use GIS mechanisms to diagnose areas at risk, the assessment of catchment conditions mostly is based on digital maps and remote sensing data which have become available in national databases. Large volumes of spatial data are processed with the use of geographical information systems and related technologies [24]. Flooding is in the "Midar" region. To achieve this, we will use a range of tools, including:

- Topographic maps of the study area.
- Satellite image of the "Midar" Center.
- Map defining the administrative boundaries of the municipality of "Midar".
- Database containing information on residential buildings in "Midar".
- Digital Elevation Model (DEM) for creating elevation and topographic maps, as well as the hydrological network of the area.
- Road network map of the "Midar" Center.

Fieldwork was conducted to collect and establish the geographical database, which is one of the critical steps in this study. The analysis results hold little value if the statistical data used for the analysis were not collected properly.

2.2.2. Data Analysis

To analyze the data effectively, the following maps were utilized:

- Elevation map of the "Midar" Center.
- Map displaying the distribution of buildings.
- Map of the water network.
- Map of the central road network.

Through the analysis of these maps (as shown in **Figures 3-6**), we aim to identify flood-prone areas and place particular emphasis on neighborhoods located near "Kart Valley", as they are considered the most vulnerable. These neighborhoods include "Bouhjar", "Bouyandoz", "Al-Masira" district, "Anzagh", and "Boughlab".

Afterward, we determined the elevation levels of the buildings in relation to the valley floor, ranging from 381 to 387 meters. This was achieved by converting the polygon representation of the built environment on the map into a point representation, as illustrated in **Figure 7**. This conversion process enables accurate assessment of the elevation of the buildings adjacent to the valley. To accomplish this, we utilized the "Point to Feature" command within the "Features"

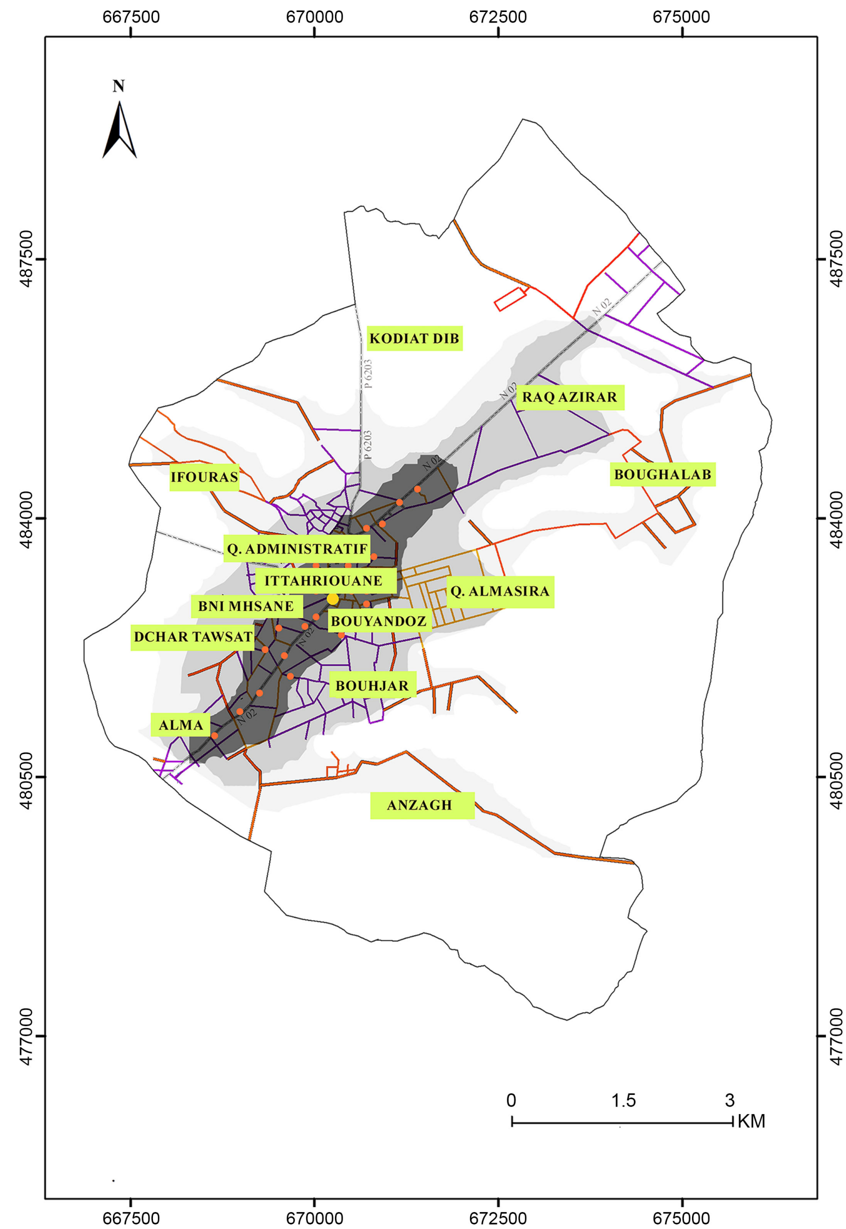

Figure 3. Road network map.

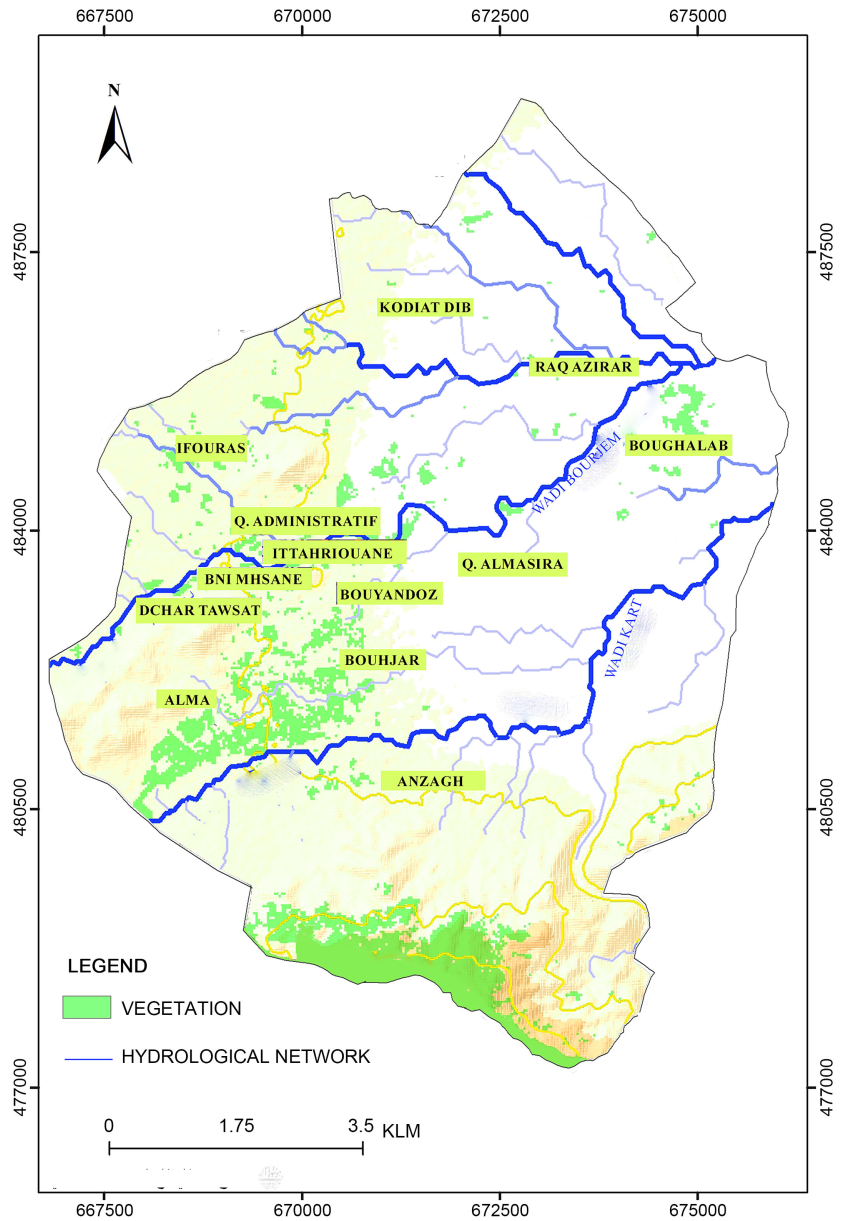

Figure 4. Hydrological network map.

section of the Data Management Tools in the Toolboxes. Additionally, it is noteworthy that this approach allows us to gather valuable data on the vertical dimension of the urban landscape, facilitating further analysis and planning.

The subsequent stage in our methodology involves integrating point data, derived from maps, into the digital elevation model (DEM). This integration process encompasses several key steps:

• Georeferencing: The initial phase involves assigning real-world geographic coordinates to the points obtained from the maps, ensuring they align accurately with other spatial datasets.

• Interpolation: After georeferencing, these points undergo interpolation. This step fills gaps between points, creating a continuous surface. Techniques like triangulation and inverse distance weighting are employed, tailored to the data's characteristics and the required accuracy level.

• Merging with DEM: The interpolated data is then merged with existing elevation data within the DEM. This combination updates the DEM with refined elevation details, derived from the point data.

• Enhanced Data Integration: Beyond elevation, this process can incorporate additional attributes in the points, such as land cover or vegetation density, into the DEM. This enriched data can significantly aid in applications like hydrological modeling, slope analysis, and land-use planning.

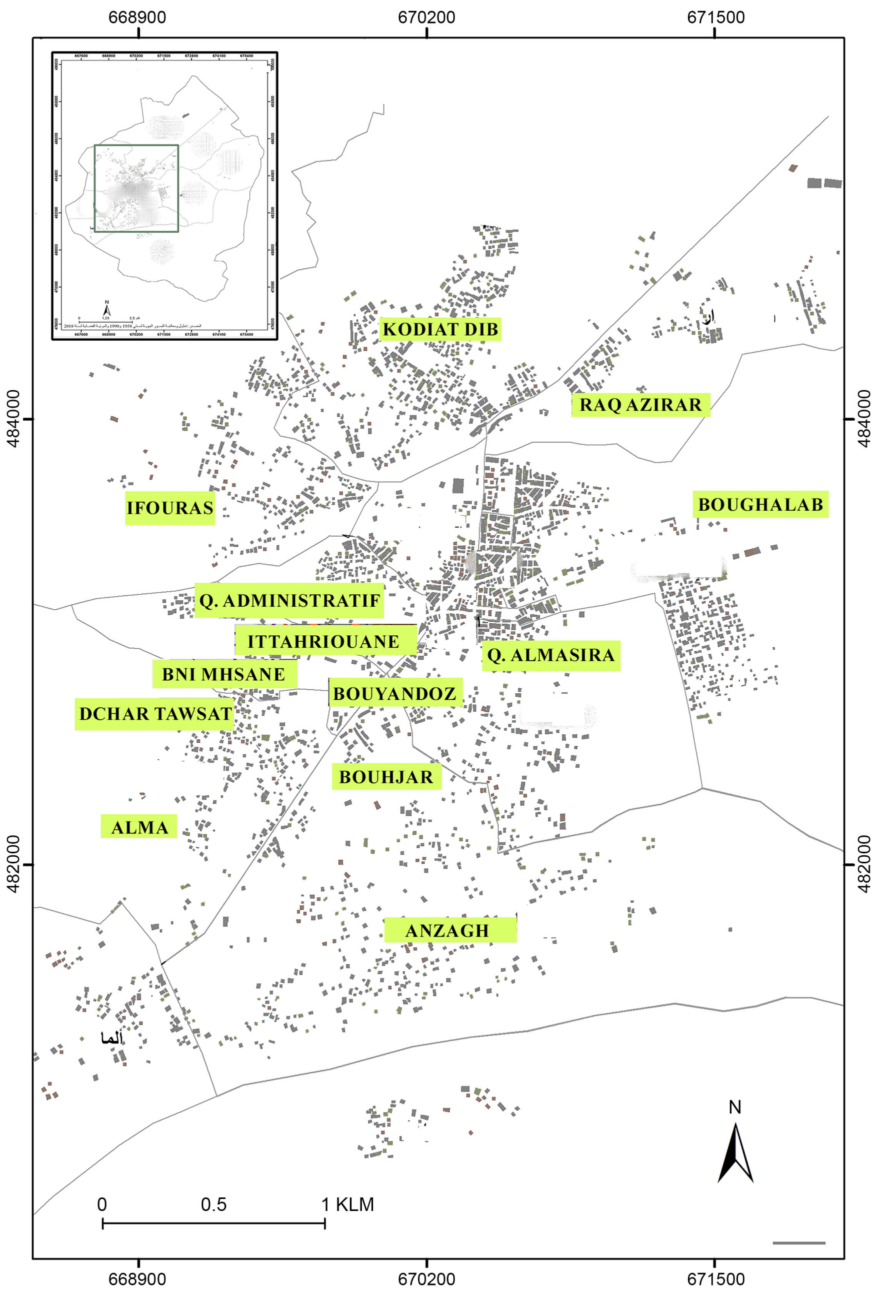

Figure 5. Map of the buildings in "Midar".

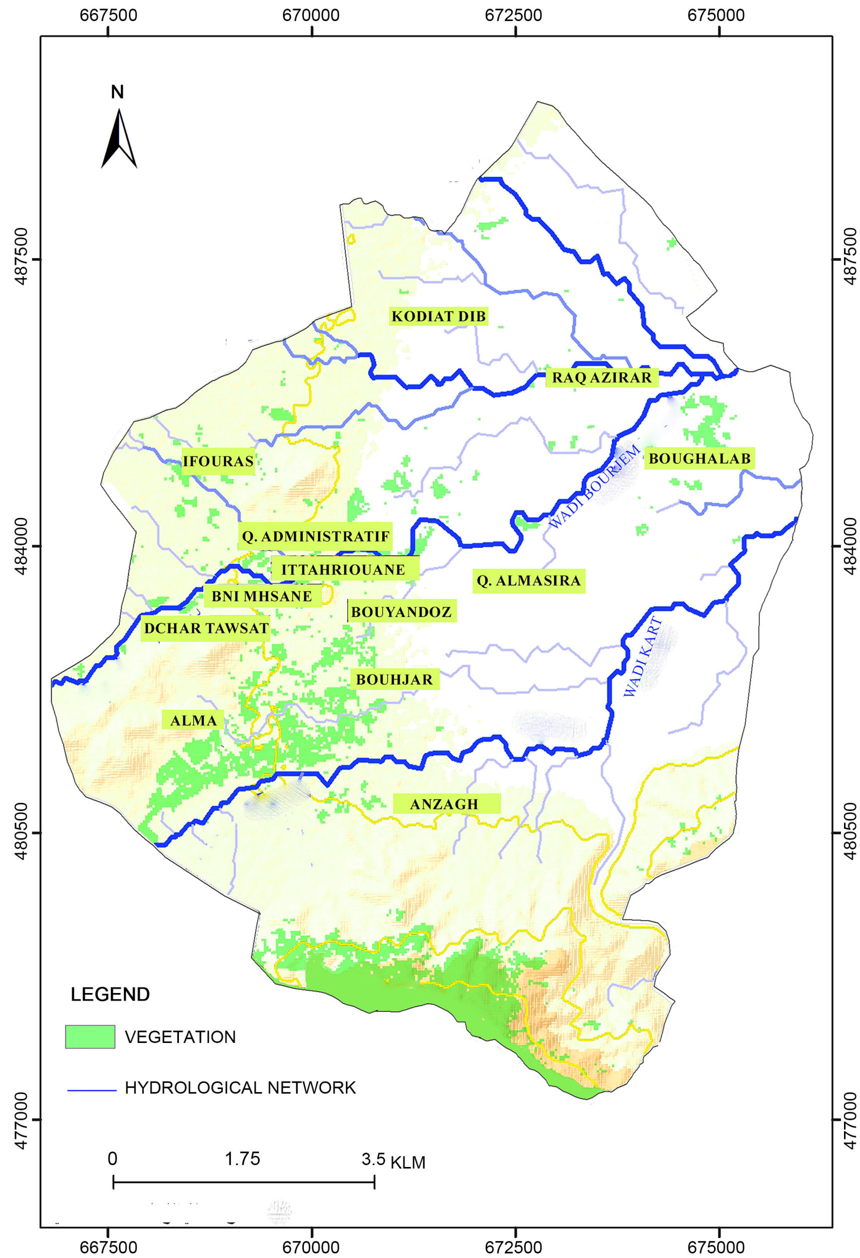

Figure 6. Digital elevation map.

In summary, converting maps to point data and integrating them into a DEM is crucial for capturing detailed terrain information. This multifaceted process, involving georeferencing, interpolation, and merging, enhances the DEM's utility in landscape analysis and planning.

3. Results and Discussion

In our research endeavor, we have achieved a commendable feat by successfully crafting a highly detailed point-shape layer that meticulously delineates the structural characteristics of buildings, as vividly depicted in **Figure 8**. This meticulously crafted layer is a composite of geographical coordinates and elevation

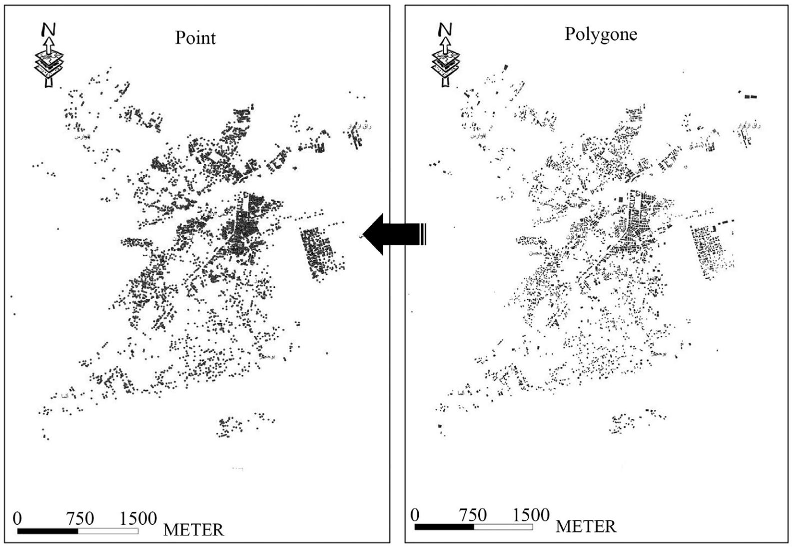

Figure 7. Transform the shape of the Buildings layer.

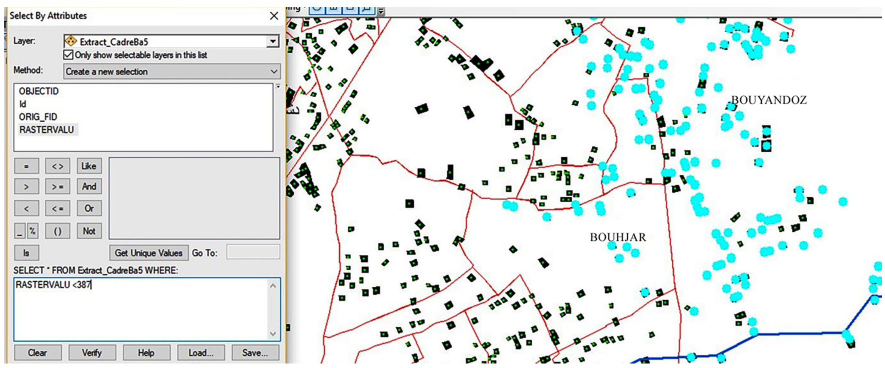

Figure 8. Automatic identification of buildings at risk of flooding in "Midar".

data, with an explicit emphasis on the Z-dimension, which denotes elevation. The paramount significance of this elevation data lies in its pivotal role in enabling us to ascertain the precise heights of various buildings. This, in turn, empowers us to conduct a thorough and nuanced assessment of potential flood scenarios within the confines of the "Kart Valley" region.

Our central objective revolves around the meticulous identification of structures that exhibit a heightened vulnerability to potential flooding events. The strategic utilization of a digital elevation model (DEM) has unveiled the valley's elevation, which stands at approximately 387 meters above sea level. To embark on a more profound exploration of flood risk scenarios, we have meticulously devised a comprehensive plan that hinges on harnessing the advanced capabilities of Geographic Information Systems (GIS) software.

This multifaceted strategy revolves around the judicious application of the RASTERVALU function, meticulously configured to a critical elevation threshold of 387 meters. The paramount aim of this strategic maneuver is to orchestrate a robust and nuanced assessment of buildings' susceptibility to flooding relative to this specific elevation benchmark.

Our enhanced analysis endeavor strives to unravel the intricate interplay between elevation and flood risk within the topographical tapestry of the "Kart Valley." By scrutinizing the topographical nuances of the region, we endeavor to pinpoint and elucidate precise areas where strategic intervention and proactive mitigation measures are both warranted and imperative.

This painstakingly thorough examination of the elevation-flood risk nexus is poised to serve as a linchpin in the formulation of effective urban planning strategies and flood mitigation initiatives. Such measures are pivotal in bolstering the resilience of the region and fortifying it against the potential cataclysmic impact of future flood events.

Our in-depth analysis of the neighborhoods within the "Midar" Center and its neighboring "Kart Valley" has revealed a pronounced susceptibility to flooding, a concern that becomes more pressing with even minor increases in water levels, as depicted in **Figure 9**. The densely populated nature of these areas elevates the need for an urgent and comprehensive approach to flood management. These neighborhoods, situated in a terrain that is predominantly low-lying, are at a heightened risk of flooding. This risk is exacerbated not only by the specific topographical characteristics of the area but also by the looming threats posed by climate change. Addressing this requires a multifaceted and proactive flood response strategy.

This strategy should include a meticulous evaluation of buildings at risk, paying special attention to structural vulnerabilities and the potential impacts of floodwaters. It is imperative to carry out a thorough and extensive mapping of zones that are prone to flooding, utilizing advanced geographic information systems to accurately predict and visualize flood scenarios. The implementation of engineering solutions must be customized to meet the unique demands of the area. This involves reinforcing infrastructure to make it resilient against flood damage, upgrading drainage systems to handle extreme water flows efficiently, and modifying building designs, such as elevating structures above known flood levels.

Furthermore, the establishment of robust early warning systems is critical. These systems should be capable of delivering timely alerts to residents, allowing for efficient and effective emergency responses. Such systems can play a vital role in minimizing the impact of flooding when it occurs.

The role of community involvement and heightened awareness cannot be overstated. It is crucial to educate the local population about the risks associated with flooding, the necessary preparedness measures, and the significance of having flood insurance. These educational efforts can greatly reduce the adverse effects of flood events. Integrating these structural measures with community-based initiatives will significantly bolster the resilience of the "Midar" Center and "Kart Valley" neighborhoods against the increasing threats of flooding. By doing so, we can ensure that these communities are better prepared, more informed, and more resilient in the face of such natural disasters.

In the face of natural disasters, particularly flooding, it becomes imperative to engage in a process of decision-making that focuses on establishing response

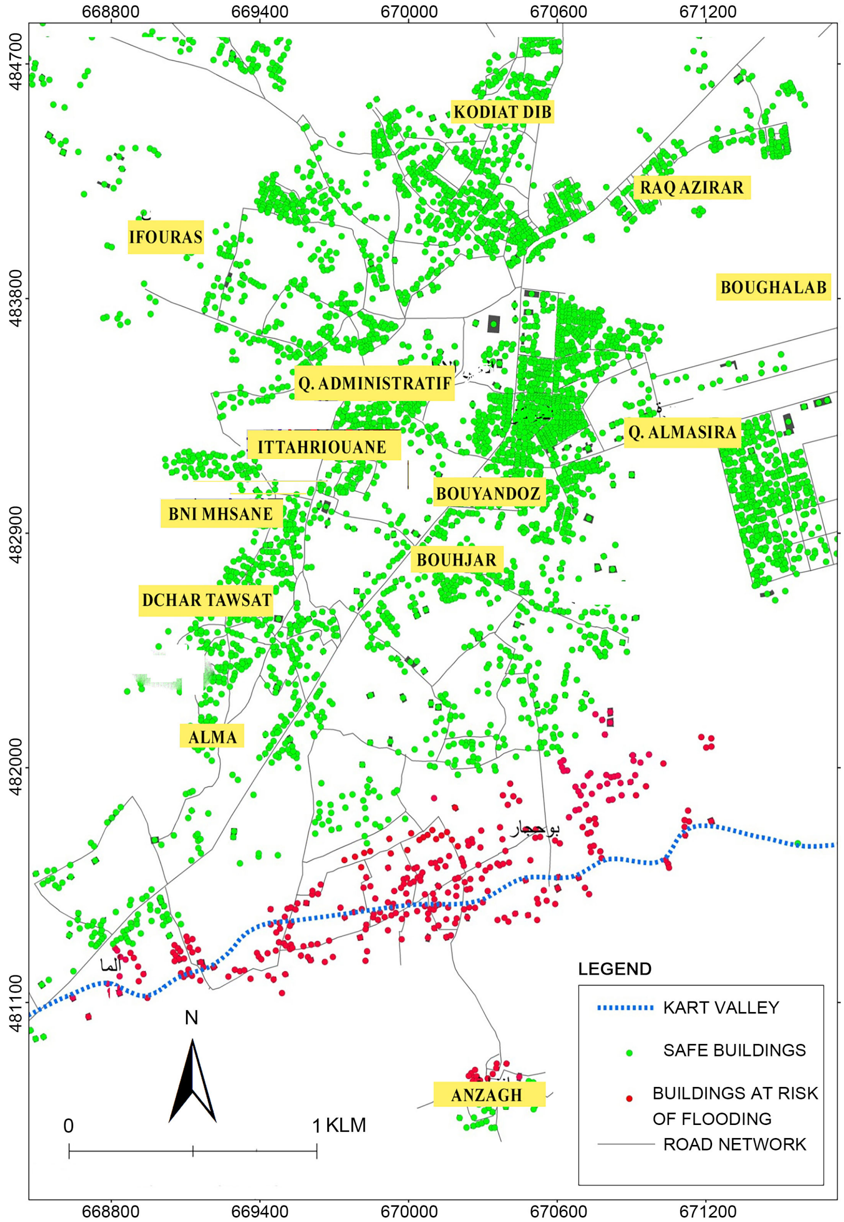

Figure 9. A Determining flood zones in "Midar".

mechanisms and designating supervisory authorities. These authorities are tasked with providing the necessary resources and capabilities to effectively manage such crises. A key aspect of this management involves the implementation of preventative measures, which includes restricting urban development in areas that are deemed unsuitable for such expansion due to their vulnerability to disasters. This is particularly relevant in the context of the study area, where the high population density must be taken into account.

One of the critical techniques utilized in managing flood risks is the assessment of flood hazards. This assessment is instrumental in the creation of Flood Hazard Mapping (FHM) or delineation of flood zoning areas. Such strategies are not just about understanding flood risks but are also aimed at reducing the impact and frequency of flooding events (as referenced in the work [25]). This approach acknowledges that while it may not be possible to entirely prevent natural disasters, there are proactive measures that can significantly reduce material damages.

Central to these measures is flood control, a concerted effort to lessen the impacts and losses caused by flood events (as discussed by [26]). This involves a systematic process that begins with a thorough field diagnosis. This diagnosis includes identifying areas prone to flooding and determining safe zones for evacuation. The steps in this process are critical and include:

- The identification of buildings at risk of flooding.
- The determination of buildings that are considered safe.
- The establishment of optimal gathering points for population evacuation during a flood event.

During this process, several factors are meticulously considered, including the concentration of the population and the accessibility of these areas via the road network. These considerations are analyzed using Geographic Measurement Tools and Spatial Statistics to ensure an efficient and effective response.

Further, the analysis of the road network and accessibility levels using the analytical tools specific to the "Midar" Center has been pivotal. It has led to the identification of main axes that can facilitate rapid intervention in the event of floods. This identification aims to reduce material losses and enhance the safety and well-being of the city's residents. These findings, including the strategic routes and safe zones, are visually represented in **Figure 10**, providing a clear and comprehensive guide for emergency response and evacuation planning.

Geographic Information Systems (GIS) represent a convergence of computer technology and geographic science, revolutionizing the way maps are created, data is processed, and geographic information is interlinked. These systems are at the forefront of spatial data analysis, skillfully merging geographical data with descriptive details. This fusion leads to outcomes that are rapid, accurate, and multifaceted, manifesting in various formats such as detailed maps, comprehensive charts, and in-depth reports. The true power of GIS lies in its ability to enhance geographical studies. It does so by providing tools for precise measurement, thorough analysis, and insightful interpretation. This functionality is invaluable in forecasting natural events and understanding human behaviors, thereby playing a pivotal role in shaping decision-making processes, especially in the realms of development and urban planning.

The applications of GIS are vast and diverse, extending far beyond traditional mapping. In urban planning, it assists in the design and management of cities, balancing development with environmental sustainability. In environmental management, GIS is a key tool for monitoring ecological changes, assessing environmental impact, and planning conservation strategies. Its role in disaster response is crucial; GIS enables efficient evacuation route planning, disaster risk assessment, and coordination of relief efforts. In the realm of public health, GIS

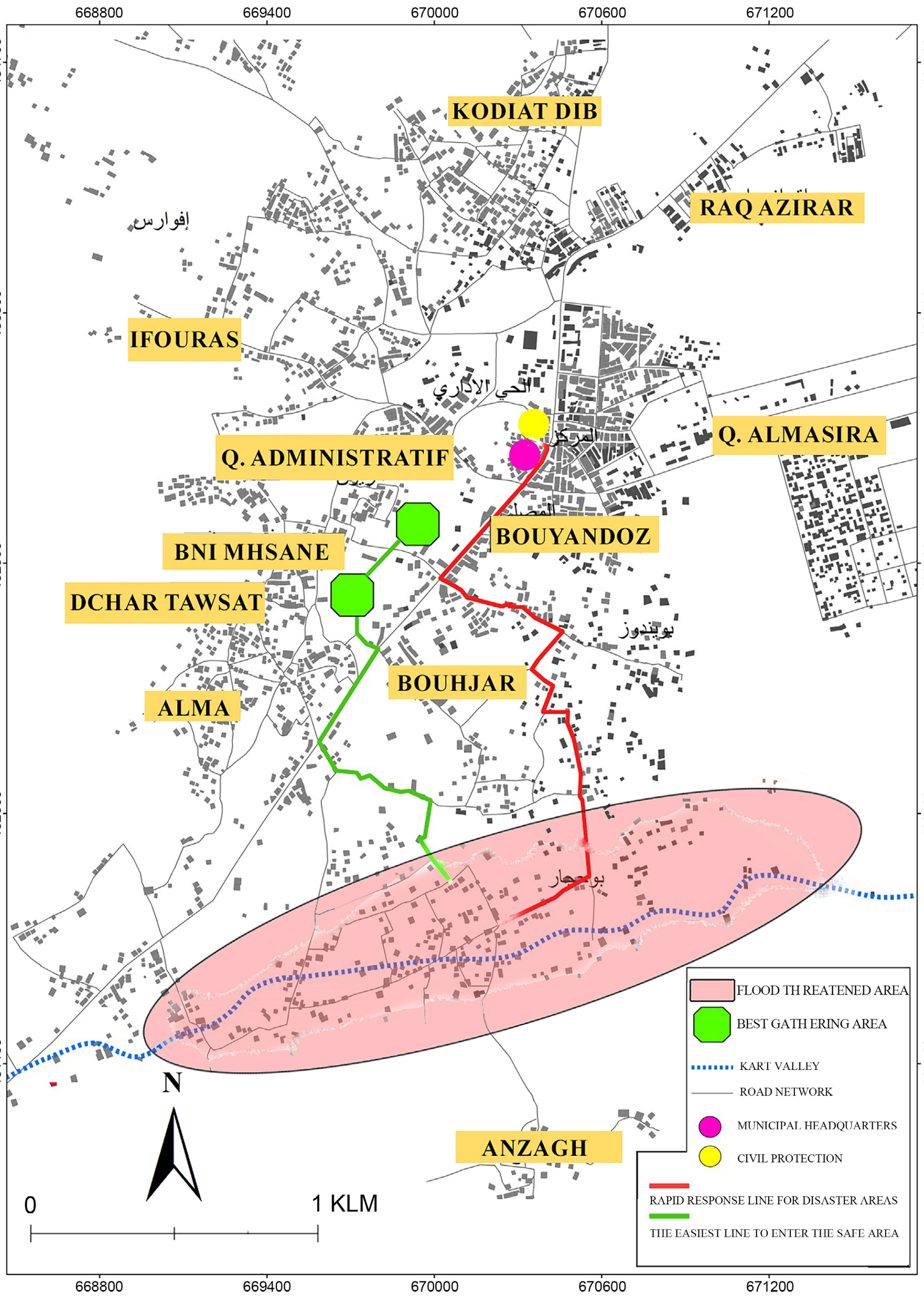

Figure 10. Mechanisms of rescue and intervention for floods in "MIDAR".

aids in tracking disease patterns, managing health care resources, and planning health services outreach. The system's ability to integrate a variety of data sources, including satellite imagery and ground survey data, exponentially increases the reliability and scope of its results.

As technology evolves and data becomes more accessible, GIS's relevance in society continues to grow. Its advanced capabilities in data integration, analysis, and visualization make it an indispensable tool in addressing complex challenges in a rapidly changing world. From local urban development to global environmental issues, GIS's contributions are critical in informing strategies, guiding policy decisions, and enhancing our understanding of the spatial dimensions of various phenomena.

Strategies for Flood Risk Management Using GIS

- **Integrated Risk Assessment:** Enhancing flood risk assessments by integrating GIS with comprehensive hydrological and meteorological data. This approach allows for a more nuanced understanding of flood dynamics, considering factors such as rainfall intensity, river flow rates, and soil saturation levels. By combining these data sets, GIS can provide a multifaceted risk profile, essential for effective flood management.
- **Dynamic Flood Modeling:** Utilizing GIS for the simulation of flood scenarios is a powerful tool in predicting potential flood events and planning accordingly. GIS can model various flood scenarios based on different weather conditions and landscape changes, aiding in the development of robust flood response plans and evacuation strategies.
- **Community Participation:** Involving local communities in the flood risk management process is crucial. Using GIS to gather and analyze data on local knowledge and experiences enhances the accuracy of risk identification. Moreover, it empowers communities, building resilience through increased awareness and participation in risk mitigation strategies.
- **Land Use Planning and Zoning:** Implementing stringent land use policies, guided by GIS analysis, to control construction and development in flood-prone areas. This includes zoning regulations that prevent high-density development in areas at high risk of flooding, thereby reducing potential damage and loss.
- **Environmental Preservation:** GIS can be instrumental in identifying and preserving natural floodplains and wetlands. These areas are crucial for absorbing excess floodwaters and reducing the velocity of flood flows. Preserving these natural buffers is a key strategy in mitigating the impacts of floods.
- **Cross-Sectoral Collaboration:** Promoting collaboration across different sectors is vital for optimizing the use of GIS in flood management. This involves creating frameworks for cooperation among various stakeholders, including government agencies, academic institutions, non-governmental organizations, and local communities. Sharing data, expertise, and resources through these collaborative efforts leads to a more comprehensive and effective approach in assessing and managing flood risks.

4. Conclusions

In summary, the judicious application of Geographic Information Systems (GIS) in managing flood risks, particularly in high-vulnerability areas like the "Kart

Valley" and "Midar" Center, represents more than a mere necessity; it's a paradigm shift in tackling environmental challenges. GIS's unparalleled capacity to integrate and analyze diverse data sets, transforming them into practical, actionable insights, is crucial for safeguarding infrastructure and communities against flood risks. However, the essence of an effective flood management strategy goes beyond just technological implementations. It calls for a holistic approach that melds the precision of technology with the richness of community engagement, the foresight of dynamic modeling, and the synergy of interdisciplinary collaboration.

Expanding on this, the role of GIS must be viewed as part of a larger tapestry of flood management efforts. It should be integrated with community-led initiatives, where local insights and experiences play a key role in shaping risk assessment and response strategies. This community-centric approach ensures that the solutions are not only scientifically sound but also culturally and socially relevant.

Additionally, the use of dynamic modeling in GIS, which allows for the simulation of various flood scenarios, becomes a pivotal tool in strategic planning. This modeling should be continuously updated to reflect new data and changing environmental conditions, ensuring that the flood response strategies remain effective and adaptable.

In embracing this integrated, multi-faceted approach, combining technological sophistication with human insights and collaborative efforts, we lay the groundwork for building communities that are not only resilient in the face of current flood risks but also prepared for the evolving challenges posed by water-related disasters in a changing climate. Adopting this comprehensive framework is a critical step towards minimizing material losses, enhancing public safety, and securing a sustainable future for regions prone to flooding.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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